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A PRACTICAL MANUAL

OF

AUTOGENOUS WELDING

(OXY-ACETYLENE)

WITH A CHAPTER ON THE CUTTING
OF METALS WITH THE BLOWPIPE.

BY

R. GRANJON AND P. ROSEMBERG,
DIRECTEURS DE L'OFFICE CENTRAL DE L'ACÉTYLÈNE ET DE LA
REVUE DE LA SOUDURE AUTOGÈNE.

TRANSLATED BY

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LECTURER ON AUTOGENOUS WELDING AT THE NORTHERN POLYTECHNIC.

THIRD EDITION.

With 257 Illustrations.

LONDON:
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1915.

PREFACE TO FIRST EDITION.

Autogenous welding by oxy-hydrogen and oxy-acetylene blowpipes has, within the last few years, been applied in thousands of workshops. In spite of the fact that these applications have, at least in many cases, been undertaken without precise methods, without theoretical or practical knowledge, in a word, without technique, it has become an extremely important process capable of numerous and varied applications in all branches of metallic construction and repair. A great future can be foreseen for this process from the moment its technique becomes known to the welder, and when manufacturers who use the process realise that knowledge and reflection are at least as important as skill and dexterity of hand.

Autogenous welding is certainly the one process of construction and repair that requires, from top to bottom of its application, most reflection, intelligence, and conscientiousness.

It is, for the welder, a trade which differentiates it from the majority of others in this sense that mechanical work is completely excluded from its practice, and that an immediate judgment cannot always be passed on the realisation, more or less perfect, of an intimate joining of which the metal holds the secret.

This handbook is intended for the welder as well as for all those who wish to acquire a simple and reliable technique in the art of autogenous welding. It has been simplified by the omission of all intricate scientific considerations relevant only to a more advanced study of the subject, but it has not been deprived of the fundamental and technical principles serving as the base for all the applications of the science.

Such a work should not frighten the practitioner. Even the least inexpert welder will find useful instruction relating to manipulation, methods of operation, dexterity of hand, various apparatus and their safety; he will acquire a mass of information concerning the process which he uses, sufficient technique to increase his efficiency and enable him to apply his art in a rational and easy manner.

The *Union de la Soudure Autogène*, by their publications and practical courses, have already disseminated the principles for obtaining work as perfect as possible, and at the same time securing absolute safety for those in charge.

In this practical handbook we continue the enterprising work by entering further into the details of the process. Its publication has been delayed because such a work should be complete. True, it is neither perfect nor final, since the technique of autogenous welding is still in its infancy. This technique, already on a solid foundation, will be enriched by further studies. Those that utilise autogenous welding have only themselves to thank for any benefits which they may derive from this book, since the work emanates from their association, the *Union de la Soudure Autogène.* We are only their collaborators.

R. GRANJON AND P. ROSEMBERG.

NOTE TO THIRD EDITION.

THAT a third edition of this work should be called for in less than twelve months from publication of the second edition is sufficient evidence of its usefulness. A few enterprising English firms, from whom apparatus and materials can be obtained, have gladly availed themselves of advertisement space at the end of this book. A gentleman named Swingle, of Chicago, has shown his appreciation of the book by copying, without acknowledgment, some of the text and illustrations, which he has issued as a booklet, and which British and Colonial booksellers are warned not to sell.

May 1915.

TRANSLATOR'S PREFACE.

No apology is needed for the presentation of a work in English which has already proved its value by a second French Edition being called for within a year of its publication.

There being no other work on the subject in the English language, the Translator and Publishers anticipate a ready welcome for this Edition, which has been prepared from the second French Edition, and embodies all the latest important advances that have been made in the industry.

A study of the pages which follow will quickly convince engineers and manufacturers of the great importance of the process, and, indeed, the new power which has been placed in their hands.

A process which has such varied application as, for instance, to render *as new* the damaged aluminium crank-case of a motor, or such light article, and, on the other hand, can be taken to the stem or rudder of a steamship, and a complete repair made *in situ*, must make a very strong appeal.

Welders will find full and complete information of the process and the materials and apparatus involved, and in order that the work may maintain its reputation as a complete vade-mecum on the subject, in English as well as French, the prices and conditions of sale of dissolved acetylene, other regulations, and all tables and dimensions have been rendered in their English equivalent.

The policy of the British Acetylene and Welding Association in establishing classes for theoretical and practical instruction in oxy-acetylene welding in London and other industrial centres has emphasised the need for such a work.

In conclusion, the Translator desires to express his cordial thanks to the Publishers, who have rendered every assistance and made many valuable suggestions.

D. RICHARDSON.

LONDON, *October* 1913.

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CHAPTER I.

THE DIFFERENT METHODS OF MAKING PERMANENT METALLIC JOINTS.

In order to appreciate thoroughly autogenous welding, it is useful before studying the process to examine briefly the other methods for bringing about permanent metallic joints, to know their characteristics, their applications, their advantages and disadvantages.

All the practical methods have their own particular value, their legitimate application, their defects and good qualities. They complement each other more than they replace each other; each has its special application as none of them are universal.

SOFT SOLDERING.

Soft soldering is generally used for joining pieces of thin metal together. In the majority of cases in which it is used the object is to obtain an air- or water-tight joint rather than a strong joint.

As its name indicates, the "soft solder" used has a much lower strength than that of the metals to be joined; its tensile strength is extremely low, and it is necessary to increase the surface of contact so that firmness is obtained at the joint by *adhesion*, something like the use of gum in joining paper.

When it is impossible to obtain a large surface of contact and thus obtain sufficient resistance by adhesion, it is necessary to add *additional* solder, that is, to make the joint thicker in order to increase the resistance; for example, in the soldering of lead pipes end to end.

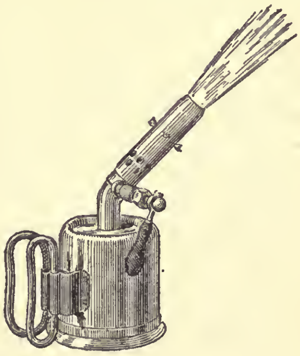
Fig. 1.—Plumber's soldering lamp.

Soft soldering is principally used for tin plates, zinc, lead plates, galvanised plates, sometimes copper or brass, and wherever the joint has not to stand any serious strain.

The melting-point of the solder must, obviously, be lower than that of the metals to be joined, or the surfaces will be destroyed. The joint is always weaker than the actual metal joined, and really only constitutes a connection and never an alloy.

To apply the solder a "soldering iron" or soldering flame of gas, acetylene, etc., is used.

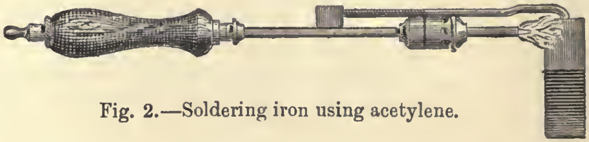

Fig. 2.—Soldering iron using acetylene.

A *flux* is always necessary to clean the joint and prevent or remove any oxide formed during the soldering. The flux used depends on the metals to be joined. Fluxes used are colphonium and sal ammoniac, zinc chloride, resin, etc.

COMPOSITION OF VARIOUS SOFT SOLDERS.

Name of Solders.	Composition.			Melting-Point.	Flux generally used.
	Tin.	Lead.	Bismuth.	° C.	
Plumber's solder, coarse .	1	3	...	245	Resin or tallow.
,, ,, ordinary	1	2	...	220	,, ,,
,, ,, fine .	1	1·5	...	200	,, ,,
Tinman's solder, coarse .	1	1	...	180	Resin or chloride of zinc.
,, ,, ordinary	1·5	1	...	170	,, ,,
,, ,, first class	2	1	...	170	,, ,,
Very fusible solder . .	4	4	1	160	,, ,,
,, ,, ,, . .	2	2	1	145	,, ,,
,, ,, ,, . .	5	3	3	94	,, ,,

GROOVING.

Grooved seams are used for joining tin plate and thin sheets. The process consists of grooving the edges from a ¼ inch to ⅜ inch, adjusting them so that they clasp each other, and then closing them with a hammer or machine.

These clasped joints are not perfectly air-tight, and the operation is frequently followed by the application of a soldering iron, using a soft solder. When this is done the joint is perfectly air-tight and its resistance is increased, but the joint now possesses excess thickness.

RIVETING.

Riveting, which without doubt will be used for a long time yet, is used for joints which must have great strength and where autogenous welding is difficult to apply.

Riveting offers a resistance which depends either on the adhesion of the overlapping plates or upon the rivets themselves, which act as a kind of link.

A good adhesion is not obtained unless the rivets are previously heated. If the operation is well carried out, the resistance is about 21,000 lbs. per square inch of the section of the rivet used, this for plates of medium thickness. For plates of great thickness the joints are not easily made, because the rivets frequently break on cooling and thus the adhesion is very weak. When the rivets are put in cold (up to about ½ inch), the adhesion is practically nil.

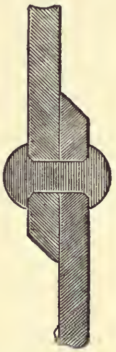

Fig. 3.—Single riveted lap joint.

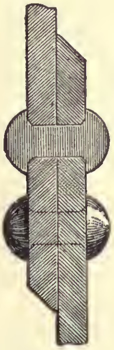

Fig. 4.—Double riveted lap joint.

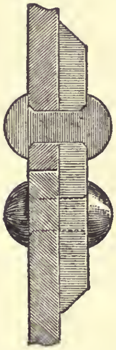

Fig. 5.—Butt joint with single cover.

M. Fremont, in an article on the "Resistance of Riveted Joints," has pointed out that the resistance is insufficient to absorb the more important shocks, with the result that there is permanent deformation, the plates become dislocated and get a certain amount of play, which is increased by each new shock, air and moisture get in between, oxidising the plates and the rivets.

A series of expansions and contractions produce the same effects as a series of shocks; it follows that in joints which are alternately submitted to heat and cold—for example, the furnaces of boilers—the holding power of the rivets is rapidly lowered, and inevitably leads to the complete destruction of the joint.

Riveted joints can have a single, double, or treble row of rivets, and the joints can be lap or butt. In the latter a single or double cover can be used.

The strength of the joints can be obtained by a more or less rigorous formula into which the thickness of the plates, diameter of the rivets, and pitch of the rivets enter.

In ordinary practice well-designed joints should have the following efficiencies :—

Single riveted = 55 to 60 per cent. the strength of the solid plate.
Double „ = 70 „ „ „ „
Treble „ = 75 „ „ „ „

DIMENSIONS FOR RIVETED JOINTS (IN INCHES).

Thickness of Plates.	Diameter of Rivets.	Length of Shank.	Pitch of Rivets.	Lap.		Diameter of Head.
				Single Riveted.	Double Riveted.	
$\frac{3}{16}$	$\frac{5}{16}$	$\frac{13}{16}$	$1\frac{3}{16}$ to $1\frac{7}{16}$	$1\frac{3}{16}$	$1\frac{7}{8}$	$\frac{7}{16}$
$\frac{1}{4}$	$\frac{1}{2}$	$1\frac{1}{16}$	$1\frac{7}{16}$ to $1\frac{11}{16}$	$1\frac{7}{16}$	$2\frac{7}{16}$	$\frac{5}{8}$
$\frac{5}{16}$	$\frac{5}{8}$	$1\frac{7}{16}$	$1\frac{11}{16}$ to $1\frac{7}{8}$	$1\frac{7}{8}$	$3\frac{3}{16}$	$\frac{3}{4}$
$\frac{3}{8}$	$\frac{11}{16}$	$1\frac{9}{16}$	$1\frac{13}{16}$ to $2\frac{1}{16}$	$2\frac{1}{8}$	$3\frac{3}{8}$	$\frac{13}{16}$
$\frac{7}{16}$	$\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{7}{8}$ to $2\frac{1}{8}$	$2\frac{1}{4}$	$3\frac{7}{16}$	$\frac{15}{16}$
$\frac{1}{2}$	$\frac{13}{16}$	$2\frac{3}{16}$	$2\frac{1}{16}$ to $2\frac{5}{16}$	$2\frac{5}{16}$	$3\frac{11}{16}$	$1\frac{1}{4}$
$\frac{9}{16}$	$\frac{7}{8}$	$2\frac{1}{2}$	$2\frac{3}{16}$ to $2\frac{1}{2}$	$2\frac{1}{2}$	$4\frac{1}{8}$	$1\frac{3}{8}$
$\frac{5}{8}$	$\frac{15}{16}$	$2\frac{13}{16}$	$2\frac{9}{16}$ to $2\frac{13}{16}$	$2\frac{7}{8}$	$4\frac{15}{16}$	$1\frac{1}{2}$
$\frac{11}{16}$	$1\frac{1}{16}$	$3\frac{1}{16}$	$2\frac{7}{8}$ to $3\frac{1}{16}$	$3\frac{1}{16}$	$5\frac{5}{8}$	$1\frac{5}{8}$
$\frac{13}{16}$	$1\frac{1}{8}$	$3\frac{1}{4}$	$3\frac{1}{16}$ to $3\frac{1}{4}$	$3\frac{1}{4}$	$5\frac{15}{16}$	$1\frac{3}{4}$

BRAZING.

If one compares brazing to soft soldering, it can be called "hard soldering." It is characterised by the use of a metallic cement melting at a high temperature and possessing a high mechanical resistance.

Given these facts, one can see that it is necessary to heat strongly the edges to be joined and to use a cleaning flux melting at a high temperature.

The "metallic cement" used is called brazing metal, and can be applied in the form of a powder, paste, filings, or grains often mixed with the flux. Its melting-point is just below that of the metal to be joined, so that in heating the pieces to be brazed, the brazing metal melts and adheres to the edges to be joined when they reach a high temperature, thus even forming an intermediate alloy, and the joining is obtained simply by cooling.

When it is a question of joining end to end or edge to edge, the brazing is done with bevelled faces placed side by side. It is clear that this increase of surface in contact increases the resistance of the joint.

Brazing necessitates the use of a forge or blowpipe. The use of a forge is costly, inconvenient, and cannot be applied to articles of all shapes and dimensions. The blowpipe requires, for brazing, great skill in manipulation, because the localisation of the heat tends to "burn" the metal, especially in the joining of brass. Note, however, that the use of blowpipes giving high temperatures, oxy-acelytene for example, enables one to use brazings less fusible, red copper among others, for joining pieces of cast-iron. Brazing rarely fulfils the conditions required for perfect joining, the following being the chief disadvantages: the part brazed possesses a different colour to that of the metal; this same part has different chemical, physical, and mechanical properties from that of the piece; electrolytic action may little by little disintegrate the joint thus constituted; the operation is risky; success is not controllable, etc.

The cleaning fluxes generally used for brazing are: white sand, used for brazing iron which forms with the oxide of the metal a very fusible ferrous silicate; and borax, which is more generally employed and which acts as a kind of solvent for the metallic oxide. Brazing mixtures for various purposes are sold ready for use.

Composition and Application of Brazing Metals.

Application.	Composition.				
	Copper.	Zinc.	Malleable Brass.	Silver.	Gold.
For copper, brass, iron	2	1	...	...	...
,, ,,	...	1	5	...	...
For copper (very fusible)	50	48	...	2	...
For turning brass	45	45	...	10	...
For brass	1·5	6	10	...	...
For steel	1	...	1	19	...
For plates	...	...	1	2	...
For copper or iron	...	...	1	1	...
Fusible solder	...	1	1	5	...
For silver (950 parts in 1000)	23	10	...	67	...
For gold	1	...	...	...	5
For gold (750 parts in 1000)	1	...	...	1	4

WELDING AT THE FORGE.

Fire welding has been known from the most remote time. It is practically only applied to iron and steel. One obtains a joint by energetic hammering of two pieces together which have previously been raised to *welding heat.*

The chief difficulty of fire welding consists in the exact appreciation, at a glance, of the welding temperature by the colour of the metal, because iron can only be welded within certain definite limits of temperature. This peculiarity was well known to the ancients, and the engraving which we reproduce, drawn from a fresco, shows an antique Greek smith very attentive to the colour of the metal which he is about to weld.

The success of a fire weld depends on the exact external observation of temperature and the state of the surfaces to be united, because all interposition of slag or oxide hinder complete welding.

It is therefore necessary to sprinkle the surfaces to be welded with a *flux* capable of dissolving the oxide of iron and to form with it an extremely fluid compound which can be expelled by hammering. As for the brazing of iron, the materials used for fire welding are generally white sand and borax. Certain special materials, of satisfactory composition and easy use, are sold and give excellent results.

Fig. 6.—An ancient Greek blacksmith.

Fire welding has the following disadvantages:—

(1) It is necessary to heat a large portion of the articles to be united, hence deformations and necessity for working after welding.

(2) Large quantity of heat lost, hence process costly.

(3) Difficult to ensure success, and impossibility of control.

Fire welding is, where possible, done by joining the two sections obliquely, known as a scarf weld, thus increasing the surface of contact and the resistance of the joint. The adherence of fire welds very rarely exceeds 70 per cent. the resistance of the metal.

The elongation of fire welds is always very low. From the point of view of brittleness, fire welds give very mediocre results, and frequently in tests by shock separation at the welded line takes place under extremely weak shocks. The results obtained are notably inferior to those obtained for oxy-acetylene welds well executed.

WELDING BY WATER-GAS.

Welding by "water-gas" constitutes a kind of perfect fire welding. Instead of raising the edges to be joined to a welding heat by fire, they are submitted to the action of a blowpipe fed by *water-gas.* This gas is chosen because it can be produced on the spot very economically. It is made by passing steam over red-hot coke, and consists of carbon monoxide and hydrogen which produce a very high temperature by their combustion.

Pneumatic tools rapidly hammer the two edges of the weld when they have been raised to a welding heat by the flame.

Welding by water-gas necessitates a very costly installation, and does not pay unless it is used continuously on a very large scale; it is not practically applicable unless the plates have a thickness of at least $\frac{5}{16}$ inch.

ELECTRIC WELDING.

It is more than thirty years since electricity was proposed for the autogenous welding of metals. The process, however, is not largely used, and its application remains limited to special industries, viz. manufacture of chains, utensils in thin plate, etc. The rapid development of other processes of welding indicates that they are superior in many respects.

Fig. 7.—Welding by the voltaic arc.

Fig 8.—Resistance electric welding machine.

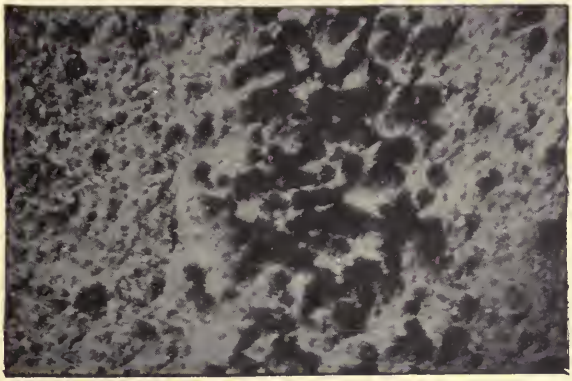

Fig. 9.—Microphotograph showing blowholes in an electric weld.

Electric welding is obtained by two processes which are quite different, *resistance welding* and *arc welding*. The latter system is the one which is most used; it can be applied to work of all kinds and to repairs. Resistance welding is used in the manufacture by machinery of articles of small dimensions in large quantities.

Resistance welding modifies the mechanical properties of the metals, which lose their elongation; if the surfaces to be welded are not perfectly clean there must always be interposition of oxide or dirt, which reduces the solidity of the joint.

Arc welding is generally difficult to apply; the localisation of the heat is not favourable to the perfect joining of the metal, and unless one uses judiciously a satisfactory flux, there will be an interposition of oxide in the joint. Lastly, blowholes are almost inevitable, and these considerably lower the strength of a joint which in appearance may be perfect.

THERMIT WELDING.

This process is only applicable for the joining of iron and mild steels of great thickness.

It consists essentially in burning in a crucible a mixture of powdered aluminium and iron oxide. The temperature of combustion is excessively high, and can attain 3000° C. (or over 5400° F.). The aluminium unites with the oxygen to form alumina, whilst the iron which is set free accumulates in a molten state at the bottom of the crucible.

This is made to flow, by the aid of a suitable mould, round the parts to be joined, and its temperature is high enough to melt the edges to be joined; thus a weld which might be called autogenous is obtained.

It will be understood that the process, which requires costly material, can only be used for important or repetition work. It has chiefly been used for the welding of rails and the repair of very large steel castings. Oxy-acetylene welding is largely replacing it.

BLOWPIPE WELDING.

Blowpipe welding consists in uniting the metal by means of a flame of appropriate temperature with the addition of metal of the same composition. The joint thus obtained is called *autogenous*.

Strictly speaking, the welds obtained by the fire, water-gas, or electricity can be called *autogenous*, since they have been obtained without the interposition of a "metallic cement" whose properties differ from that of the metal joined.

In current language the name *autogenous welds* is understood to mean those which are obtained by melting the metal under the action of the flame of a *blowpipe*.

The blowpipe is an instrument in which the flame is produced and projected on to the metallic parts to be welded.

Blowpipe welding has been known for a long time, at least for the joining of metals whose melting-point is not very high, and was easily obtained by combustible flames burning in air or in a current of air. The autogenous welding of lead was thus obtained by the Egyptians, the Greeks, and the Romans.

The autogenous welding of metals with high melting-points was not possible until the industrial manufacture of oxygen permitted the use of this gas for the production of flames of high temperature.

First of all the *oxy-hydrogen* (oxygen and hydrogen) flame, then the *oxy-acetylene* (oxygen and acetylene) were thought of. After these *oxy-coal gas* (oxygen and coal-gas), *oxy-benzene* or *oxy-benz* (oxygen and vapour of benzol), etc.

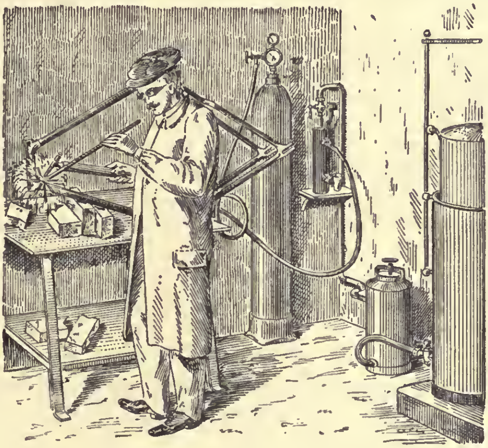

Fig. 10.—Autogenous welding by oxy-acetylene.

Autogenous welding by means of the blowpipe is the process that has been most developed in recent years. This is proved by its use in the majority of workshops for construction and repairs.

It gives incontestable advantages from all points of view over similar processes. Its one defect is that its use is too easy, or at least *appears too easy*, so that it is applied by all sorts without previous study, without care, and without technical ability. Hence the failures.

It requires a long apprenticeship for joining two pieces at the forge, for brazing, even for welding tin, and in all cases one can judge whether the work is good or bad. On the contrary, after an hour's trial one can join iron by melting with the blowpipe, and after a few days one can produce good-looking welds. But are they perfect, even passable? Incontestably no, and that is, we repeat, the very great defect of the process. The reader's attention is drawn to this question in the course of the chapters which follow.

CHAPTER II.

AUTOGENOUS WELDING WITH BLOWPIPES.

We have just pointed out that the term "autogenous welding" is usually applied to obtaining joints by fusion of the metal under the action of the flame of the blowpipe. The term "autogenous welding" is, however, more particularly applied to *oxy-acetylene* welding, since this is the process most commonly used.

It is an advantage, however, to study the various systems of blowpipe welding which have been proposed or used, and to compare one with the other. This second chapter, which we will make as brief as possible, will enable the reader to become acquainted with the various processes, to place each in its relative position, and to appreciate the general advantages which oxy-acetylene welding offers over all the others.

GENERAL CONSIDERATIONS ON THE CHOICE OF A SYSTEM OF BLOWPIPE WELDING.

The manufacturer who wishes to apply autogenous welding should study the various systems which are offered, and find which gives him the most advantages.

The principal points to which he should direct his attention are the following:—*Adapting the System to the Type of Work; Safety; Quality of Work; Economy; Convenience; Cost of Material.* Let us consider these different questions:—

Adapting the system to the type of work.—When a process is no longer applicable to the work under consideration all interest in the process lapses. Under the title "*In which cases should autogenous welding be applied,*" we shall later study the same question, but from a different point of view than that which we deal with here.

In reality, the value or economy of any particular system of blowpipe welding depends upon the type of work. Among the processes of which we will speak, it is first of all necessary to discern which is best applicable to the type of work.

Safety.—It can be considered that all the processes of blowpipe welding have been sufficiently studied and developed as not to offer any serious danger if the usual precautions are observed. The systems using benzol or other combustible liquids have become extremely safe and are practically free from danger. The question of safety then does not arise, but we take this first opportunity, in speaking on *safety*, to put the reader on his guard against plant and arrangements for autogenous welding badly designed or made, in any system, that is to say, whatever combustible is used. We shall return to this question, which is of first importance.

Quality of work.—The *quality* of the work produced by blowpipe welding is not the same in all systems. According to the metals and their thickness the welds may be more or less well finished or more or less *sound*, and a combustible which may be satisfactory in one case may not prove so in another. It is therefore necessary that each system should be kept to its best sphere of application, but one should avoid unnecessary limitations.

Economy.—This is a factor which has essentially a different value according to the application of autogenous welding. In certain cases the cost of the work is of first importance, whilst in others it is only a secondary consideration.

Let us simply remark that a process may *appear* economical and not be so, or again may be very economical under certain conditions, for certain welds, etc., and not for others. The question of net cost of welds is always intimately bound up with those of the quality of work and convenience.

Convenience.—The convenient application is an important factor in the choice of a process, and should be studied from all points of view—installation, maintenance, supervision, etc.—because appearances are often deceptive. A system which *seems* to offer great simplicity and hence many conveniences, may not be so in practice on account of certain points which were not obvious at first sight. Great reflection is therefore necessary, followed by a comparison of the different processes with reference to the kinds of work to be done.

Cost of material.—The various systems of blowpipe welding do not have the same purpose in view, and the importance which is attached to some of them is only on account of the facility and economy of their installation. They are applicable where others are not, and it is from this point of view that they deserve to be mentioned; but, on the other hand, when it is a question of serious work in which the question of cost is not an essential factor, the cost of material plays a very secondary part in the choice of a process, as the extra cost is very rapidly recovered on account of the more economical realisation, more convenient, and better results.

OXY-ACETYLENE FLAME.

Although oxy-hydrogen welding was proposed before oxy-acetylene, we shall study the latter process first, since it is the most common. It will also serve as a basis for comparison with the others.

The use of oxy-acetylene welding is little more than twelve years old, since the first blowpipes, working with acetylene under pressure, were made in 1901 by MM. Fouché and Picard. From 1903 it has been applied industrially, and the progress of the process has been extremely rapid.

In 1895 M. Le Chatelier, in a paper read before the Académie des Sciences on the temperature of flames, stated that "acetylene burnt with an equal volume of oxygen gives a temperature which is 1000° C. higher than the oxy-hydrogen flame. The products of the combustion are carbon monoxide and hydrogen, which are reducing agents"; and the paper concluded with this sentence: "This double property makes the use of acetylene in blowpipes of very great value for the production of high temperatures in the laboratory."

As was first pointed out by M. Chatelier, the oxy-acetylene flame results from the combustion of a mixture of oxygen and acetylene in *equal volumes.* Theoretically it requires 2½ volumes of oxygen to completely burn 1 volume of acetylene, and this is actually what takes place if one takes into account the oxygen taken from the air during the last phase of the combustion; but the blowpipe need only supply the *oxygen necessary to form the white welding jet*, and for this the volume is exactly 1 volume to 1 volume.

We shall see that in practice one requires a little more (1·2 to 1·4 for 1), because the mixture of the two gases is not absolutely perfect.

For those who are not afraid of chemical formulæ we give the equations representing the phases of oxy-acetylene combustion.

Burnt with an equal volume of oxygen, acetylene produces hydrogen and carbon monoxide:—

$$C_2H_2 \quad + \quad 2O \quad = \quad H_2 \quad + \quad 2CO.$$

Acetylene and oxygen yield hydrogen and carbon monoxide.

The hydrogen and oxide next burn, taking the necessary oxygen from the air and producing water vapour and carbon dioxide:—

$$CO \quad + \quad O \quad = \quad CO_2.$$

Carbon monoxide and oxygen yield carbon dioxide.

$$H_2 \quad + \quad O \quad = \quad H_2O.$$

Hydrogen and oxygen yield water vapour.

The carbon monoxide formed in the first part of the combustion is therefore entirely burnt in the second, and it could not be otherwise unless one deprived the flame of air. A paper by M. Mauricheau-Beaupré to the Académie des Sciences in January 1906 describes a series of tests which point to the complete absence of carbon monoxide in the atmosphere surrounding the oxy-acetylene flame. Poisoning of welders has therefore never existed other than in the imagination of manufacturers of blowpipes for gases other than acetylene.

The combustion of 1 cubic foot of acetylene produces 410 calories, or 1630 British Thermal Units, nearly five times as much as that of hydrogen and three times as much as oil-gas. Of these, 68 calories, or 270 B.Th.U., are due to the heat of dissociation of the acetylene, which is an endothermic gas, and disengaging suddenly at the moment of its decomposition, explains *the very high temperature at the beginning of the flame.* Observe that the other gases which are used in autogenous welding do not possess this remarkable property.

The temperature of the oxy-acetylene flame, taken at the extremity of the white jet, is very much higher than that of all other flames. M. Chatelier calculates it to be 4000° C., or more than 7000° F. In all cases, the white jet of the oxy-acetylene flame can melt lime, the melting-point of which is estimated at 3000° C., and this can only be obtained otherwise in the electric arc.

The final products of combustion are, as we have said, carbon dioxide and water vapour, this latter in a less quantity than for the oxy-hydrogen flame, but the molten metal, under the action of the flame, only comes in contact with the carbon monoxide and the hydrogen produced in the first stage of combustion, since the welding is done at the extremity of the white jet. These gases, which have a reducing action, are in all cases the most neutral, considered from the physical or chemical point of view as capable of modifying the value of a weld.

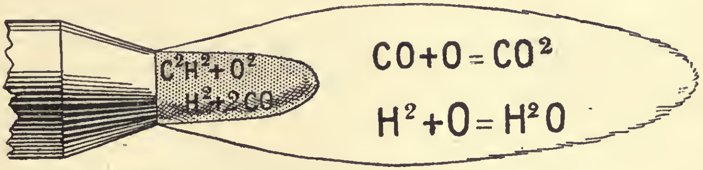

Fig. 11.—Phases of the combustion in the oxy-acetylene flame.

The utilisation of the heat of the flame, or the coefficient of utilisation, is very high in the case of the oxy-acetylene flame, on account of the high temperature of the flame being concentrated at the point of the flame (white jet).

The regulation of the blowpipes is extremely easy, and neither their working nor their maintenance offers any difficulties. They are constructed for all deliveries, from 50 to 4000 litres (1·75 to 140 cubic feet) of acetylene per hour, that is, they can weld from the smallest to the largest thicknesses.

Safety in use is absolute in all well-designed installations.

The price of 1 cubic foot of acetylene may be estimated at 0·34d., and that of oxygen at 0·5d. Taking the relative consumption as 1·3 of oxygen for 1 of acetylene, then 1000 calories or 4000 B.Th.U. costs 2·4d.

OXY-HYDROGEN FLAME.

The oxy-hydrogen flame has been known for a long time. The first blowpipe appears to have been suggested by Robert Hare of Philadelphia about 1805. In 1820, Broke, in Germany, designed an arrangement by which a mixture of oxygen and hydrogen, previously compressed by means of a force-pump into a strong plate vessel, escaped by a capillary tube of glass. When the extremity of this tube melted or became stopped up, it was only necessary to break off a small portion to set it in working order again.

This type of blowpipe, the manipulation of which was dangerous because of pre-mixing of the two gases, was first modified by Berzelius. Next Pius Sainte-Claire Deville obtained a blowpipe, using oxygen and hydrogen compressed in two separate vessels. He succeeded in melting iron, silver, and platinum.

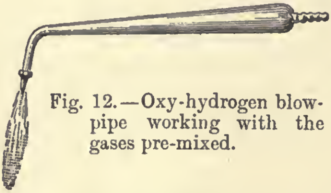

Fig. 12.—Oxy-hydrogen blowpipe working with the gases pre-mixed.

The oxy-hydrogen blowpipe remained a laboratory instrument until such time as the gases could be produced at a low price and arrangements devised for their safe storage. It was introduced for industrial autogenous welding in 1901.

The oxy-hydrogen flame is produced by the combination of 2 volumes of hydrogen with 1 volume of oxygen forming water vapour. Expressed chemically:—

$$H_2 + O = H_2O.$$

Hydrogen and oxygen yield water vapour.

In the first applications to autogenous welding it was found that the water vapour which is produced exclusively and abundantly, provoked considerable oxidation of the metal when raised to melting-point or simply heated, and that all serious joining was impossible. The only artifice possible was to *dilute the water vapour with an excess of hydrogen*, and in order to produce good welds, one must raise the proportion of the gases from 2 to 4 volumes of hydrogen, for 1 volume of oxygen, and this is what has been done in practical applications.

One may therefore say, that the oxy-hydrogen flame used in autogenous welding results from the combustion of a mixture of 4 volumes of hydrogen and 1 of oxygen, half the hydrogen used serving to dilute the water vapour formed at the beginning of the reaction, then burning afterwards in oxygen borrowed from the air.

It is understood that in spite of the artifice of using excess hydrogen, the disadvantage of oxidation of the metal by the water vapour still exists in part, because diluting this water vapour does not get rid of it. The metal, during welding, heated or melted, is always therefore in contact with an atmosphere which is less neutral than in the case of acetylene.

One cubic foot of hydrogen produces 88 calories or 350 B.Th.U. compared to 410 calories or 1630 B.Th.U. in the case of acetylene. The commercial price of hydrogen can be fixed at 0·28d. per cubic foot, and the oxy-hydrogen mixture being formed of 4 parts of hydrogen to 1 of oxygen, one may calculate that 1000 calories or 4000 B.Th.U. costs about 4·7d. compared to 2·4 in the case of acetylene, or almost double.

For the same number of calories, the oxy-hydrogen flame is less in volume than the oxy-acetylene flame, the heat is less easily utilised for obtaining autogenous welds, because the high temperature zone is less localised. Moreover, the temperature is not so high; according to the engineer of the Company which exploited the oxy-hydrogen process, it does not exceed 2300° C. or 4170° F.

In fact it is difficult, with the oxy-hydrogen blowpipes, to melt the edges to be welded, even in thin pieces, where the heat is absorbed and lost by conductivity. It is practically impossible to weld satisfactorily plates of steel exceeding $\frac{1}{4}$ inch in thickness.

The use of the oxy-hydrogen process is therefore limited to thin pieces (say up to $\frac{3}{16}$ inch), in the case of iron and steel or more fusible metals. Even within these limits the welds are not as good and cost more than with the oxy-acetylene process.

On the other hand, the cost of the installation is limited to the cost of the blowpipes and the apparatus for the expansion of the gas, the cylinders containing the oxygen and hydrogen being in most cases supplied free.

It should, however, be mentioned that the same applies to the use of dissolved acetylene, which is also delivered in steel cylinders, and in spite of the higher price of the gas thus stored, the process again costs less and gives better results than that of oxy-hydrogen welding.

Lastly, let us add that a considerable amount of practice is required for satisfactorily regulating the flame of the oxy-hydrogen blowpipe.

OXY-COAL GAS FLAME.

The term *oxy-coal gas* is given to the flame produced by the combustion of a mixture of oxygen and illuminating gas.

In 1838, Debassyns de Richemont replaced the hydrogen in oxy-hydrogen blowpipes or hydrogen and air, by coal-gas. Brazed joints and autógenous welds on lead were obtained by the use of the flame thus produced.

When the oxy-hydrogen and oxy-acetylene processes became known industrially, due to the production of oxygen at a low price, the use of coal-gas for obtaining autogenous welds was again considered. One of the first blowpipes specially constructed for the use of this combustible was designed by M. Georges Claude.

The process was tempting, because it allowed a cheap and easy instillation for autogenous welding in all workshops supplied with the gas. But, as we shall see, welding by oxy-coal gas has not, nor can it have, serious application.

Illuminating gas is a mixture of various gases, and its composition is not absolutely constant. One cubic foot of average quality contains about :—

0·5 cubic foot of hydrogen.
0·35 ,, ,, methane.
0·08 ,, ,, carbon monoxide.
0·02 ,, ,, carbon dioxide.

The combustion of 1 cubic foot of the gas produces 155 to 190 calories, or 600 to 750 B.Th.U. The cost of 1 cubic foot of the gas being taken as 0·05d. (practically 4s. per 1000 cubic feet) requires 0·675 cubic foot of oxygen at 0·5d. per cubic foot for producing the normal welding flame, the cost of 1000 calories or 4000 B.Th.U. is therefore 2·5d. compared with 2·4d. for acetylene, and 4·7d. for hydrogen. But the temperature of the oxy-coal gas flame is not higher than the oxy-hydrogen flame, and the coefficient of utilisation of heat is no better; on the contrary, one might say that the process does not offer, first of all, any economic advantage.

Further, it gives results which are decidedly bad from the point of view of the quality of welds, and one can understand the reason why.

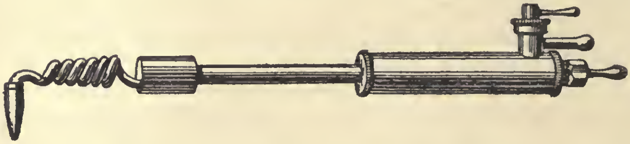

Fig 13.—Oxy-coal gas blowpipe ("Claude" system).

We have said that in oxy-hydrogen welding the strong oxidation of the metal can only be avoided by diluting the water vapour produced with a large excess of hydrogen. The oxy-coal gas flame produces as much water vapour as the oxy-hydrogen flame, and therefore one should follow the same procedure. But, apart from the disadvantages produced by an excess of coal-gas in the flame, it would not be possible to introduce an appreciable excess on account of its low pressure; unlike hydrogen in the oxy-hydrogen process, the oxygen has to draw it by suction, and the quantity is necessarily limited.

The welds obtained by oxy-coal gas blowpipes are therefore always very strongly oxidised and excessively fragile, so that their resistance is practically nil. In fact, oxy-coal gas welds should be prohibited in all cases where the work is likely to be subject to strains, and little recommended for joints which do not require to be strong or tight. In iron and steel work one can only apply it on thin material.

Notice, in passing, that the arrangements for pre-heating the gases previous to combustion, with a view to obtaining a higher temperature in oxy-coal gas or oxy-hydrogen flames, do not achieve the desired result. This is because, if the temperature is increased, the water vapour dissociates with the absorption of heat, the two elements recombine much further in the flame, thus giving back, it is true, their heat of formation, but which has already been absorbed.

OXY-BENZ AND OTHER FLAMES.

The term "Oxy-Benz" comes from Germany, and has been universally adopted to describe welding flames produced by the combustion of mixtures of oxygen and the vapours of benzol, benzine, or, generally speaking, all other liquid hydrocarbons.

Certainly these processes, in very particular cases, can prove of value; but, for the usual applications of autogenous welding, one can say that they offer no advantage, have many disadvantages and dangers, and are not of wide application.

The oxy-benz process itself possesses one great defect: that of using a combustible liquid which must be vaporised. This operation, to be automatic, requires time, care, and constraint on the part of the welder, and can never give the desired regularity. The blowpipes are complicated instruments, delicate and irksome.

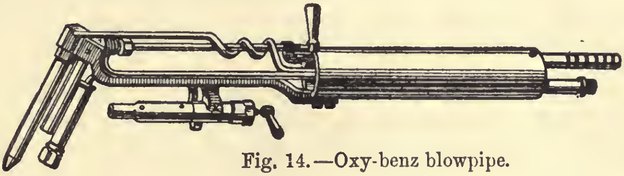

Fig. 14.—Oxy-benz blowpipe.

The acetylene generator or hydrogen cylinder is replaced by a vessel containing the liquid, which is generally under pressure. The use of a branch from the oxygen for obtaining this pressure is accompanied by grave dangers, and in order to avoid all risk of explosion, it is necessary to resort to devices which, while being ingenious, are extremely complicated.

And what advantages do these oxy-benz flames offer in the autogenous welding of materials? None. True, the temperature is higher than in the oxy-hydrogen or oxy-gas flames, but much lower than the oxy-acetylene flame, and it has the defect of being very difficult to regulate on account of the variation in the vaporisation of the liquid used, with the result that the flame is sometimes oxidising, sometimes carbonising. Is the heat cheaper than in the case of acetylene, and is the utilisation of heat as good? The calculation would be difficult on account of the variable calorific value of these combustible liquids, the figures given vary strangely according to who presents them, and manufacturers of the oxy-benz process are singularly assisted in drawing up their advertisements.

And, moreover, what real industrial value is obtained by an insignificant lowering of the cost of the combustible in welding blowpipes (if one admits this is so), in proportion to the cost of oxygen, workmanship, facility of use, and, above all, the quality of work obtained? All these considerations are very important, and must be borne in mind in the choice of a process.

The great success of the oxy-acetylene blowpipe has given rise to other processes, and will, without doubt, lead to others being launched. We have already *Liquid Gas*, *Blau Gas*, *Vulcan Gas*, etc. These systems, apart from the question of safety, convenience, and cost, give a flame whose temperature is much lower than the white jet of the oxy-acetylene blowpipe, do not utilise the heat so well, are more difficult to regulate, and give welds which are not as sound.

CONCLUSIONS ON WELDING FLAMES.

Acetylene offers considerable advantages over all the other combustibles utilised for welding flames from various points of view, viz. facility of work, quality of welds, cost of work, etc. Moreover, it is the only process with which welds from the smallest to the largest thickness can be obtained, and which offers a genuine guarantee from the point of view of the strength of the joint.

Oxy-hydrogen welding is definitely inferior to the oxy-acetylene process; it gives, however, better results than oxy-gas welding, which should be rejected in all cases where the joint has to withstand a strain.[1]

Oxy-benz welding and similar processes have no value except for intermittent application and in cases where the work is not important enough to justify an acetylene installation.

. . . .

It is therefore to oxy-acetylene welding that the following chapters are particularly dedicated. The greater part of it will also apply to all the systems of which we have just spoken, and the term "autogenous welding" always implies the application of a flame produced by mixtures of acetylene and oxygen.

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[1] In a recent work by M. A. Grebel, specialist in oxy-gas, it is stated that oxy-gas welds are distinctly inferior to oxy-acetylene welds from all points of view, including quality of work and net cost.

CHAPTER III.

IS AUTOGENOUS WELDING OF EASY APPLICATION? IN WHAT CASES SHOULD IT BE EMPLOYED?

Before studying the gases used for autogenous welding, the blowpipes and other details, it may be useful to call the attention of the reader to the questions: *Is autogenous welding of easy application? In what cases should it be employed?*

We will be brief, but this chapter appears to us to be essential.

IS AUTOGENOUS WELDING OF EASY APPLICATION?

Yes, because the process is extremely simple in itself, and after a few hours' practice anyone can learn it more or less. *No*, because on account of its easy application one loses sight of the fact that it has a technique which has been arrived at as the result of many experiments.

The welder has one main object: *to penetrate the heart of the weld*, to use the expression employed, and then to finish with a *smooth surface.* He doesn't trouble about oxidation, the nature of the metal produced, or internal strains. He has welded to the heart; the weld is good looking, and that is sufficient to save his honour. With these conditions, the trade is no more difficult than any other; on the contrary, it does not require much intelligence or reflection when treated in this way. It is true that if the weld has not produced the object aimed at, one usually blames the method and not the worker.

On the other hand, it does not require a great effort to master the technique of welding; it is sufficient to learn certain elementary principles and then exercise judgment in each application.

Thus understood, autogenous welding is easily employed, and gives good results.

To melt iron, cast-iron, or copper by the flame of the blowpipe is not welding. Welding consists in uniting the metal whilst in the liquid state, and to operate in such a manner that its physical, mechanical, and chemical properties are not seriously modified at the welding place, so that they approach as nearly as possible the properties of the original material.

IN WHAT CASES SHOULD AUTOGENOUS WELDING BE APPLIED?

We ought really to add to the above question: *In what cases should we abstain?*

A definite answer would be difficult, chiefly due to the progress in the technique and new ideas, so that what we might say to-day may become untrue to-morrow. We will therefore only limit ourselves to generalities.

We will divide the question into two principal classes, viz. Construction and Repairs, and in each case with regard to the employment of autogenous welding we must ask, first, *is it exclusive?* second, *is it technically preferable?* third, *is it more economical?* fourth, *is it of more easy application?*

Construction.—Certain joints can only be satisfactorily realised with autogenous welding, at least from the industrial point of view, such as in the case of certain branches to tubes, pieces for machines, aeroplanes, etc., and numerous other devices which one could not think of making before autogenous welding was applied.

The second case, as to whether autogenous welding is preferable to other methods from the view of obtaining the best joint—the seam is much more solid than in the case of brazing; air-tightness is the advantage over riveted seams, etc. etc. We will quote as examples the construction of vessels for containing compressed gases, liquid oils, buoys, vapour collectors, various tubes, boilers, radiators, etc.

Quality and strength being satisfied, economy of the process is one of the most important factors, and from this point of view autogenous welding should be applied almost wherever possible, but not in every case. It is admitted, for example, that above a certain thickness of plate ($\frac{1}{2}$ inch) joining with riveting or welding with water gas is more economical. Fire welding, water-gas welding, or brazing all have their economical application; let these keep their place, and let us give to oxy-acetylene welding only what really belongs to it.

Lastly, the employment of autogenous welding can be recommended if the work is easy, although it gives the same results apparently as fire welding or brazing for example, which require specialists who are not always at hand especially for odd jobs. Each one must decide according to the work and the workman, whether the application of autogenous welding is preferable.

Repairs.—It is incontestable that autogenous welding is an excellent process for the perfect repairing of broken metal pieces, and in general no other process can rival it for this type of work. But it is not always applicable, and one must guard against too wide a generalisation.

In those cases where autogenous welding constitutes an exclusive method for repair—and such cases are too numerous to mention—the comparison of the conditions for obtaining a perfect joint, economy, and ease of application disappear, since they cannot be compared to other methods, but this does not mean that we should ignore these factors. Let us remark that the technical principles involved are even more important in repair work than in construction.

In certain cases other blowpipe systems can compete with acetylene welding, and their results are comparable from the point of view of more easy application, or economy. Why, then, should we suggest the use of autogenous welding in such cases?

. . . .

There are cases where the application of autogenous welding, even when well applied, does not give good results. For example, the joining of a thick partition to a thin piece, repairs to pieces where it is impossible to avoid the effects of expansion, special alloys whose composition is unknown to the welder, etc. etc. We shall return to these points later; we must remark again, that although the application of autogenous welding is easy, many mistakes will be made if the process is applied without a knowledge of the elementary principles and technique.

CHAPTER IV.

OXYGEN.

PROPERTIES OF OXYGEN.

Oxygen is invariably the combustion agent used in autogenous welding with the blowpipe. It is useful and even necessary for those using it to be familiar with its properties, manufacture, storage, methods of use, etc.

Oxygen is, of all bodies, the most widely distributed in nature. It exists in a state of mixture in the air, which contains about one-fifth of its volume of this gas. Water is a compound of oxygen and hydrogen, containing nearly 89 per cent. of the former element. It is found in nearly all mineral and organic substances.

This gas was isolated by Priestley in England and Scheele in Sweden. Lavoisier studied its properties and gave it the name of oxygen.

Physical properties.—Oxygen is a colourless, tasteless, and odourless gas. Its density is 1·1056.

One litre of oxygen at 0° C. and atmospheric pressure weighs 1·43 grams.

It is not very soluble in water; 100 volumes of water at 0° C. can dissolve nearly 5 volumes of oxygen at atmospheric pressure.

Formerly, oxygen was considered a body not capable of existing in the liquid state. In 1877 M. Cailletet and Pictet succeeded in liquefying it by compressing it to 320 atmospheres and lowering its temperature to 140° C. below zero. In the liquid state its density approaches that of water.

Like all other gases, oxygen can be *compressed.* We will return to this property later.

Chemical properties.—Among chemists oxygen is known by the symbol O. Its atomic weight is 16.

The characteristic property of oxygen is its power of supporting combustion; a glowing candle will instantly burst into flame if plunged into a jar of oxygen.

Iron heated to redness burns in oxygen.

The combustion is a chemical reaction between the oxygen and the body which burns in it. The product of the combustion is called *oxide.*

In the same category as this rapid combustion one can place what are called *slow combustions*, which are phenomena of oxidation in which the temperature of the body is not specially high. Oxidation of metals by contact with oxygen (or air which contains one-fifth) is slow combustion. The intensity of the reaction increases with increase of temperature; thus most metals rapidly oxidise when heated to redness in air, and, of course, much more so in contact with pure oxygen. *We shall continually refer to this phenomena of oxidation, which can be produced very intensely during the execution of autogenous welds.*

INDUSTRIAL MANUFACTURE OF OXYGEN.

Oxygen is usually prepared in the laboratory by heating *manganese dioxide* to a bright red heat, when it gives up one-third of its oxygen, or by heating *potassium chlorate*, which likewise gives up its oxygen. If the potassium chlorate is mixed with about one-eighth its weight of manganese dioxide the reaction is much more regular.

These processes are not industrial. They were and are even now applied in countries where oxygen could not be obtained in any other way.

It is due to the manufacture of oxygen at a low price that autogenous welding has developed, and, *vice versa*, it is this development which has stimulated inventors and manufacturers to search for processes or improvements which would give oxygen at an advantageous price.

In order to obtain oxygen cheaply one would naturally try to obtain it from materials which are free, *i.e.* air and water, the one containing it in the form of a mixture, and the other in a state of combination. Processes for obtaining it by chemical means are reserved for cases where it has to be prepared at the place of consumption (Colonies, places a long distance from industrial centres, etc.).

Manufacture by electrolysis of water.—Water is a compound of hydrogen and oxygen. It can be split up into its elements, and the two gases can be collected separately. This operation is easily carried out by electricity, and is called electrolysis.

Water to which a small quantity of sulphuric acid or potash has been added is treated with an electric current in an apparatus called an electrolyser.

The oxygen is liberated at the negative pole and the hydrogen at the positive pole. The gases are then separately collected and conveyed to gasometers. The hydrogen is used for oxy-hydrogen welding, filling balloons, or other purposes.

Oxygen made by this process is generally very pure, but the electrolysers require a great amount of care and supervision, especially to avoid mixtures of the two gases, such mixtures being extremely dangerous. This risk has been largely diminished in recent years by the use of automatic indicators, which give an alarm in case of diffusion of the oxygen and hydrogen.

The process is considered more costly than that of extracting the oxygen from the air, but according to the scale of production and the general conditions of working it may compete with them.

Extraction of oxygen from the air.—Attempts were made long ago to extract oxygen from the air, where it exists as a simple mixture with nitrogen (nitrogen 79 per cent., oxygen 21 per cent.).

A mechanical treatment of air rich in oxygen was tried, but a complete separation of the two gases was not possible. This process was abandoned, but, without doubt, the last word has not been said, and there is still the possibility of it being applied industrially some day.

Boussingault devised a method for the extraction of the oxygen from the air which is still being used, although going out of use. It consists in gently heating to dull redness in air baryta (BaO). The oxygen combines with the baryta forming the dioxide (BaO_2), but at a bright red heat this parts with the additional oxygen with the reproduction of baryta. By thus alternately varying the temperature a regular production of gas can be obtained. This simple method somewhat modified was previously carried out on a large scale by Brin's Oxygen Company.

The process of Mothay and Maréchal consisted in passing air over a heated mixture of manganese dioxide and soda. The substance absorbs the oxygen and is converted into manganate. Water vapour is then passed over the manganate to decompose it, that is, to liberate the oxygen which it has absorbed, which regenerates the mixture of manganese dioxide and soda. This process of manufacture has many disadvantages, and has been abandoned.

During the last few years the economical production of oxygen has been obtained by the *liquefaction of air* and the separation into its two constituents.

Professor Linde was the first to work out an industrial arrangement for the liquefaction of air and for the separation of the liquid into its two constituents, oxygen and nitrogen. Claude, Pictet, Lévy, Helbronner, etc., completed the problem, and designed extremely ingenious plant destined for the economical production of liquid air and its rational distillation.

We can only give the main outlines of the operations. The air to be liquefied is first compressed, then expanded; this lowers its temperature and ultimately reaches liquefaction, profiting (Claude process) by the work of expansion.

Although the oxygen and the nitrogen liquefy simultaneously, M. Claude succeeded in obtaining the first jet of liquid rich in oxygen, which, by a process of rectification, gets rid, little by little, of its nitrogen. The Linde process consists of the fractional distillation of liquid air, which brings about the production of pure oxygen. Other plants have been designed besides these, using more or less these two systems or their combination, hence the patents and claims of these are contested by the others.

As a general conclusion one might say that the liquid air process is the most economical. Moreover, it is the one which has been most developed; the obtaining of autogeneous welds economically is a result of the lowering of the price of oxygen due to the process.

Other processes.—Other processes for the manufacture of oxygen for industrial purposes have been recommended and exploited; we have already mentioned the methods of preparation by the decomposition of potassium chlorate and manganese dioxide which were in use until a few years ago.

The use of potassium perchlorate is an interesting improvement on the old methods, especially as this body is made to give up the greater part of its oxygen by *auto-combustion.* It forms the basis of a product known under the name of *Oxygenite.*

Oxygenite is a yellow substance of sandy appearance. It is unaffected by air and does not deteriorate if stored in a dry place. A special apparatus is used for the combustion and the storing of the oxygen under pressure. It is only necessary to place the product in a chamber for the purpose, introduce it into the apparatus, light, then close the gas-tight cover; after a few minutes oxygen is produced under pressure. One pound of oxygenite gives about 112 litres or 4 cubic feet of oxygen. The cost price of the gas is not less than $1\frac{1}{4}$d. per cubic foot, that is, much higher than the actual price for oxygen made from air or by electrolysis of water. The only interest of the process is that it permits the manufacture at the place of consumption, and, as a consequence, the application of autogenous welding in isolated countries or places very far from oxygen-producing works. The cost of hiring and transport of the steel cylinders containing compressed oxygen makes their use impossible in places which are far removed from industrial centres, etc. Oxygenite may therefore in such cases render valuable service, since the cost is limited to the transport of 25 lbs. of the material for every 100 cubic feet of oxygen produced.

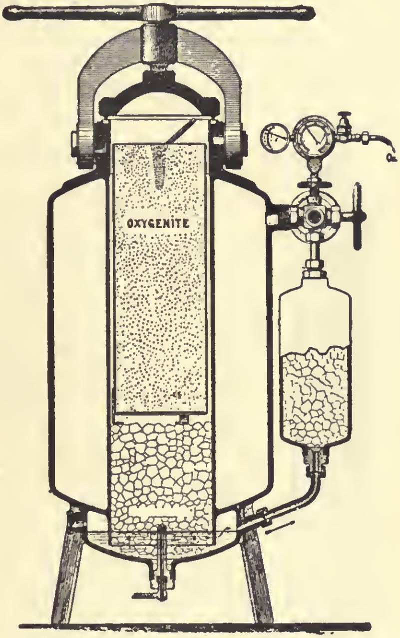


Fig. 15.—Apparatus for the production of oxygen from oxygenite.

To be complete, we mention the obtaining of oxygen from *Epurite.*

A mixture of chloride of lime, iron sulphate, and copper sulphate is soaked in water; the reaction takes place slowly. This process is always more costly than the preceding one.

Lastly, we mention *Oxylithe*, a product which we might say is to oxygen what carbide of calcium is to acetylene, that is to say, it is only necessary to bring it into contact with water to immediately obtain oxygen. Unfortunately the price of oxygen from oxylithe is so high that one could not think of using it in autogenous welding.

OXYGEN IN CYLINDERS.

Oxygen extracted from the air or made by the electrolysis of water is delivered from the works in steel cylinders and under a pressure of 120 atmospheres per square inch. These are the cylinders, *tubes*, or *bottles*, as they are variously named, which feed the autogenous welding installations. It is therefore an advantage to study all that belongs to the supply and use of commercial oxygen.

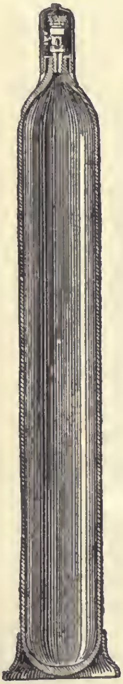


Fig. 16.—Section of oxygen cylinder.

Description of the cylinders.—Cylinders destined to contain oxygen under pressure are made of steel of first quality. The thickness of the walls must be sufficient to withstand a much higher pressure than the 120 atmospheres per square inch to which the oxygen is compressed. The manufacturers generally test it to double the employed pressure, that is, to 240 atmospheres per square inch, the test being made hydraulically.

Since oxygen is an indecomposable gas, its use in a compressed state does not present any risks of explosion.

Frequently the base of the oxygen cylinder is encased in a foot, usually square, which enables it to be placed upright and avoids sudden shocks during manipulation on a part which is under pressure.

The top of the cylinder is made dome-shaped, and terminates in a screwed portion into which the cylinder *valve* is fixed. This valve is of complex construction, but its manipulation and maintenance are very simple. We shall refer to this later.

Frequently the valve is protected against shocks during transport and manipulation by a *cap* screwed on by hand and which completely covers it.

Compression of the gas into the cylinders.—The oxygen obtained from liquid air or by the electrolysis of water is stored in a large gasometer, from which it is taken to the compressors, and pumped into the cylinders just described.

The cylinders to be filled are grouped round a frame to which the valve is connected; a number of cylinders are filled at the same time.

When a gas is compressed *heat is liberated*; on the contrary, when it is allowed to expand, *decompressed*, so to speak, heat is absorbed; this may be called *liberation of cold.* We shall return to this latter point later.

The compression of the oxygen is increased as a result of the temperature of the gas, and it is therefore necessary to compress higher initially, say to 125 atmospheres, in order that the cylinder when cool should be at 120 atmospheres.

As a result of storing the oxygen in contact with the water in the gasometer, its increase of temperature in the compressor, or bad working of the latter, a certain quantity of water vapour is carried with the oxygen. When the gas cools this water vapour condenses. This vapour explains the presence of water in the cylinders of compressed oxygen. We shall return to this disadvantage later.

CONTENTS OF THE OXYGEN CYLINDERS.

The oxygen cylinders usually employed in autogenous welding contain a volume of gas varying from 10 to 200 cubic feet. The cylinders of 100 cubic feet are mostly used in England.

We have said that the oxygen is generally compressed to 120 atmospheres per square inch.

This is only an approximate figure. For the moment let us assume that it is correct. What would be the actual volume of gas in a cylinder of given capacity, and what volume remains in a cylinder partly used?

The law of gases known in this country as Boyle's Law[1] is so simple that almost anyone can apply it to this small calculation. It states that: "The temperature remaining constant, the volumes of the same mass of gas vary inversely as the pressure."

That is to say, a gas under a pressure of 150 atmospheres would, on lowering the pressure to 1 atmosphere, occupy 150 times its previous volume. Hence the volume which a compressed gas would occupy at atmospheric pressure is calculated *by multiplying the capacity of the vessel by the pressure of the gas expressed in atmospheres.*

Example.—The actual capacity of a cylinder, measured by pouring water into it, is 0·80 cubic foot (5 gallons of water), and the gauge registers 120 atmospheres; the compressed gas represents a volume of $0{\cdot}8 \times 120 = 96$ cubic feet.

If the water capacity is engraved on the cylinder, and the reducing valve is sufficiently accurate, the welder can determine at any instant what approximate volume of oxygen remains in the cylinder. Here is another example, or rather a problem:—

Required to do a welding job taking on the average an hour when using a blowpipe consuming 800 *litres or* 28 *cubic feet of acetylene*

---

[1] On the Continent of Europe it is more commonly called Mariotte's Law, from a French investigator who traversed the same ground fourteen years after Boyle's results had been communicated to the Royal Society.

per hour. The welder has only got one 100-*cubic-feet cylinder, indicating a pressure of* 50 *atmospheres. Can he undertake the work?*

Suppose the internal capacity engraved on the cylinder is 0·83 cubic feet. Since the pressure is 50 atmospheres, the volume of oxygen at the disposal of the welder is equal to ·83 × 50 = 41·5 cubic feet. We shall see later that a blowpipe delivering 800 litres of acetylene per hour consumes at least 1000 litres or 35 cubic feet of oxygen. Hence we have 41 cubic feet in the cylinder, and we estimate that we shall use 35 cubic feet. If we deduct the 2 to 3 cubic feet which remain in the cylinder when the pressure has fallen to 1½ or 2 atmospheres, and a little for the possibility of the delivery of the blowpipe being in excess of the figure given by the maker, we see that we have just enough gas to do the work. It would be advisable in such a case to work rapidly and try to finish the weld in a little less than one hour.

It is, of course, understood that such a calculation is only approximate, but in practice it can become of real value to the welder.

Boyle's Law itself is only approximate. For oxygen it requires serious corrections, especially at certain pressures. The law is only strictly true when applied to so-called *perfect* gases (which are imaginary), and oxygen is not among these. The scientist Amagat drew up tables of corrections for the gases mostly used, and among others for oxygen.

When oxygen is compressed, say, to 120 atmospheres, the cylinder contains more than 120 times its volume of gas reckoned at atmospheric pressure. Were the manufacturers to ignore this fact when filling the cylinders we should be benefited by a gratuitous overweight of gas.

The Amagat correction varies with the pressure, and therefore to calculate accurately the quantity of oxygen remaining in a partly spent cylinder it would be necessary to have a complete table of corrections for all pressures.

We mention, in passing, that in the case of compressed hydrogen the corrections to be applied are opposite to those of oxygen; that is to say, that in order to have 120 times the volume of gas in the cylinder the hydrogen must be compressed to a higher value than 120 atmospheres.

We will now deal with the effect of temperature, because this is an important factor.

We have already explained that the volume of a gas increases with an increase of temperature, and that this is true for a gas under pressure, the increased volume following Boyle's Law. *Consequently, when the temperature of oxygen in a cylinder is increased or diminished, the pressure rises or falls.*

The calculations are usually based on a temperature of 15° C. (60° F.). This is the temperature for which Amagat constructed his curves of correction for Boyle's Law. *For calculating the volume of the gas stored in oxygen cylinders the pressure must therefore be taken at* 15° *C.*

Let us examine how the pressure varies according to the temperature.

An interesting investigation undertaken by the military establishment at Chalais-Medon indicates that oxygen compressed into a cylinder at 15° C. and 150 atmospheres is raised to the following pressures as its temperature is increased:—

At 20° C.	152·8 atmospheres.
„ 25° C.	155·6 „
„ 30° C.	158·4 „
„ 35° C.	161·4 „

and if the temperature is lowered:—

At 10° C.	147·2 atmospheres.
„ 5° C.	144·4 „
„ 0° C.	141·6 „
„ – 5° C.	138·8 „

These figures are interesting. They show clearly that in calculating the volume of oxygen under pressure, temperature is not a negligible factor and must be taken into account. Note that the temperature to be taken is that of the surrounding air in which the cylinder has been *resting* for several consecutive hours; and it should be known that directly after a quantity of oxygen has been taken out the temperature is considerably lowered as a result of the cooling due to expansion. For this same reason, the gauge pressure on the reducing valve of a cylinder always rises a little after a large delivery, because the expansion causes a lowering of temperature in the cylinder, and as the cylinder regains the normal temperature of the surrounding air the pressure consequently rises.

To summarise, in order to make an exact calculation of volume under standard conditions of pressure and temperature it is necessary:—

(1) *To apply the Amagat corrections.*
(2) *To express the Pressure in atmospheres.*
(3) *To correct for temperature, which should be at* 15° *C.*

MANIPULATION OF OXYGEN CYLINDERS.

Cylinders of compressed oxygen can be manipulated without any special precautions. For use they are placed, according to their shape, upright or lying down. An excellent arrangement consists in inclining them on a support of 10 to 15 inches high, so that the valve is in a good position for handling. Carefully avoid letting them fall, which occurs rather frequently with large cylinders, especially if the floor is not level. Such accidents do not affect the cylinder, but may injure the welders, and in the majority of cases damages the reducing valve.

The cock or valve is the delicate part of oxygen cylinders. The welder has only, in theory, to open and close the valve at the beginning and end of the work. This operation, so simple in itself, requires certain precautions. Often, on the arrival of the cylinders, the valve is very hard to open. The welder should make sure of its working before placing the reducing valve in position, so that any powdered oxide or other dust is blown away. The oxygen on escaping into the air produces a violent hissing; the valve is opened and closed alternately two or three times, and then tested for being gas-tight when closed. The slightest escape can usually be detected by the ear.

All being well, it only remains to screw on the reducing valve, and the only important precaution is to open the cylinder *very slowly* at each starting (see Chapter VII., Reducing Valves). The valve may be hard to manœuvre or shift, either at the union for the reducing valve or at the stuffing-box nut under the key or handwheel.

In no case should oil, grease, soap, or any fatty matter be used. Oxygen under pressure has an oxidising action on oil, grease, and fatty bodies, and the heat produced can start combustion; the conflagration may spread to the ebonite part of the valve and destroy the steel parts. The oxygen then escapes in large quantities from the cylinder, thus tending to produce a brisk combustion by contact with a lighted body, and serious accidents may result.

If, after closing the valve, there is still an escape, which is shown by the pointer of the gauge rising after the valve of the cylinder has been closed, try to screw the valve tighter, but without overdoing it, because it becomes difficult to reopen.

If the leak still continues, remove the reducing valve and open the valve briskly two or three turns and then immediately close; repeat this two or three times. If this proves a failure, it only remains to use the reducing valve for obtaining tightness, the regulating screw being completely free in such a manner that the pressure does not act on the diaphragm.

Leaks sometimes occur past the nut of the stuffing-box under the key or handle (9 in fig. 17); this is because the packing (10 in fig. 17) is worn. This can be changed by screwing off the nut, *but before carrying out this operation one must make sure that the valve is entirely closed*, because, on unscrewing, the pressure can, with great violence, blow the various details out, and the cylinder be entirely emptied.

Great caution is recommended in dismounting a valve of a cylinder under pressure, and it is better to abstain entirely if one is not perfectly familiar with the operation. In this case, and when the leak is considerable, the cylinder should be returned with an explanatory label attached to it.

Let us add that, in the common interest, all cylinders returned of which the valve is faulty (hard to work, leaky, etc.) should have a notice attached stating the fault, so that the manufacturers can proceed to repair it before refilling.

As mentioned in the paragraph on "compression of the gas into cylinders," there is always a little water in the latter. It is an advantage to remove this and so avoid freezing in the valve, especially in winter, when using a blowpipe of large delivery, as the expansion produces considerable cooling. It is only necessary to invert the cylinder so as to collect the water near the head, and then expel the liquid in jerks by successively opening the valve. Following this, one puts back the cylinders on end and, before fixing the reducing valve, operate for the expulsion of dust in the manner we have previously indicated.

With regard to the freezing of the valve or the reducing valve by the solidification of water vapour carried along with the gas (and produced by expansion), we particularly warn against melting the ice by heating with the flame of the blowpipe. This is a bad practice, and may lead to accidents. The only thing to use is warm water. However, if the water has been carefully expelled, there can be no freezing of the valve or reducing valve under the ordinary conditions of autogenous welding.

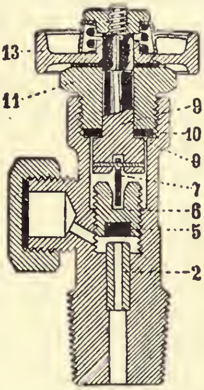


Fig. 17.—Section of a cylinder valve (Dræger).

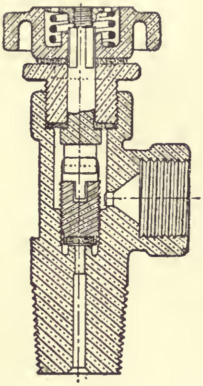


Fig. 18.—Section of cylinder valve (Titan).

In order to avoid excessive expansion of the gas and the resulting increase in pressure, the cylinders should always be kept away from a warm place; avoid placing them in the sun or near fires, etc., especially when painted black.

After emptying, the valve should be closed and the cap immediately put on, then returned to the company.

PRICE AND CONDITIONS OF SALE OF OXYGEN IN CYLINDERS.

Oxygen is sold by the cubic foot. The price varies according to the time, place, and quantity. The normal price appears to be from $\frac{3}{8}$d. to $\frac{1}{2}$d. per cubic foot.

The cylinders used in autogenous welding generally contain from 10 to 100 cubic feet; those of 100 cubic feet are mostly used because, although they are a little more difficult to manipulate, the waste is less and the transport less heavy for the same volume of gas.

As a rule, the companies do not pay carriage on cylinders except by special arrangement. In towns where there are oxygen manufactories, carriage is usually free within a certain radius.

The cylinders generally belong to the manufacturers, but one can purchase them in order to avoid rent charges. No charge is made for rent until after one month has expired; the charge then varies with the terms of the contract. If the oxygen is supplied in the customer's own cylinders, the price is lowered.

LAWS, INSURANCE, TRANSPORT.

There are no special laws regulating the use of oxygen stored under pressure.

In accordance with Government recommendations all cylinders are annealed (before being subjected to the usual hydraulic test for the first time), and then annealed at intervals of four years.

All cylinders are tested hydraulically, to a pressure of 3360 lbs. per square inch, annually.

The Insurance Companies have no special regulations, and make no excess charges concerning their use.

Oxygen cylinders are conveyed by the Railway Companies by goods train at the same rate as mineral waters (Class 2). Returned empty cylinders are conveyed at reduced rates by goods train. Cylinders consigned by rail, whether passenger or goods, must be packed in cover or case as specified by the Railway Companies.

ANALYSIS OF OXYGEN.

Impurities.—Oxygen obtained from liquid air may contain more or less nitrogen. That obtained by the electrolysis of water might contain a little hydrogen. These two gases are considered as impurities.

If hydrogen were present to an appreciable extent, it would produce the disadvantage of forming with the oxygen an explosive mixture.

It has been demonstrated that in the cutting of iron and steel by blowpipe cutters the presence of nitrogen, even in small quantities, has an adverse effect on the quality and rapidity of the work.

Commercial guarantee.—Oxygen compressed in cylinders is generally delivered containing 96 to 99 per cent. of oxygen, but the commercial guarantee may be as low as 95 per cent.; that is to say, if analysis gives a result lower than this figure, no claim can be made except in case of special agreements. The British Oxygen Company, for example, guarantee the quality of their oxygen as 98·5 to 99·5 per cent.

Oxygen specially sold for use with cutting blowpipes should be as pure as possible, and have a minimum guarantee of 97 per cent.

Methods of analysis.—The methods of analysis consist in acting on a definite volume of the gas with a chemical which rapidly absorbs the oxygen and leaves the impurities intact (hydrogen, nitrogen, or carbon dioxide). The quantity of gas absorbed, compared to the original volume, gives the degree of purity.

The analysis is done in graduated test tubes, generally of 100 cubic centimetres' capacity and graduated 0 to 100. The absorbent liquid takes the place of the oxygen absorbed, so that when the reaction is over it is only necessary to read off the level of the liquid to know the percentage purity of the oxygen.

Until recently the absorbing liquid generally used was a mixture of a saturated solution of pyrogallic acid and potash or caustic soda. The preparation and use of this liquid presented many difficulties, especially to those who were not accustomed to gas analysis. In addition, the alkaline solution of pyrogallate has the disadvantage of absorbing carbon dioxide and of liberating bubbles of carbonic oxide, which vitiates the result. It was formerly the practice, after analysis, to add .2 per cent. to the observed result, because it was always about this value below the real percentage.

The *Union de la Soudure Autogène* have obtained a much more practical process; it consists in using a solution of *hydrosulphite of sodium* as the absorbing liquid. We give the details of the process, so that purchasers of oxygen can easily test the purity of the oxygen which they use.

Analysis by sodium hydrosulphite.—Sodium hydrosulphite is a white salt sold at about 3s. per lb. In the dry state it is not acted on by the oxygen of the air and is practically unaltered. To preserve it, it is necessary to keep it in well-stoppered bottles in a dry place.

A solution in water has a great affinity for oxygen. The solution becomes a yellowish-brown colour on absorbing oxygen.

The analysis is performed with the aid of a burette graduated to 100 cubic centimetres, having a well-ground glass cock at each extremity. The tube is connected to the oxygen cylinder by a branch tube; the cocks are opened and the gas is allowed to stream through for 20 or 30 seconds to make sure of expelling the air; the taps are then closed successively in the direction from which the gas is flowing, so that the sample to be analysed shall not be under pressure.

This done, the burette is then transferred to a vessel containing a solution of hydrosulphite in such a manner that one end is dipped into the liquid (the percentage strength of the hydrosulphite solution should be about 15). The lower tap is now opened, and the reaction commences. The liquid rises in the tube as the oxygen is absorbed. The reaction can be hurried by carefully closing the cock and shaking the tube, thus acting on a larger surface of the liquid. The burette is again inverted over the hydrosulphite, the cock again opened, and the liquid rises in the tube. By repeating this operation two or three times the analysis is extremely rapid. When the liquid ceases to rise any more the reaction is terminated, and by reading the level of the liquid the purity of the oxygen is known, which may reach over 99 per cent., that is, the absorbing liquid almost completely fills the tube.


Fig. 19.—Analysis of oxygen.

A few precautions are necessary, especially in filling the tube, to make sure that all air is expelled, and to manipulate in such a manner as to avoid introduction of air through the cocks, under the effect of a vacuum, or the inserted end.

One can facilitate the rising of the liquid at the beginning by creating a slight pressure in the vessel containing the absorbing liquid. This can be done either by pushing down the cork through which the end of the burette passes, or by air from an indiarubber bellows (fig. 19).

It is possible to operate differently; for example, the hydrosulphite solution could be introduced into the burette by means of a funnel fixed above the upper cock; on opening the cock the liquid rapidly flows down, taking the place of the oxygen which it absorbs. This method requires certain precautions, notably to avoid the introduction of air, and necessitates a specially graduated test tube.

CHAPTER V.

ACETYLENE.

PROPERTIES OF ACETYLENE.

Acetylene was discovered in 1836 by Humphrey Davy, an English chemist, and Berzelius, a Swiss chemist. They found that the residue which had been obtained incidentally in the production of metallic potassium was capable of decomposing water with the evolution of a gas which contained acetylene. It is also produced during the incomplete combustion of certain gases. Thus, when a Bunsen burner lights at the bottom of the tube, acetylene is produced. But until the industrial manufacture of calcium carbide it remained a laboratory gas.

Chemically, acetylene consists of carbon and hydrogen, and is represented by the formula C_2H_2, meaning that it has the constant composition of 24 parts by weight of carbon and 2 of hydrogen, or 92·3 per cent. of carbon and 7·7 per cent. of hydrogen. Of all the hydrocarbons it is the richest in carbon. Acetylene is a colourless gas, which, when pure, has an odour which is not unpleasant. The penetrating and disagreeable odour is due to impurities, notably phosphoretted hydrogen, hydrogen sulphide, and the polymers of the gas; these latter result from the heat generated in certain generators.

Acetylene is lighter than air in the proportion 91 to 100; its specific gravity or density is therefore said to be 0·91. One cubic foot of the gas weighs 0·074 lb. One lb. of the gas occupies, under standard temperature and pressure, 13·65 cubic feet.

Acetylene is soluble in a large number of liquids; under ordinary temperature and pressure water dissolves little more than its own volume, essence of turpentine and petrol 2 volumes, benzene 4, pure alcohol 6, and acetone 25. The solubility increases with the pressure.

Acetylene is scarcely soluble in water saturated with marine salt.

When heated to a temperature of about 600° C., acetylene polymerises into a number of products more or less related to benzene. The formation of benzene by polymerisation takes place with disengagement of heat (178 calories or 44 B.Th.U.).

Acetylene under atmospheric pressure becomes a liquid at − 82° C. and a solid at − 85° C.

Acetylene under no pressure or under a slight pressure is not explosive, but this is not the case when compressed.

Berthelot showed that acetylene, subjected to a pressure of 1½ atmospheres, can decompose into its elements under the influence of a shock, slight heating, or any percussion whatever. Such decomposition produces a violent explosion.

In practice the maximum should be much lower than this, and *acetylene should never be kept under a pressure of more than a few pounds.* The regulations forbid it. On the other hand, acetylene absorbed under pressure by liquids which dissolve it, such as acetone, is absolutely safe.

Acetylene is an *endothermic* body, that is to say, it is formed with the absorption of heat. This heat is entirely given up again at the moment of dissociation, thus contributing powerfully to the rise of temperature when combustion takes place.

Mixtures of acetylene and air, and, of course, more so of acetylene and oxygen, explode violently when ignited. The temperature of ignition being very low, a spark is sufficient to ignite the mixture.

The formation of such mixtures should be avoided, and most certainly their ignition. The propagation of the flame can take place through extremely small orifices.

The explosion of a vessel of 1 *quart capacity, containing a mixture of acetylene and oxygen, is sufficiently violent to cause the death of a person in the vicinity.*

It is extremely easy to avoid the formation of these mixtures, as we shall see later.

The properties of acetylene, such as heat of combustion, products of combustion, and temperature of the flame, have already been given in Chapter II.

CARBIDE OF CALCIUM.

Composition and properties of carbide of calcium.—The discovery of the manufacture of carbide of calcium was due to the work of the French chemist, Moissan, and the American electro-metallurgist, Wilson. The first communication was made to the Académie des Sciences by Moissan on 12th December 1892.

Chemically, carbide of calcium consists of calcium and carbon, and is represented by the formula CaC_2. It consists of 62·5 per cent. of calcium and 37·5 per cent. of carbon. The colour varies from earthy grey to luminous black, sometimes possessing a range of colours similar to tempered steel; the texture is usually massive and crystalline, but sometimes spongy; *but neither the colour nor texture serves to indicate the good or bad qualities of the carbide.*

Carbide of calcium has the hardness of stone. The specific gravity varies from 2·2 to 2·3. It is non-inflammable; it softens and melts at about 3000° C.

In the presence of water vapour or water the carbide decomposes into acetylene gas and oxide of calcium (lime):

$$CaC_2 + H_2O = CaO + C_2H_2$$
$$64 + 18 = 56 + 26.$$

According to this equation, 64 parts by weight of carbide requires 18 parts by weight of water, or 1 lb. of carbide requires 0·225 pint of water. These are theoretical quantities, because we must take into account the evaporation of the water and the absorption of water by the lime, forming quicklime. In practice it is necessary to use 1·2 to 1·6 pints of water for each pound of carbide in those generators known as "water to carbide" and "dipping," and 5 to 5·5 pints in "carbide to water." These quantities ensure that the lime residue may be removed in liquid form.

Theoretically, 1 lb. of carbide yields 5½ cubic feet of acetylene at standard temperature and pressure. The reaction is always accompanied by rapid liberation of heat (226 calories or 900 B.Th.U. for each pound of carbide).

Manufacture of carbide.—Carbide of calcium is made by fusing a mixture of lime and carbon (coke or anthracite), in the proportion of 56 parts by weight of lime to 36 parts by weight of carbon, in the *electric furnace*, the temperature of which is about 4000° C. The carbon should not contain more than 5 per cent. ash, and the lime should be as free as possible from phosphates.

The economical production of carbide depends, to a great extent, upon the low price of electrical energy. Manufacturers of carbide cannot establish themselves unless a minimum water-power of 2000 to 3000 horse-power can be utilised.

Under the enormous temperature of the electric furnace the lime and carbon combine, and the liquid carbide which results flows like a jet of fire, then cools, and solidifies in large blocks.

As soon as they are sufficiently cool the blocks of carbide are conveyed to the crushing and granulating room. The carbide passes through the crushers, the pieces being then graded, according to size, by sieves, the dust being eliminated. One part of the crushed carbide is carried to the granulating apparatus, which separates it into pieces of regular dimensions. The carbide is immediately packed in drums, the covers of which are hermetically sealed.

Classification.—The pieces of carbide are divided into three classes according to size:—

(1) *All sizes.*—From the size of the fist down to fragments, $\frac{5}{8}$ to $\frac{7}{8}$ inch.

(2) *Broken.*—Pieces limited to the following dimensions: $\frac{5}{8}$ to $\frac{7}{8}$ inch; $\frac{7}{8}$ to $1\frac{5}{8}$ inch; $1\frac{5}{8}$ to $2\frac{3}{8}$ inch; $2\frac{3}{8}$ to $3\frac{1}{8}$ inch.

(3) *Granulated.*—These are grains of various sizes, viz.: $\frac{1}{16}$ to $\frac{1}{8}$ inch; $\frac{1}{8}$ to $\frac{3}{16}$ inch; $\frac{3}{16}$ to $\frac{1}{4}$ inch; $\frac{1}{4}$ to $\frac{3}{8}$ inch; $\frac{3}{8}$ to $\frac{5}{8}$ inch.

The dimensions are only approximate, and are subject to a variation of 25 per cent. above and below the sizes.

Quality and yield.—Carbide is sold in England under guarantee to yield not less than 4·8 cubic feet per lb., at a barometric pressure of 30 inches and temperature of 60° F. (15·55° C.).

Carbide yielding less than 4·8 cubic feet can be accepted by the purchaser, but the price to be paid shall bear the same relation to the contract price as the gas yield bears to 4·8 cubic feet per lb. All carbide giving less than 4·2 cubic feet can be refused.

The guarantee only applies to classes (1) and (2), i.e. *all sizes* and *broken*, the *granulated* being exempt.

Carbide should not contain more than 5 per cent. of dust, such dust being defined as carbide capable of passing through a mesh of one-sixteenth of an inch.

In case of dispute as to quality, either the buyer or the seller has the right to have one unopened drum per ton of carbide, or part of a ton, sent for examination to one of the analysts appointed by the Acetylene Association.

Price and conditions of sale.—Carbide is sold in lots weighing 150 to 160 lbs. gross weight; this includes the weight of the drums (7 to 9 lbs.). Drums are not returnable as a rule, on account of cost of transport and deterioration in value. The price varies from 12 to 14 shillings per cwt. in normal periods; this is, of course, for those towns which have depôts, and not out-of-the-way places.

Granulated and broken carbide costs about a shilling a cwt. more.

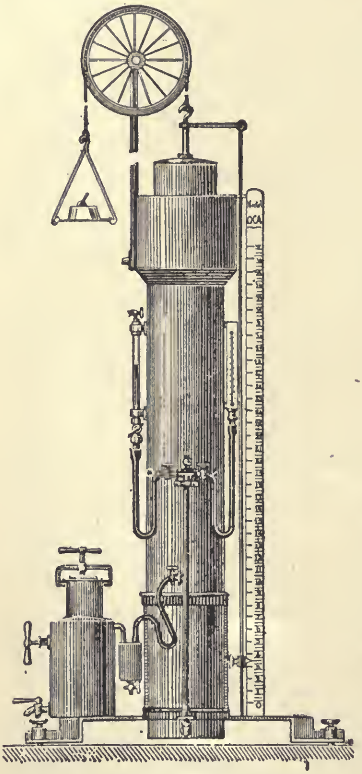


Fig. 20.—Apparatus for analysis of carbide, O.C.A. pattern.

Analysis of carbide of calcium.—The exact gas yield of carbide cannot be measured by the volume calculated from the meter reading, nor by the delivery at the blowpipe, nor by the length of time taken to exhaust a certain quantity of carbide. These indications are of some use for comparison of different samples of carbide, provided the gas is always liberated under identical conditions. They give an *approximate* idea of the respective qualities, but are always liable to errors.

The accurate analysis always necessitates the employment of a special apparatus, which will indicate accurately the amount of gas liberated by a sample. The detailed description of such an apparatus would lead us too far. Fig. 20 shows the apparatus used in the *Central Acetylene Office* in Paris, for the rapid and accurate analysis of samples of carbide.

ACETYLENE GENERATORS.

General principles of production.—The production of acetylene by the action of water on carbide of calcium is, chemically, one of the simplest of reactions. But in practice it is not so simple.

Before describing the different types of apparatus, let us draw attention to the two chief difficulties that present themselves in the production of acetylene by the action of water on calcium carbide. These are, heating, and excess production or "after generation."

Heating.—Recall the heating phenomena of the reaction. Water consists of hydrogen and oxygen, the dissociation of which takes place with the absorption of heat. On the other hand, the oxygen liberated combines with the calcium carbide and produces by the reaction more heat than is absorbed by the above reaction.

The heat liberated exceeds 226 calories or 900 B.Th.U. per lb. of carbide; that is to say, 1 lb. of carbide would raise 1 gallon of water from 0° C. to 50° C., or through 90° F. No device or arrangement can alter the amount of heat liberated, but, of course, the temperature of the mass can be influenced. Thus, for example, in attacking the carbide with an excess of cold water, one is sure not to go above the temperature at which the water boils. But if no external cooling is brought into play and the carbide is *in excess*, in proportion to the water, the temperature can reach higher values.

Two causes bring about this result—(1) the liquid water vaporises and reacts with the carbide, thus supplementing the heat of decomposition; (2) under the influence of heat, the lime can give up the water, which it retains strongly at a low temperature, to the carbide. The reaction continues between these two bodies, and if no external cooling takes place the temperature rises. Lime being a bad conductor of heat, the mixture can become red hot.

The disadvantages which result from the generation of acetylene at a high temperature are of two kinds—polymerisation and great impurity.

Polymerisation.—Under the influence of heat acetylene polymerises, or condenses into liquid and solid products. This takes place more readily during its formation than after generation. Numerous experiments have shown that these polymers are formed in acetylene generators at a temperature of 130° C. (266° F.). These tarry substances fix on the lime and colour it yellow. Being formed at the expense of the acetylene, they therefore correspond to a loss of gas.

Great impurity.—This disadvantage is of great importance. Carbide gives up sulphides on the action of heat; water decomposes these into hydrogen sulphide and organic sulphur compounds, which are detrimental to acetylene. The higher the temperature of production the more impure the gas. Heating imparts to the gas the unpleasant odours of the sulphur polymers.

Excess production or "after generation."—No acetylene apparatus produces the gas in the proportion to which it is consumed. The production therefore has necessarily to be either in excess or in deficiency. The production should be in advance, and a sudden stoppage of consumption cannot possibly correspond to the abrupt arrest of the reaction.

The reaction continues, and this phenomena has received the name of *excess production or "after generation."* In "dipping" and "water to carbide" apparatus, it is necessary to take into account the fact that the slaked lime which covers the carbide at the moment when the water ceases to be in contact, gives slowly to the carbide the water it requires, which brings about the liberation of acetylene, right up to dryness.

. . . .

It is evident that for any particular generator heating and after generation are in direct relation to the delivery. It is therefore impossible to formulate rules on these points without taking into account the delivery.

With reference to the maximum delivery of any particular apparatus—

(1) The heating should never exceed a temperature of 130° C. (266° F.).

(2) It should be possible to accumulate and use the "after generation" in case of stoppage.

Classification.—Acetylene apparatus can be divided into two classes:—

(1) Apparatus for *intermittent production*, called also *non-automatic*, in which the quantity of gas is prepared beforehand, and kept in a gasometer of a size suitable for the maximum consumption for one or several days. Such apparatus is constructed on the principle of the fall or immersion of a fixed quantity of carbide into a mass of water.

(2) *Automatic* apparatus, in which acetylene is produced in proportion to the consumption, such apparatus being mostly employed. Automatic apparatus can be divided into three main classes, viz. water to carbide, dipping or contact, and carbide to water.

The "water to carbide" apparatus is on the principle of a gasometer with a movable bell, or on the principle of the flowing back of water from the gasometer. The automatic function is brought about in the first case by the movement of the movable bell, and in the second case by the change in pressure.

In the "dipping" or contact generators, the carbide can be fixed and the water moving, or the water fixed and the carbide moving.

In the "carbide to water" generators carbide of all sizes, broken or granulated, is used. The carbide is usually automatically regulated by the movement of the movable bell.

Advantages and disadvantages of each system of production.—Every system for the production of acetylene has its advantages and disadvantages. Before attempting to describe these, it is essential to say that these advantages and disadvantages come more or less into consideration according to the use to which we wish to put the apparatus, its importance, and construction. To put it another way, any particular disadvantage or advantage may be diminished or increased according to the particular use for which a particular acetylene plant is destined.

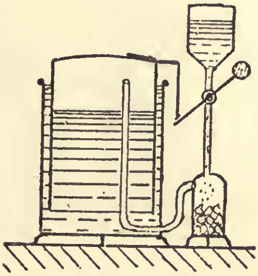


Fig. 21.—Outline diagram of automatic "water to carbide" generator.

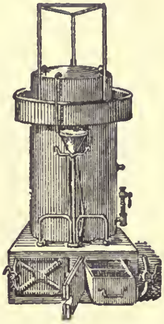


Fig. 22.—One type of automatic "water to carbide" generator.

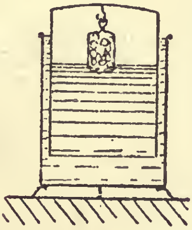


Fig. 23.—Outline diagram of automatic "dipping" generator.

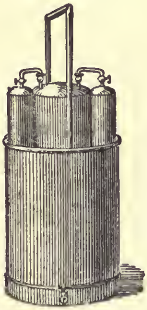


Fig. 24.—One type of automatic "dipping" generator.

Water to carbide.—Compared to "carbide to water" generators, they have the disadvantage of necessitating longer and less convenient cleaning, of producing less pure gas, and of losing gas, especially in the case of sudden stoppage with a gasometer of insufficient size. On the other hand, these generators consume less water, are simpler in working, are absolutely safe, and produce an excellent yield of gas, especially if the "after generation" is well stored.

Dipping.—These generators give the greatest amount of heating, the greatest amount of "after generation," and the most impure gas. Their great simplicity renders their use advantageous for small portable plant with small delivery, and which have to work until the whole of the carbide is exhausted. With ordinary carbide this method should be rejected for large generators.

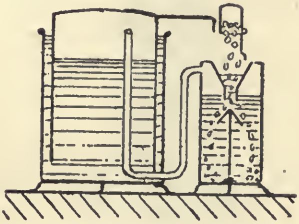


Fig. 25.—Outline diagram of automatic "carbide to water" generator.

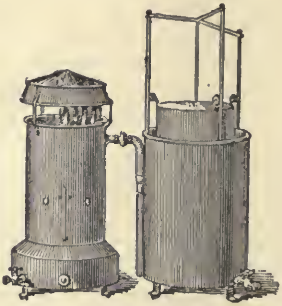


Fig. 26.—One type of automatic "carbide to water" generator.

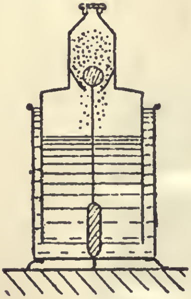


Fig. 27.—Outline diagram of granulated "carbide to water" generator.

Fig. 28.—One type of granulated "carbide to water" generator.

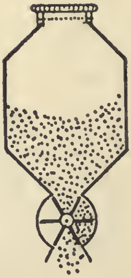


Fig. 29.—Distribution of granulated carbide by bucket wheel.

All sizes "carbide to water."—The disadvantages of "carbide to water" generators in comparison to "water to carbide" is as follows:—With equal yield of gas, greater encumbrance, slightly less yield, greater consumption of water, and abundance of liquid residue.

The advantages on the other hand are—gas is produced cool, free from ammonia and hydrogen sulphide; greater facilities for obtaining great variations of delivery; easy cleaning, and even the possibility of automatic emptying.

Granulated "carbide to water."—The disadvantages of this type of generator over the last are—lower yield of gas and price of carbide higher.

All generators of this type in which the granulated carbide is distributed by a conical valve, flap-valve, etc. (fig. 27), should be rejected as dangerous where the provision for carbide exceeds 2 to 5 lbs., or at least in all cases where working does not take place in the open air.

It is always possible, as a result of bad working, for a granule of carbide which is too large, or a foreign body, to cause the whole charge to fall into the water at once. On the other hand, such an occurrence cannot take place if the granulated carbide is distributed by a bucket wheel (fig. 29) in which the distribution is rigorously divided up.

These generators are less cumbersome, easy to charge, and of remarkable elasticity in delivery. They only require small gasometers, the fall of carbide can be very frequent on account of the rapid decomposition of the granules.

CHOICE OF A SYSTEM OF ACETYLENE GENERATION FOR AUTOGENOUS WELDING.

As we have shown in the previous paragraph, each system of acetylene production has its advantages and disadvantages, and the adoption of any particular type depends on the use for which the generator is destined.

The conditions for the production of acetylene in the installation for autogenous welding are not the same as for lighting, and these differ themselves, as we shall see, and vary according to the place in which the welding is to be done, their importance, and use.

As it is a question of industrial use, the general arrangement of the plant should be simple, strong, and easily moved. It is necessary to draw attention to this point, for most generators lightly built and which satisfy the requirements of lighting would not prove satisfactory for autogenous welding.

The delivery of a gas under regular pressure is an important point, because change of pressure brings about modification in the composition of the flame, and such variation should be avoided.

But the characteristic quality of every acetylene plant destined for welding is the *flexibility* of the plant. A generator is *flexible* if it adapts itself to fluctuating employment, that is, rising to the maximum or minimum yield without delay, without heating, without excess production, without defect, and without jerks.

The above, of course, only applies to *automatic* generators for welding installations which use blowpipes that require a large delivery, for example, 400 to 500 litres (14 to 18 cubic feet) of acetylene per hour.

"**Dipping**" generators are the least flexible, and the **granulated "carbide to water"** the most flexible. We know that the last mentioned has other faults, and that it requires special conditions to give good results. The majority of accidents are with this system.

Between these two types lie the **water to carbide** and **the fall of carbide in pieces**, which are actually those most employed in welding installations. They also have their faults, which have been summarised in a preceding paragraph.

Briefly, in any given case, the preference would be given to the one or the other, according to the room at one's disposal, facility for cleaning and disposing of the residue, consideration of the selling price, and other factors which would probably not be negligible.

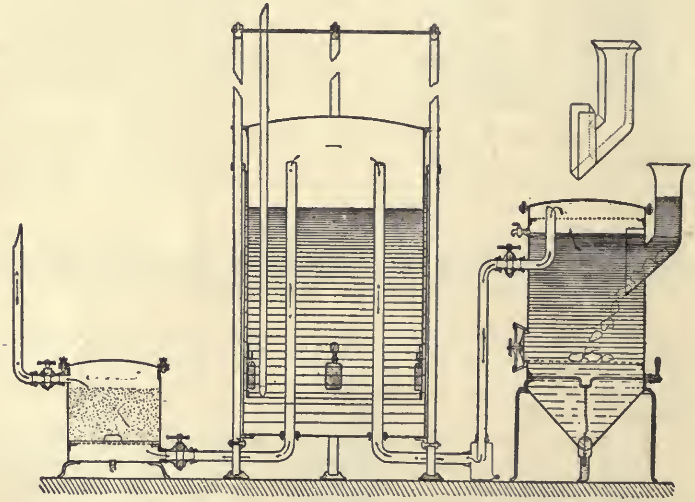


Fig. 30.—Non-automatic generator, type "Autogenous Welding."

Let us examine the *non-automatic* generator used for autogenous welding, in which the gas is made in large quantities in advance, and stored in a gasometer of from 30 to 350 cubic feet capacity and even more. This system is evidently the most practical, the most sure, and the best, but it requires space which one generally cannot allow. Lastly, the price of these plants is too high.

Acetylene generators should always be chosen with a larger power than is really required. Not only will its working be more regular and not give rise to excess production or polymerisation, but, moreover, it can be used to feed a blowpipe larger than the one originally intended, or an increased number of blowpipes can be worked at the same time.

Guarantees.—Certain conditions for good working are necessary for all kinds of generators, and one should always require that they are fulfilled. We will now give the information in the form of "guarantees" which it is advantageous to specify by letter or agreement:—

(1) The generator is constructed according to the regulations of the Acetylene and Welding Association, with materials of the nature and quality demanded and of required strength.

(2) Its normal charge of carbide is lbs. The maximum output per hour of which the generator is capable is cubic feet.

(3) For this rate of production the temperature of the carbide during decomposition will not reach the point at which acetylene undergoes polymerisation, that is, there shall be no tarry matters, benzene, nor any deposition of yellow material on the lime residue, when carbide of standard quality is used.

(4) The capacity of the gasometer is sufficient to contain the acetylene given off after the water supply has been cut off, and there must be no excess of gas which will be blown to waste in the course of working.

(5) The pipes and cocks between the separate parts of the plant should be of such size that there can be no considerable variation in pressure, except in cases where variation of pressure is a function of the generating apparatus, even in case of maximum delivery.

(6) The pressure of the gas measured at the exit of the generator should be at least equal to 5 inches of water (if possible obtain 6).

(7) This pressure is practically constant, the variation not exceeding half an inch in either direction, at any time during the working of the generator.

(8) The generator can be charged or emptied without any appreciable loss of gas. The quantity of air introduced in emptying and charging the generator should be so small that on mixing with the smallest quantity of acetylene which the gasometer can contain, it shall have no bad effect on the working of the blowpipe.

(9) Subject to ordinary wear and tear, and provided the purchaser uses the generator according to the rules, the good working of the generator is guaranteed for ten years.

GAS YIELD FROM ACETYLENE GENERATORS.

It will be understood that acetylene generators do not have a yield of 100 per cent., because even in the best plants there is an appreciable loss of gas during recharging, cleaning, dissolving in the water, etc. It is for this reason that one cannot measure the yield of the carbide of calcium by the amount of the acetylene produced in various generators.

On an average, *in good acetylene generators*, in which no "after generation" or polymerisation takes place, the yield should be in the neighbourhood of 90 per cent. that of the carbide.

In practice, one would admit without exaggeration that in order to use 40 *cubic feet of acetylene we require* 10 *lbs. of carbide of calcium yielding on analysis* 4·6 *to* 4·8 *cubic feet per lb.*

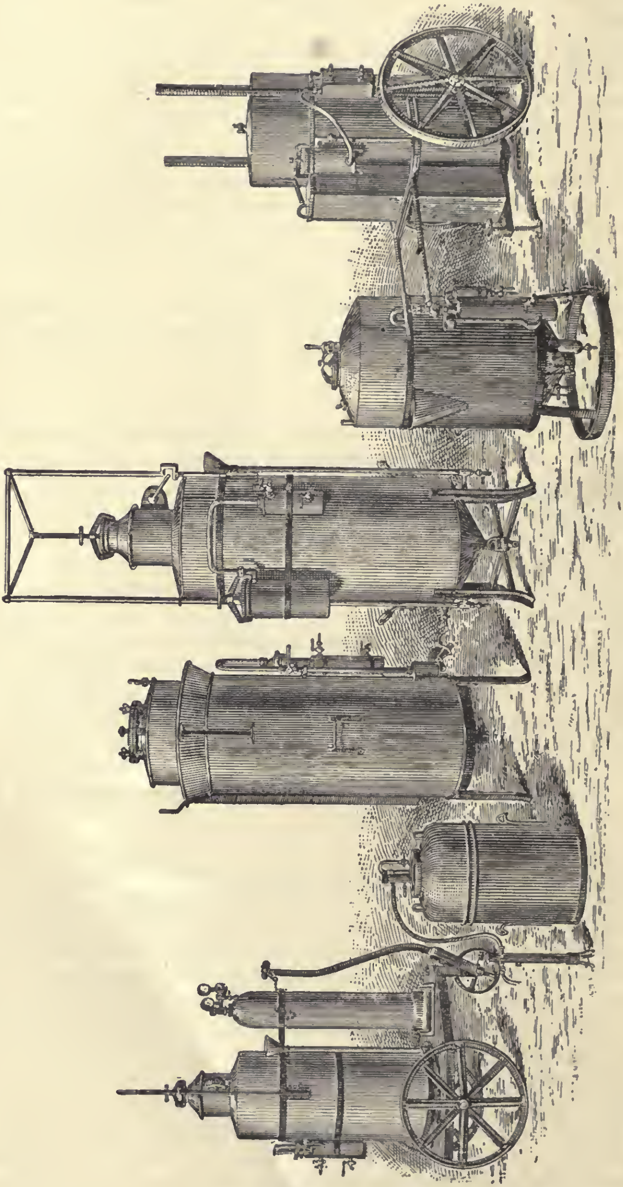


Fig. 31.—Common types of portable generators for autogenous welding.

PORTABLE GENERATORS.

All the statements made in the previous paragraphs apply only to fixed acetylene installations for supplying welding workshops.

There are many cases where autogenous welding or cutting with the blowpipe is required in out-of-the-way places. The acetylene generator in these cases must be easily *transportable.*

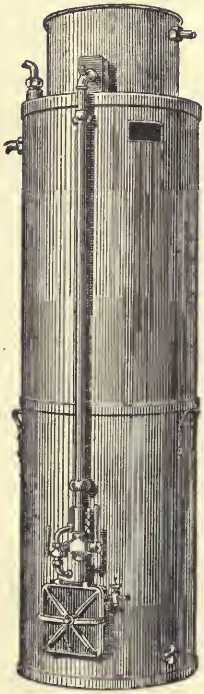


Fig. 32.—Medium pressure generator of the Universal Acetylene Company.

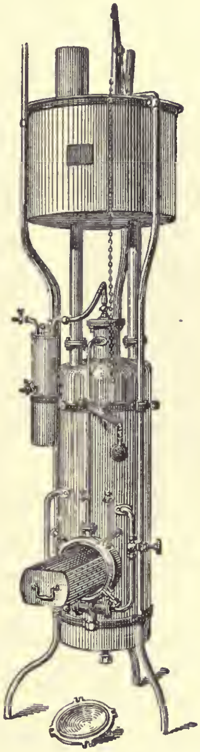


Fig. 33.—Medium pressure generator, system "Molas."

Now it is very difficult to maintain those qualities, of which we have previously spoken, in *portable* plants. It is necessary to be much more tolerant, notably in the heating, excess production, and the maintaining of constant pressure, etc.; and one would admit, as a general principle, that the more portable the plant is, the less will it possess those qualities which it should possess.

The fault to call attention to is the common adoption of a portable generator in places where a permanent plant could be fixed.

One obtains in this way an easy and economical installation, but it is a "penny wise and pound foolish" policy. The faults of the portable plants can scarcely be accepted where portability is unnecessary, and the idea of installing such a generator in a workshop should be rejected. Unfortunately, the designers of welding workshops are often the first to propose them for places where they should be proscribed.

SPECIAL GENERATORS.

There have been made for welding purposes special acetylene generators which give certain results which are of more or less importance. The special characteristic is the obtaining of an increase of pressure, which makes it possible to use blowpipes for *medium pressure acetylene* (see Chapter VI.); other advantages obtained with these transportable generators is the absence of excess production, regularity of working and facility of employment, which makes them recommendable in practice. One type of this generator made for fixed installations is on the "flowing back of water from the gasometer" principle, and is capable of supplying acetylene at from 60 to 100 inches of water pressure.

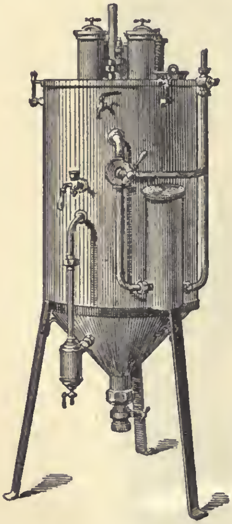


Fig. 34. — Generator for using the carbide in compressed cakes.

The portable generators possessing the characteristics of which we have just spoken use the carbide in a mixed and compressed cylindrical form, which is sold under the name of *Carbic*, *Béagid*, *Comprimés Delta*, etc. These generators are of the "dipping" type, and are specially constructed to use the carbide in the form mentioned.

These special systems offer interesting advantages and, on the other hand, disadvantages which are peculiar to "special" systems. We cannot dwell longer on these types, which are not much employed, but it is well to remember that systems which are "special" to-day may become the "common" practice to-morrow.

PURIFICATION OF ACETYLENE.

Impurities in carbide and acetylene. — Industrial carbide of calcium is not, and cannot be, a pure product. The chief constituents are, as we know, lime and carbon (metallurgical coke or anthracite), and no matter what care is taken will contain impurities; thus one finds compounds of sulphur in the best coke or coal, and phosphates in the purest lime. These impurities combine with calcium in the electric furnace, and, like carbide, the products formed are decomposed by water or heat, so that acetylene always contains, more or less, phosphoretted hydrogen and hydrogen sulphide, the amount depending on the generator used.

To these two gases one includes a little ammonia produced by the decomposition, by means of the water in contact with the lime, of the nitrides and cyanamide which the carbide contains, due to combination with the nitrogen of the air at the moment of cooling.

To these chemical impurities it is necessary to add the solid matters in a fine state of division which are suspended in the gas and which have been given off by the lime at the moment of decomposition.

The phosphoretted hydrogen is always carried along with the acetylene; the hydrogen sulphide, ammonia, and the fine dust from the lime can be retained by the generator according to the system, but they generally go, more or less, with the acetylene.

Necessity for purification in welding with oxy-acetylene.—The impurities in the acetylene, even in very small quantities, can do considerable harm to the strength of the welds.

One knows with what great care metallurgists endeavour to remove phosphorus and sulphur from their iron and steel, because these bodies alter considerably the mechanical qualities of the metal.

Now, strange coincidence, we find them exactly in that state as impurities in acetylene destined to melt the metal for obtaining welds, that is to say, ready to incorporate themselves in the welding zone, which should be particularly clean in order that the weld should be perfect.

Phosphoretted hydrogen and hydrogen sulphide by combustion produce phosphoric acid and sulphuric acid, and these are able to give up their phosphorus and sulphur to the metal being melted. It is true that the incorporation is not complete, but minute as it is, the weld is spoilt—that is incontestable.

As far as other metals than iron and its alloys are concerned, this disadvantage does not exist, and in the case of copper, for example, the presence of phosphorus cannot be anything but favourable—but this is an exception.

The bad effects of the presence of phosphoretted hydrogen and hydrogen sulphide have been frequently proved, especially in the case where dissolved acetylene and acetylene from a generator have been employed successively. For example, in the manufacture of vessels destined to receive liquids or gases under pressure, cracks have been frequent when using non-purified gas from a generator, and infrequent in the case of dissolved acetylene, which is practically pure acetylene. It is in such cases that the superiority of purified gas has been realised.

It remains for us to examine the bad effects of the fine dust that is carried along with the gas, and which is so finely divided that it does not settle down with long standing in the gasometer nor by energetic washing. It is unnecessary to show the disastrous influence of these particles of lime when incorporated in the weld, and how the weld has been weakened; their elimination is absolutely necessary. A further disadvantage is that they obstruct the passage of the gas through the blowpipe and form a crust in the nozzle.

It is obvious therefore that the employment of gas which has not been purified presents many faults; the statement of which has not been exaggerated, and these disadvantages always exist in gas which has not been purified.

The oxy-acetylene flame in the case of impure gas is coloured, and more difficult to regulate. Lastly, the anhydrides of phosphorus and sulphur produced by the combustion of impure acetylene spread in the atmosphere and have a dangerous physiological effect on the welders.

Process of purification.—How shall we purify acetylene, and what is purification?

Washing of the gas only constitutes a slight purification and does not dissolve the phosphoretted hydrogen at all, and only partially the other impurities. Filtration through wadding, sand, or felt, etc., does not abstract the fine dust, and the passage of the acetylene through solid wood charcoal, coke, sawdust, etc., only constitutes, in general, an imperfect filtration.

The only practical way is to fix the impurities by chemical combination.

The question of purification has for a long time occupied numerous chemists, the manufacturers of carbide and acetylene generators. It is extremely complicated, and presents difficulties of many kinds which it is not necessary to dwell on here.

Liquid purifiers have had to be abandoned completely, and solids have been made possessing the necessary chemical properties to fix the impurities and allow the acetylene to pass through without being attacked.

Purifying materials.—Products containing alkali hypochlorites and alkaline earths which are able to retain by chemical combination phosphoretted hydrogen have been abandoned because they do not constitute a perfect purifier and produce other serious difficulties. The gas is not filtered and carries along free chlorine and lime dust, which are bad for welding, and which increase as the passage of the gas through the purifier is increased, following the use of a larger blowpipe.

In France and England, Hératol is the purifier most used. It is a powdered product of which the base is chromic acid, and is practically the only purifier of acetylene destined for lighting. Why has this product been so little used for installations for autogenous welding? The causes are many.

First, the importance of purification in the case of acetylene for welding installations is not sufficiently known, and manufacturers are not anxious to add purifying vessels to their plants.

Secondly, purification by Hératol is costly, because it is necessary to use 2½ to 3 lbs. of purifier for each 100 lbs. of carbide, costing 1s. 9d. to 2s. 3d., and representing about 12 per cent. of the cost of the carbide.

Lastly, the use of Hératol for autogenous welding necessitates purifiers with a large surface, at least in cases where large delivery is required. The passage of the gas through the purifier must not exceed 0·23 cubic foot of gas per hour for each square inch of purifying surface; if this is exceeded, bad purification and heating of the mass takes place, which brings about decomposition of the acetylene. Thus for a delivery of 2000 litres per hour or 70 cubic feet, which is very common where many blowpipes are working at the same time, the Hératol purifier should have a minimum diameter of 20 inches.

. . . .

These conditions of use are not encouraging, but the use of such a purifier is not less recommendable, and those that have used it have always praised the result produced.

A new purifying material has just been made which satisfies all the required conditions, especially for autogenous welding. It has been named Catalysol.

This product is similar to Hératol, that is to say, it is a yellow-coloured powder with a specific gravity between 0·6 and 0·7. It consists of iron oxy-chlorides, which act catalytically in such a way that the impurities of acetylene are completely oxidised by contact, and the acetylene leaves the purifier pure and unattacked.

Its purifying power is slightly superior to that of Hératol, but the principal property of Catalysol is its power of regeneration by simple exposure to the air, and this can be repeated three or four times until the product has become inactive owing to the presence of impurities which it has retained during successive purifications. In counting the first purification and three regenerations, Catalysol therefore purifies four times consecutively, and as its purifying power can be reckoned as 2½ lbs. of purifier to each 100 lbs. of carbide used, 1 lb. of Catalysol will therefore purify 160 lbs. of carbide of average quality, that is to say, 770 cubic feet of gas, compared to 160 to 200 cubic feet in the case of Hératol.

The cost of Catalysol is 10d. per lb.; the purification therefore costs 6d. per 100 lbs. of carbide, compared to 1s. 9d. to 2s. 3d. in the case of Hératol, or 4 per cent. the cost of the carbide. This is very satisfactory.

The process of regeneration is extremely simple, since it is only necessary to take the used purifying material and replace it in its original box instead of throwing it away, as is done with other purifying materials. At the end of a few days the regeneration is complete. If one has only a single charge, the regeneration can be made more rapid by exposing the material in thin layers, care being taken that it does not become moist.

A special quality is prepared for autogenous welding installations which goes under the name of Welding Catalysol or Catalysol S.

The velocity of the gas through the purifier can attain 0·7 cubic foot per hour for each square inch of surface. Taking an average of 0·5 cubic foot, the capacity of the purifier can be diminished to half that required in the case of Hératol, and whatever be the velocity of passage of the acetylene, heating and decomposition of the gas need not be feared.

Let us add that the purifying material also performs the function of a filter in retaining the solid particles of dust carried along with the gas. It is also practically equal to the hydraulic safety valve as a guarantee of safety, since a strong layer of powdered material is interposed between the generating apparatus and the piping, which effectually opposes the return of the flame.

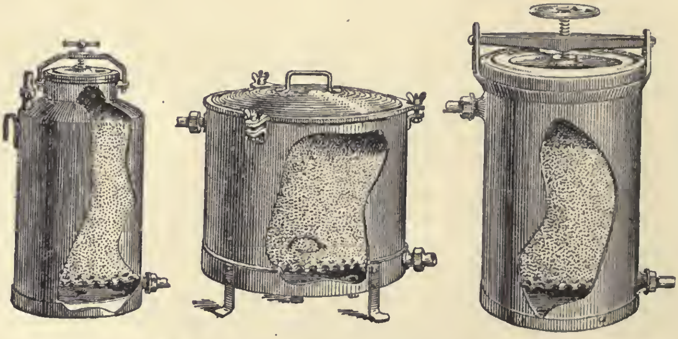


Fig. 35.—Types of purifiers for Catalysol.

Such a product should appeal with certain success in the economical complete purification of acetylene for use in autogenous welding.

Purifiers.—The purifiers generally consist of cylindrical vessels made of sheet-iron or steel closed by a cover, the joint being made of indiarubber. A perforated plate with very fine holes is supported in the vessel at a distance of 2 to 3 inches from the bottom, according to the type. The gas arrives under the plate, and passes out near the top immediately under the cover.

The only conditions to observe when Catalysol is used are as follows:—In order to avoid loss of pressure with the charge too high, the layer of material should not exceed 12 inches depth; 10 inches is more favourable. The purifying surface (surface of perforated plate) is calculated on the basis of 0·5 cubic foot per hour for every square inch of surface, and *for the maximum consumption of the welding shop.* With this data, and knowing the density of Catalysol, which is from 35 to 45 lbs. per cubic foot, it is easy to calculate the charge of purifying material required for a given installation. The following is a table with the necessary calculations made:—

DATA FOR CATALYSOL PURIFIERS FOR AUTOGENOUS WELDING INSTALLATIONS.

Diameter of Purifier.	Height of Purifying Material.	Approximate Total Height of Purifier.	Maximum Delivery of Acetylene per hour.		Weight of Catalysol required.
inches.	inches.	inches.	litres.	cubic feet.	lbs.
8	10	12½	600	21·2	11
11	10	13	1200	42·4	22
14	10	13½	1800	63·6	33
16	10	14	2400	84·8	44
18	11	15½	3000	106	66
20	12	16½	3800	135	88
22	12	16½	4700	166	110
24	12	16½	5600	198	132

The cross-section of the joints or passages through the cocks of the purifier should be at least equal in area to that of the piping.

If the acetylene is not too highly charged with water vapour, it makes no difference which way the gas is passed through the purifier.

The placing of a disc of felt or other porous material between the perforated plate and the purifying material enables the gas to pass through better, and prevents the material from falling through the holes into the double bottom, especially if the holes should be too large.

The purifying material should be simply poured in without any patting down, except lightly near the edges, to prevent the formation of "chimneys."

Lastly, the interior of the purifier and the perforated plate should be carefully painted with an adherent coating, for example, *coal tar* applied warm, because the oxidation rapidly attacks the plates, even when galvanised or leaded.

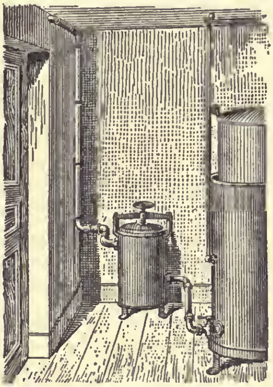


Fig. 36.—Position of purifier with regard to acetylene generators.

Position, maintenance, and supervision of purifiers.—The purifier can be placed in any position between the piping, between the place of welding and the apparatus. The best place is near the acetylene generator if there is sufficient room, but never between the generator and gasometer.

The maintenance is limited to the regeneration or the removal of the purifying material when it is destroyed. This exhaustion of the purifying material is indicated by the change of colour in the product but one can observe this without having to visit the purifier, either by the colour of the flame, or by making use of the reaction with silver nitrate.

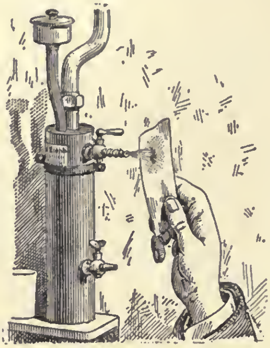


Fig. 37.—Verification of purification by silver nitrate.

The flame of a blowpipe using impure acetylene is yellowish and opaque instead of a transparent blue when the gas is perfectly purified. But the simplest way to test the purification is by the simple reagent paper.

Take a 10 per cent. solution of silver nitrate, obtainable from any chemist. Place a drop of the solution on a filter paper or white blotting paper; place the paper against the escaping acetylene by means of a cock opened for the purpose.

If the paper turns black in a few seconds under the influence of the gas, the purifying material is completely destroyed. If the paper remains white, the purifier is still good. If it changes slowly and slightly, the purifier is only slightly exhausted.

INSTALLATION AND MAINTENANCE OF ACETYLENE PLANT.

Position of plant.—It is incontestable that the best place for an acetylene plant is in the open air, or rather under a simple roof or open shed, but this is not possible with all types of plant.

A kind of hut or shed in a yard is very satisfactory, provided it is well ventilated and all elementary precautions against carelessness are taken.

If it is impossible to find such a place, then it is best to place it in the most ventilated part, and near daylight.

If it is necessary to place an acetylene plant in the interior of a building, it should be isolated by a partition so as to prevent all sparks and flames in the immediate neighbourhood reaching the plant. Also, to have a good draught of air from the exterior to make sure of ventilation.

In no case should acetylene generators, even small ones, be placed in underground cellars, badly ventilated places, dwelling places, or basements.

One should remember that acetylene apparatus, though not dangerous in itself, can, by the escape of the gas due to excess production or leakage, form with the air a dangerous and explosive mixture.

Administrative regulations. — The manufacture and use of acetylene is regulated by administrative laws. The construction and position of acetylene apparatus are supervised by the authorities.

Strange to say, plants known as "portable" seem to escape the regulations, and manufacturers of such plants generally advise one to neglect to inform the authorities when they know the position of the plant is to be a fixed one.

This is a very personal matter, but it seems to us to be short-sighted on the part of those who wish to be perfectly safe, because although the authorities are very tolerant at present, they may become much less so when serious accidents occur.

In view of the great development of oxy-acetylene welding special regulations may be anticipated.

Fire insurance.—Fire Insurance Companies look on acetylene as additional risk, and modify the policy accordingly.

If the acetylene apparatus is placed outside the building, no extra charge is made for fire risks. To insure against risk of explosion the cost is the same as for coal-gas.

If the acetylene apparatus is placed in the interior of a building, extra charges are made for fire and explosion risks. This constitutes one reason in favour of placing the apparatus outside buildings.

The Fire Insurance Companies like to insert clauses in the policies relative to the use of acetylene, which do not correspond at all to its industrial use. Do not let the companies insert such clauses without very good reasons for doing so.

Charging and cleaning.—It is necessary to be perfectly acquainted with the working and construction of the apparatus, and to acquire from the manufacturer full regulations for the manipulation of the plant.

The operations of charging and cleaning should only be done in daytime, and in the absolute *absence of any light or incandescent body, even a lighted cigarette.*

The generators, buckets, baskets, etc., should be cleaned with a strong flow of water and not recharged until quite dry. The baskets would be better for a second play of water.

In order to avoid the admission of air or to reduce it to a minimum in those apparatus which are not provided with a cock to clear air out of the generator, it is necessary—in carbide to water generators, automatic or non-automatic—to effect the emptying suddenly, by jerks, thus making certain that a quantity of lime sludge flows out before opening the water valve; after each opening replace with clean water and repeat. In this way effective cleaning takes place at the time of emptying. In water to carbide, dipping, or immersion generators, it is sufficient to throw a little water on the chamber which is farthest from the generator door just at the moment the generator is to be closed. In this way the gas produced replaces the air in the generating chamber.

General precautions.—In the case of defective working or sudden failure it is absolutely necessary to avoid going near the generator with a naked light or any incandescent body, more especially if the odour of acetylene is present.

In the case of all repairs which have to be made to the plant in which a flame of any kind is to be used, it is essential to *thoroughly remove all gas or mixtures of gas and air from the various parts of the apparatus.* Remember that mixtures of 10 parts of acetylene to 90 of air are highly explosive; consequently, it is necessary to remove all traces of acetylene. All parts which are not easily got at can only be thoroughly cleaned by thorough rinsing repeated two or three times.

Access and working of the generator should be forbidden to all persons who are not charged with its working. A summary of the working instructions, both for the interior and exterior, and necessary precautions should be provided.

DISSOLVED ACETYLENE.

We have seen that compressed acetylene under the influence of heat, or shock, etc., is liable to decompose with violent explosions. Liquefied acetylene possesses these disadvantages to a greater degree.

Sixteen years ago two inventors, Claude and Hesse, suggested making use of the solubility of acetylene in liquids in order to store the gas in portable form. To obtain a great solubility the acetylene must be highly compressed, and the properties of the gas in the dissolved state alter, as we shall see.

Acetylene dissolved in acetone.—Claude and Hesse found that acetone was the most satisfactory liquid for dissolving acetylene gas.

Acetone is a colourless liquid with an ethereal odour. It boils at 56° C. One pint of acetone weighs approximately 1 lb.

The coefficient of solubility in acetone varies considerably with the temperature. Berthelot and Vieille have shown that a vessel containing half the volume of acetylene at an absolute pressure of 16·17 atmospheres and 2°·8 C. rises to 33·21 atmospheres at 50°·5 C. These experiments and others which have been carried out by the French Dissolved Acetylene Company at their laboratories show that under ordinary conditions of use and working the initial pressure is increased approximately one-thirtieth for each degree Centigrade rise of temperature.

The presence of water in acetone diminishes the coefficient of solubility. It is therefore necessary to use the purest acetone and to introduce the acetylene perfectly dry.

Berthelot and Vieille have shown that up to a pressure of 20 atmospheres on the square inch a solution of acetylene in acetone is quite stable.

Porous materials.—However, the decomposition of the gas under pressure is still possible, filling the space between the liquid and the vessel, and therefore the process is not industrially applicable.

All these disadvantages have been overcome by the aid of a unique artifice which consists of completely filling the cylinders with a porous material and saturating it with acetone. Numerous experiments have shown that up to a pressure of 35 atmospheres this method is quite inexplosive—not only the solution but also the liberated gas. The decomposition provoked at any point in the cylinder can only travel a very small distance, producing an increase of pressure scarcely equal to the original pressure. In addition, the porous material has the advantage of preventing any possible flowing of the liquid; it facilitates dissolution of the gas and prevents the phenomena of supersaturation.

A number of researches have been made on the composition of porous materials suitable for filling the cylinders of dissolved acetylene, and numerous patents have been taken out. The material is introduced in the form of a paste; the cylinders are then thoroughly dried by baking from fifteen days to three weeks. It is not necessary to deal here with the technical side of the manufacture —the composition of the porous materials, the setting of the cylinders, the filling with acetone, etc.

Cylinders of dissolved acetylene.—The cylinders are made of steel plate, generally by autogenous welding, similar in shape to cylinders for oxygen.

These cylinders are completely filled with porous material saturated with acetone in such a quantity that they are not in any degree explosive. The porous material completely soaks up the acetone, so that with the cylinders in any position it is impossible for acetone to run out.

The cylinders are produced under Government regulations, and have to be tested to a pressure of at least double that to which the vessel is to be subjected in use. The necessity for renewing the porous material is found by testing the cylinders.

Fig. 38.—Cylinder of dissolved acetylene.

For the purpose of dissolved acetylene, the acetylene is prepared in a carbide to water generator under the best conditions. It is chemically purified and conveyed to a gasometer for cooling. The gas is then compressed into the cylinders containing the porous material saturated with acetone.

Contents of the cylinders. — The volume of the cylinders of dissolved acetylene varies according to the country and the destination of the gas.

In England the cylinder usually employed for autogenous welding has an external diameter of 8¼ inches and a length of 40 inches. There are also cylinders 6¼ inches diameter and 41½ inches long, and 10½ inches diameter and 52½ inches long.

One can reckon practically that 1 cubic foot of porous material at a pressure of 10 atmospheres contains 100 cubic feet of acetylene at normal pressure. The volume of gas stored in the cylinders at the pressure, 10 atmospheres as used in England, is 100 cubic feet in the $8\frac{1}{4}$ inches diameter, 60 cubic feet in the $6\frac{1}{4}$ inches diameter, and 200 cubic feet in the $10\frac{1}{2}$ inches diameter.

The volume is only *approximate*, as the dimensions of the cylinders and the weight of acetone which the cylinder contains varies. Moreover, the solubility in acetone varies with the temperature, *so that the pressure gauge gives different readings according to whether the cylinder is warm or cold.*

The only accurate test to verify the contents of the bottle under pressure is to weigh the bottle (1) *charged with acetylene;* (2) *empty of acetylene.* The difference gives the weight of acetylene used. We know that 1 cubic foot of acetylene weighs 0·074 lb., so that 1 lb. represents 13·6 cubic feet. That is to say, one has only to multiply the difference in weight by 13·6 to obtain the volume in cubic feet.

Example.—Weight of cylinder charged = $102\frac{1}{2}$ lbs.
" " empty = 95 "
Difference = $7\frac{1}{2}$ lbs. = $7\frac{1}{2} \times 13{\cdot}6 = 102$ cubic feet.

It is necessary to bear in mind that this calculation gives the volume at a temperature 0° C., which is advantageous to the purchaser, since at 15° C., the temperature of filling for the cylinders, the volume is increased.

Use of cylinders. — The cylinders of dissolved acetylene are provided with a valve opened by a key. The valve fitting also contains a thread for fixing the *reducing valve* to the cylinder.

The use of a reducing valve is indispensable—

(1) In order to know the pressure in the bottle at any instant.

(2) In order to adjust the pressure to that required.

These valves are described in Chapter VII., as they are the same in principle as those used on the oxygen cylinders.

Use of dissolved acetylene in autogenous welding.—The use of dissolved acetylene for autogenous welding has many advantages, the chief of which are—

(1) No generating apparatus and accessories required.

(2) Portability.

(3) Use of *high pressure* blowpipes.

(4) Perfectly pure acetylene.

These qualities are equally important, and dissolved acetylene would always be used if its high price did not come into account. In fact, 1 cubic foot of acetylene which costs from ¾d. to a 1d. with generators will cost two, three, or four times as much, according to the country and the distance from where the dissolved acetylene is made.

On the contrary, the use of dissolved acetylene is always to be adopted where the cost of gas does not enter into the question, such as certain repairing jobs in shipyards, that is, outside workshops where, naturally, cylinders are more convenient than fixed or portable plant. In the case of the repairs to boilers and others which require perfect welds and which cannot be carried out in the workshop, the use of dissolved acetylene should be insisted on, because the portable plants in use cannot supply acetylene under such good conditions, *i.e.* purity, pressure, etc.

Conditions of sale.—In England the dissolved acetylene plant for welding is sold complete; *or the cylinders* can be hired at a cost of 1s. per week after the first month, which is free, the gas being supplied at the rate of £7, 5s. per 1000 cubic feet free at the works. The price per 1000 cubic feet *in customers' own cylinders* is as follows:—105s. at any of the Company's works; 115s. free delivery in any towns where compressing stations are established; 150s. in other parts of Great Britain. There are discounts varying from 5 to 20 per cent. on accounts aggregating £50 to £200 in three months. *The price of the cylinders* is, for the 60 cubic feet £6, for the 100 cubic feet £7, 15s., and for the 200 cubic feet (usually used for welding) £9, 5s.

Fig. 39.—Welding with dissolved acetylene.

Manipulations and precautions.—The cylinders of dissolved acetylene can be manipulated without any special precautions. The welder simply avoids their deterioration by violent shocks, falls, etc. The part which supports the valve should be particularly looked after.

The dissolved acetylene cylinders are not affected by lowering of temperature, therefore one can leave them exposed to cold in all seasons and in all countries. On the contrary, one should avoid leaving them in a heated atmosphere.

Care should be taken that there is no leak between the valve and the reducing valve or in the reducing valve itself; all flames on the bottle, or in its neighbourhood, should be extinguished as soon as possible; and the valve of the bottle should be closed after using. Lastly, the usual necessary precautions should be taken in the case of gases and inflammable vapours.

Laws.—In England the use of dissolved acetylene is under regulation. An order of the Home Secretary allows the compression of acetylene into cylinders filled as completely as possible with porous matter to a pressure not exceeding 150 lbs. per square inch (10 atmospheres), provided that—(*a*) the cylinders have been tested by hydraulic pressure to not less than double that which it is intended to use; (*b*) the solid substance is similar in every respect to the sample deposited at the Home Office; (*c*) air is excluded from every part of the apparatus before compression takes place; (*d*) the temperature is not permitted to rise during compression; and (*e*) compression only takes place in premises approved by H.M. Inspectors of Explosives. Every cylinder has to contain the following notice, "Acetylene Compressed into Porous Substances Exempted by Order of the Secretary of State. Dated, etc."

CHAPTER VI.

OXY-ACETYLENE BLOWPIPES.

GENERAL NOTIONS ON THE OXY-ACETYLENE BLOWPIPE.

The oxy-acetylene blowpipe intended for autogenous welding of metals is an instrument of precision, being extremely simple, light, easy to handle, and in which the oxygen and acetylene are mixed together in the correct proportions. The mixture ultimately escapes, and on being lighted produces a flame which should be fixed, steady, and of suitable dimensions for the purpose of welding.

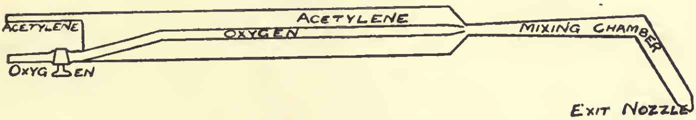


Fig. 40.—Outline diagram showing arrangement of oxy-acetylene blowpipes.

The blowpipe generally consists of a central body or handle at one extremity of which the gases, oxygen and acetylene, enter, and at the other the *mixing chamber*, which bends towards the nozzle at the end of the blowpipe.

For facility of manipulation during welding the blowpipe is bent at the extremity to an angle more or less open.

According to the pattern and consumption their length varies from 1 to 2½ feet and their weight from 1 to 4½ lbs. They are generally made of brass, and the nozzles made of red copper. They are made for all powers corresponding to an hourly use, of from 30 to 3000 litres of acetylene (1 to 100 cubic feet); that is to say, appropriate for welding metals of all thicknesses.

General principles. Difficulties to be overcome.—The blowpipe should be as safe as possible, even in the event of bad manipulation or carelessness. It should be simple, easily directed, and give a stable flame. The consumption of acetylene and oxygen should be as nearly equal as possible.

These conditions are much more difficult to realise than they appear, especially in the case of blowpipes in which the acetylene is admitted at the pressure of generation; that is to say, practically no pressure.

The chief difficulty to be overcome is to obtain the necessary stability of flame. The velocity of propagation of the flame in the case of a mixture of oxygen and acetylene is about 330 feet per second. It is therefore necessary, in order to avoid the striking back of the flame, that the velocity of the mixture at the exit should be of the same value, or at least such that it constantly prevents the return of the flame to the interior.

Of course with the oxygen being stored under great pressure it is always possible to obtain a high velocity through the nozzle, but for reasons which it would take too long to explain here, the proper working of the blowpipe requires the oxygen under the most feeble pressure possible. This pressure is almost entirely used in aspirating the acetylene and ensuring a sufficient exit velocity to the gas. The arrangement necessary to obtain this demands serious study.

The intimate mixture of the gases should be perfectly accomplished before their escape from the blowpipe. This consideration, which it is so important to obtain, is difficult to realise, because it is necessary to avoid too much loss of pressure, which would require an increase in the pressure of the oxygen in order to regain the velocity of exit necessary for the stability of the flame.

The prevention of the return of the flame, which is facilitated by the heating of the blowpipe, projection of sparks down the nozzle, etc., equally require serious study.

Lastly, a large number of details merit attention: construction of the nozzle, ease of manipulation, cross-sections of the various details, ease in taking to pieces and re-assembling, etc. etc., so that a blowpipe, which in appearance is such a common article, requires such precision in construction that it is only to be undertaken by specialists in the subject. The working and yield of different blowpipes can be compared by the stability of the flame, consumption of oxygen, etc. It is necessary to leave to specialists and experts the care and construction and even the repair of blowpipes, because the economy and good results of welding depend more on this than is generally thought.

Classifications.—Oxy-acetylene blowpipes vary according to the pressure of acetylene, as we know that oxygen can be used without limit of pressure.

Blowpipes can be divided into three principal classes:—

(1) *Blowpipes for high pressure acetylene.*
(2) *Blowpipes for medium pressure acetylene.*
(3) *Blowpipes for low pressure acetylene.*

Let us explain at once what we mean by high, medium, and low pressure acetylene.

In the first case, it is a question of the pressure varying from 4½ to 7 lbs., that is, corresponding to a water pressure of 10 to 16 feet.

The blowpipes used for "medium pressure" use the acetylene from 3 to 13 feet water pressure.

Lastly, the blowpipes for "low pressure," which are those most used, receive the acetylene at the pressure generated. This pressure is a few inches of water, which is lowered in many cases by the passage of the gas through the hydraulic safety valve. This point will be dealt with later.

In the first two classes the delivery, that is, the power of the blowpipe, can be varied by simply changing the nozzle or by regulating the openings for the gas. In the third class the delivery of every blowpipe is fixed and invariable, because for every section of nozzle there is a suitable *oxygen injector.*

Low pressure blowpipes have been constructed in which by the simple changing of a portion which contains the nozzle, injector, and mixing chamber the same blowpipe can furnish different powers. Hence there are—

(*a*) *Blowpipes for low pressure acetylene with fixed delivery.*

(*b*) *Blowpipes for low pressure acetylene with variable delivery.*

Lastly, blowpipes for low pressure have been designed for variable delivery, by regulating the oxygen injector according to the size of the nozzle, this being produced by the aid of devices for reducing the section through which the gas flows. We will call this system—

Blowpipes for low pressure acetylene with oxygen regulator.

It should be noted that blowpipes constructed for using acetylene at low pressure can also work with medium or high pressure acetylene, by reducing proportionally the pressure of the oxygen; but the majority of the devices which they contain become absolutely useless. On the contrary, the blowpipes for medium and high pressure cannot be used for acetylene at the usual generator pressure.

BLOWPIPES FOR HIGH PRESSURE ACETYLENE.

The blowpipes for "high pressure acetylene" were the first to be made. They were designed for using dissolved acetylene, and are practically only used for that purpose now. The pressure of the acetylene used varies from 10 to 16 feet of water, or 4½ to 7 lbs. per square inch.

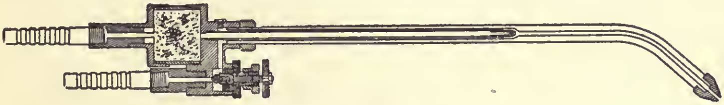


Fig. 41.—Section of a high pressure blowpipe.

These blowpipes practically work with equal pressures of acetylene and oxygen, which makes their construction quite simple. The gases arrive by different tubes, one generally surrounding the other, and are intimately mixed in a tube which conveys them to the nozzle. The regulation is obtained by valves which are placed either on the blowpipes or by the reducing valves on the cylinders.

The acetylene and oxygen being practically used at the same pressure there cannot be a return of one gas into the tube of the other. To prevent the striking back of the flame towards the source of the acetylene a screen of porous material is interposed immediately after entering the blowpipe. This allows the gas to pass through easily, but opposes the propagation of the flame.

The blowpipe sold by the different companies selling dissolved acetylene is shown in section in fig. 41, and which shows the screen made of aluminium shavings also the valve for regulating the oxygen which can be regulated by the hand which holds the blowpipe.

In order to vary the power of the flame it is sufficient to change the nozzle (the nozzles are made for various deliveries, 50 to 2500 litres, *i.e.* 1·75 to 90 cubic feet), then regulate the admission of the gases. If the velocity of the gases at the exit is greater than the velocity of the propagation of the flame, it is impossible to obtain stable combustion at the nozzle. The normal working of the flame takes place between fairly fixed limits of pressure, which are easily regulated by the reducing valves on the cylinders. These pressures increase with the power of the blowpipe, but are always below 5¾ lbs., which suffices to obtain a velocity opposable to that of the propagation of the flame.

Fig. 42.—Blowpipe for high pressure, with nozzles.

BLOWPIPES FOR MEDIUM PRESSURE ACETYLENE.

Acetylene cannot be obtained industrially from generators at a sufficiently high pressure to use the blowpipes we have just described. The most that can be done is to store the acetylene in flow back of water gasometers at a pressure varying from 40 to 80 inches.

Thus used the acetylene does not require a much higher pressure of oxygen to give the mixture sufficient velocity. As a result, an injector through which the oxygen escapes at a pressure slightly in excess of that of the acetylene (7 to 8½ lbs., for example) is sufficient to give the necessary exit velocity.

The injector nozzle of the oxygen remains the same whatever be the delivery at the blowpipe nozzle. It is only necessary to change the blowpipe nozzle to vary the power of the flame. The regulation is done by the cock controlling the gas or by the reducing valve on the oxygen bottle.

The principle of blowpipes for medium pressure is almost the same as for blowpipes using dissolved acetylene, except that the oxygen is used at a slightly higher pressure than the acetylene, which necessitates a slight modification in the arrangement.

As an example we give the section of the blowpipe for medium pressure of the Universal Acetylene Company.

This blowpipe can only be used with a generator supplying acetylene at a pressure of 40 to 60 inches of water, which is given by the generators specially made by the Company for autogenous welding

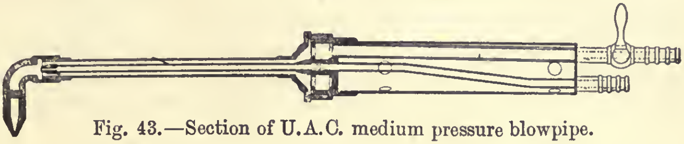


Fig. 43.—Section of U.A.C. medium pressure blowpipe.

Let us add that since the pressure of oxygen used is higher than that of the acetylene, a safety device must be used to prevent the passage of the oxygen to the generator.

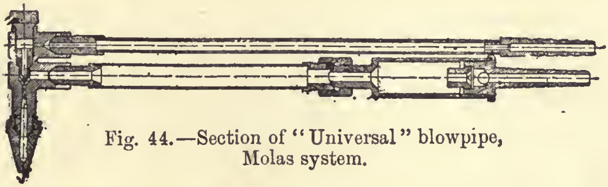


Fig. 44.—Section of "Universal" blowpipe, Molas system.

The "Universal" blowpipe invented by M. Molas is reproduced in section; it is generally used in medium pressure installations. In order to vary its power it is sufficient to change the nozzle and regulate the pressure of the gases.

BLOWPIPES FOR LOW PRESSURE ACETYLENE AND FIXED DELIVERY.

The majority of acetylene generators deliver the gas at a pressure which does not exceed 8 inches of water and is generally from 3 to 5 inches.

In order to obtain sufficient velocity at the exit, which is necessary for the good working of the blowpipe, the oxygen must be used at a sufficiently high pressure.

This meeting of the two gases in the blowpipe, one at a high and the other at a low pressure, can only take place with special devices. In order that the mixture can take place the acetylene has to flow into a tube into which the oxygen is rushing at a high velocity. This can only take place by the acetylene being aspirated or sucked in by the oxygen. It will be understood that the higher the pressure of the acetylene the less the effort required of the oxygen, and *vice versâ*.

The suction of the acetylene by the oxygen is produced by a device known as the *Giffard Injector*, applied in many analogous cases.

This consists of an *injector* of delivery appropriate to the pressure of oxygen used (14 to 28 lbs., for example). The injector nozzle opens in a conical portion, where it draws in the combustible gas. The mixed gases are then ejected through an expansion chamber where the velocity is reduced to a suitable value. The proportions and arrangements of the various details have to be carefully worked out for each case.

It is clear that the delivery of oxygen being fixed by the size of the injector orifice, the power of the blowpipe is invariable in these limits, and in practice variation of pressure clearly means bad working.

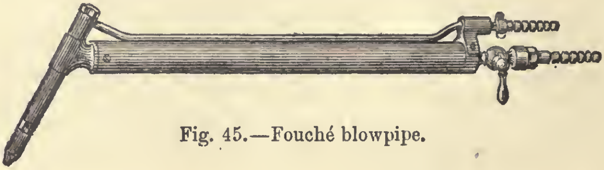


Fig. 45.—Fouché blowpipe.

Therefore, according to the number of powers of flame required, one must possess blowpipes, generally 5 to 10, for obtaining the whole range of deliveries; that is to say, from 50 to 75 litres (1·75 to 2·65 cubic feet) per hour to 2000 or 2500 litres (70 to 90 cubic feet).

The orifice at the nozzle of the blowpipe for low pressure acetylene is designed according to the delivery of the injector when using the oxygen at a pressure for which it has been designed. *It is therefore essential that it be neither reduced or enlarged.*

The first inventors of low pressure acetylene blowpipes strongly feared the striking back of the flame into the tube containing the acetylene, as for example when the exit of the nozzle became obstructed. In order to avoid this they invented many ingenious devices which are now known not to be indispensable, since the tube which brings the acetylene from the cock of the blowpipe to the injector arrangement does not offer a sufficient explosive capacity, and a safety arrangement placed at the extremity of the acetylene piping prevents the passage of the oxygen into the latter.

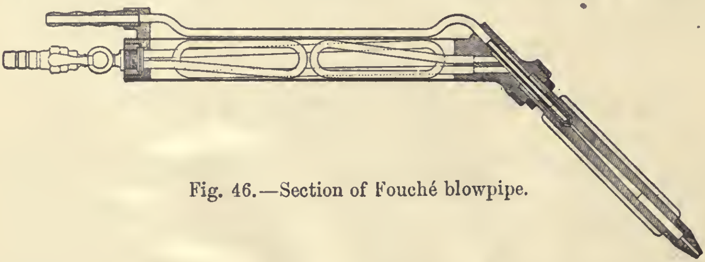


Fig. 46.—Section of Fouché blowpipe.

We will not undertake the detailed description of the principal low pressure acetylene blowpipes of fixed delivery. It will be sufficient to give a few illustrations showing the general construction of patterns of this type.

Fig. 47.—Simplex blowpipe.

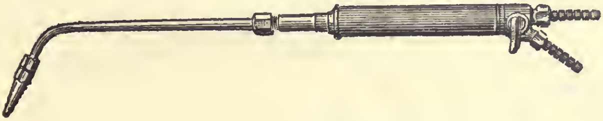


Fig. 48.—Sirius blowpipe.

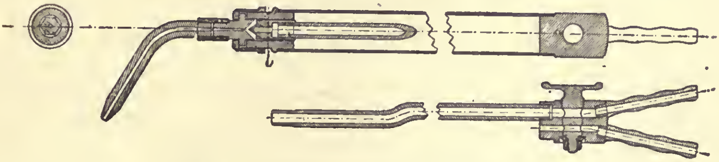


Fig. 49.—Section of Columbia blowpipe.

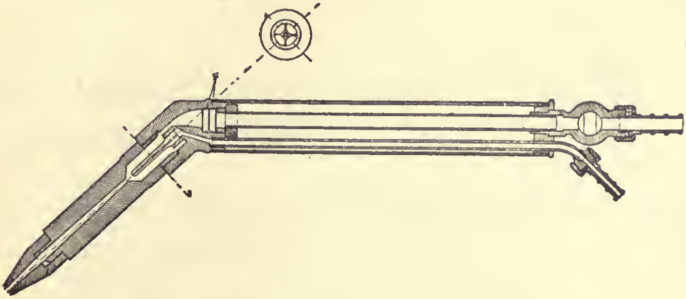


Fig. 50.—Section of Bastian blowpipe.

Fig. 51.—Section of Weber blowpipe.

BLOWPIPES FOR LOW PRESSURE ACETYLENE AND VARIABLE DELIVERY.

In the blowpipes of *fixed* delivery, if it is a question of making the power variable, the simultaneous changing of the oxygen injector, the aspiration arrangement, the mixing chamber, and the exit nozzle is necessary.

Fig. 52.—Cyclop blowpipe with interchangeable heads.

The idea of making the above details in such a manner that they could be assembled so as to make the blowpipe adjustable for all powers has been worked out.

The blowpipe has one body and several pieces which can be adapted to it, each giving flames of different powers and each containing an injector, mixing chamber, and exit nozzle appropriate to the delivery.

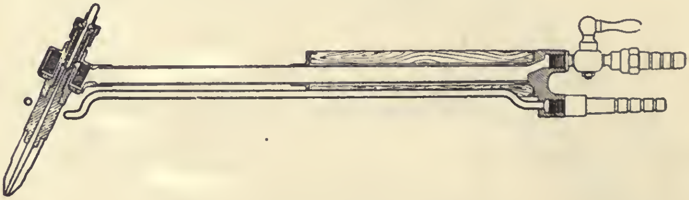


Fig. 53.—Section of Cyclop blowpipe.

In these blowpipes the double adjustment between the body or handle and the ends of the two tubes conducting the oxygen and the acetylene necessitates great precision of construction.

Another type of variable delivery blowpipe was invented two or three years ago and has obtained a well-merited success. The inventor of the injector, Giffard, indicated in the course of his work that it was sufficient to reduce or increase the orifice of the fluid aspirator in order to vary the power of the apparatus, and he obtained this result by means of a conical spindle penetrating more or less into the orifice.

It is this principle that has been adopted in this second type of variable power blowpipe. It is sufficient to place an exit nozzle for the required delivery and adjust the injector orifice to this delivery. In this way one blowpipe of this pattern can furnish a large number of flames.

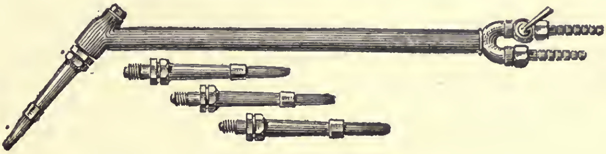


Fig. 54.—Blowpipe of the *Société l'Air Liquide* (A.L.I.).

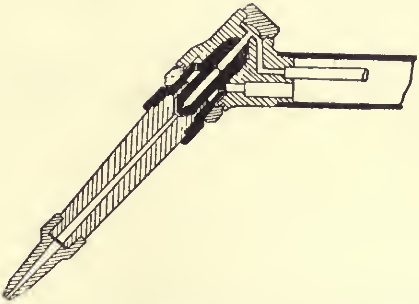


Fig. 55.—Section showing essential details of the blowpipe of the *Société l'Air Liquide* (A.L.I.).

This regulation of the oxygen is made by a small milled wheel controlling a conical needle valve which penetrates more or less into the orifice of the oxygen injector, its complete withdrawal corresponding to the maximum consumption of the blowpipe.

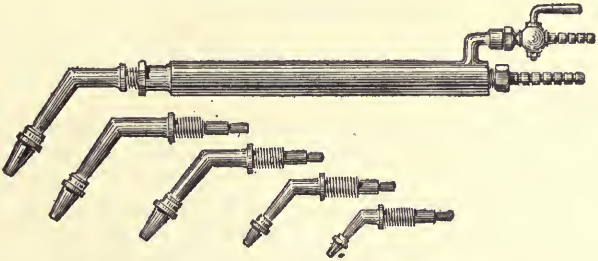


Fig. 56.—Habran blowpipe with interchangeable heads.

It will be understood that in order to give good results the details and regulator must be well made. The oxygen penetrates the aspirator detail in the form of an annular jet; the suction of the acetylene and the mixing of the gases take place just as well as in the previous type. The final regulation of the flame by means of the oxygen regulator is preferable. To sum up, this type of blowpipe offers real advantages over all the other systems using acetylene at low pressure, although good construction and perfect regulation are indispensable; also its handling and maintenance are incontestably more delicate.

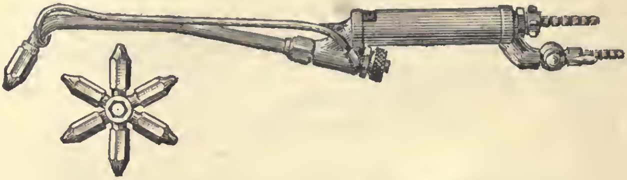


Fig. 57.—Picard blowpipe with the oxygen regulator.

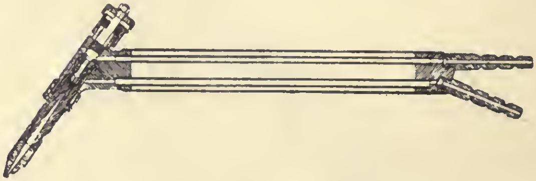


Fig. 58.—Section of essential details of Picard blowpipe (small pattern).

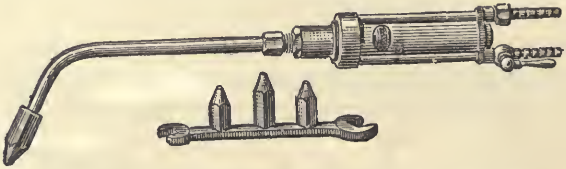


Fig. 59.—Unic-Simplex blowpipe with oxygen regulator.

CONSUMPTION OF BLOWPIPES.

The blowpipes of all systems—high, medium or low pressure acetylene—are constructed so as to give flames of all intensities requisite for the practice of autogenous welding.

Their power is reckoned according to their hourly consumption of acetylene. One speaks, for example, of blowpipes of 100, 350, 500, 1000, 1500, etc., litres, which corresponds approximately to the hourly delivery of acetylene. This designation is universally adopted to-day, and we will employ it in the following chapters to indicate the power of the blowpipe.

The blowpipes with the lowest consumption are in the neighbourhood of 50 litres (1·75 cubic feet) of acetylene per hour. Some have been made with lower powers, notably for the autogenous welding of lead, aluminium in thin sheets, etc. The largest powers deliver up to 2500 litres (88 cubic feet); some special types go up to 3000 and even 4000 litres. In the succeeding chapters instruction will be given for choosing the necessary power of blowpipe according to the metal to be welded, its thickness, etc.

. . . .

It is important to pay particular attention to the consumption of *oxygen* compared to that of the acetylene.

We know that, theoretically, the formation of the small white jet requires exactly one volume of oxygen for one volume of acetylene, measured under normal conditions of pressure and temperature. For example, a 350-litre blowpipe should equally consume 350 litres of oxygen per hour. In practice do we obtain this result?

Yes, with blowpipes using *high pressure* acetylene.

Almost, with blowpipes using *medium pressure* acetylene.

It is approached with *low pressure blowpipes of good construction and good regulation.*

These results only apply to blowpipes working under normal conditions, the flame being perfectly regulated without apparent excess of oxygen or acetylene.

For blowpipes of high pressure using dissolved acetylene all the experiments agree in showing that the respective volumes of gas used are practically equal, and this is obtained in practice if the welders are competent.

The blowpipes of medium pressure give almost identical results if the pressure of the acetylene is kept practically constant, at least equal to 50 inches of water, and provided that the oxygen pressure is not *forced* to obtain the necessary velocity. The researches published do not altogether agree, but in all cases there is no very great difference between the volume of oxygen used and that of acetylene.

The blowpipes for low pressure acetylene are those with which the most difficulty has been obtained, even in approaching the theoretical equal volumes. The oxygen being used under a high pressure it is difficult to mix the acetylene in order to give it sufficient velocity. There is evidently an energetic mixing of the two gases, but the contact is not made molecule to molecule, and stream lines of oxygen or acetylene can escape at the nozzle without being mixed. One can test this in different ways, for example, by contracting the exit tube of the mixing chamber or by increasing the pressure of the oxygen. In both cases the proportion of oxygen to acetylene is raised considerably.

One can conclude from this that a blowpipe for low pressure acetylene *consumes the least oxygen when the admission pressure of the latter is least and the arrangement for obtaining a mixture of the two gases the best.*

Let us immediately remark that in certain types of blowpipes the oxygen pressure to be used corresponds exactly with the arrangement of the mixing chamber. Change of section, abrupt bending, etc., can produce a loss of pressure. It is evidently necessary to find an equilibrium between these two factors, which are opposite. If the pressure of the oxygen is not raised too high, and the arrangement for mixing excellent, the result may be perfect.

We will now give some examples to demonstrate the importance of this question.

In a series of experiments carried out in September 1910 by the *Union de la Soudure Autogène*, with the blowpipes of all systems for low pressure acetylene and according to the instructions given by their constructors, the following results have been obtained which give the proportion between the volumes of the oxygen and of the acetylene, $\frac{O}{C_2H_2}$.

The letters A, B, C, etc., indicate the different types of blowpipe used.

Blowpipe	A (750 litres),	shortly after	ignition	1·4,	very warm	1·8
,,	B (250 ,,),	,,	,,	1·35,	,,	1·67
,,	C (450 ,,),	,,	,,	1·60,	,,	1·90
,,	D (600 ,,),	,,	,,	1·65,	,,	1·90
,,	E (750 ,,),	,,	,,	1·45,	,,	1·55
,,	F (1000 ,,),	,,	,,	1·55,	,,	1·75

It is only fair to observe that these were carried out with the best types of blowpipes being used at this period in the laboratory of the *Union de la Soudure Autogène*, the admission pressure of the oxygen being that indicated by the makers in their catalogues, and the general regulation being according to their instructions.

The considerable increase in the consumption of oxygen on the blowpipe becoming heated should be noted. This only occurs in blowpipes using low pressure acetylene. The effect of expansion on the two gases admitted at different pressures is not the same, but it is relatively easy to obviate this disadvantage, as will be shown later in the chapter containing "Regulation of the Flame."

The labours of the *Union de la Soudure Autogène* have caused many of the constructors to modify their blowpipe, and so lower the proportion of oxygen to acetylene, notable progress thus being realised.

We can take the more recent results of industrial tests which have been published following the *Congress on Autogenous Welding*. The exact volume of acetylene and oxygen consumed was obtained for each competitor (there being fifty). The blowpipes used—the choice of the competitor—were of many types; the average delivery of acetylene was fixed at 350 litres per hour, and the work to be executed lasted 30 to 40 minutes. The competitors were generally clever welders, familiar with their blowpipe. Lastly, the consumption of the gases were noted, and special prizes were given to the ten competitors consuming the least oxygen.

The best proportion of oxygen to acetylene was 1·12, the average was 1·3, and the worst 1·9.

The best results obtained by the seven types of blowpipe used by competitors were as follows :—

Blowpipe A	1·14
" B	1·24
" C	1·60
" D	1·20
" E	1·47
" F	1·55
" G	1·12

It was also shown that with the same blowpipe used by two welders, one using the oxygen at 28 lbs. pressure and the other at 13 lbs., the proportion in the first case was 1·83, and in the second 1·25, thus showing clearly the influence of excess pressure of oxygen on the consumption of the gas.

It is important to note that according to the type of blowpipe and the conditions of use, the consumption of oxygen for a constant delivery of acetylene can vary greatly, and can even double in volume.

Not only is the oxygen consumed in excess of the theoretical amount a pure loss, but also its presence in the flame oxidises the metal, lowers the strength of the weld, and renders it brittle and porous.

These considerations are very important from the two points of view—economy and good work. Those who use autogenous welding will be wise to study them.

CHOICE OF A BLOWPIPE.

After what has just been said, it can be seen that the choice of a blowpipe for using low pressure acetylene is of considerable importance. The installations of low pressure being the most numerous, we will deal particularly with a blowpipe for the latter; but, first of all, it will not be out of place to make a few observations on the *choice of an installation* itself.

We find ourselves confronted by three different systems of blowpipes, each corresponding to different installations, viz. *high*, *medium*, *and low pressure.*

The *high pressure* using *dissolved acetylene* is the simplest installation, requiring no acetylene generator, piping or hydraulic valve; the installation is exceedingly portable, consisting of two cylinders containing the gases, and simply requires one special blowpipe in which it is only necessary to change the nozzle to vary the power. Using a good blowpipe, welds are obtained under the best conditions possible.

On the other hand, acetylene dissolved in acetone is much dearer, costing at least three times (often four or five times) as much as the gas produced in generators, and this is the only fault of the system.

According to the kind of welds required, the use of dissolved acetylene installations should be given precedence where recommendable; that is, whether the nature of the work is of first importance or the cost of the same. The following are common examples where dissolved acetylene can be used advantageously:—Repairs on board ships and similar work in shipyards; garages for automobiles, mechanics' workshop, mills, etc., and in all cases where the application of autogenous welding is intermittent.

In certain large workshops where autogenous welding is used on a large scale it pays to manufacture dissolved acetylene on the spot, as this can be done without a large increase in price and permits of changing the place of welding, also using blowpipes for high pressure.

After compression the acetylene can be distributed under a pressure of 120 to 160 inches of water to the welding places by means of piping. Such installations should be carefully studied, and should not be used unless there is a very large consumption. Let us add that this appears to be contrary to the existing regulations of several countries.

. . . .

The installations of *medium pressure* require a special acetylene generator to produce the gas at a pressure of 50 to 80 inches of water; also a hydraulic safety valve *specially constructed* for the pressure. It is then a question in this case of apparatus specially constructed for medium pressure: generator, hydraulic valve, blowpipe, and these cannot be used for other purposes. Manufacturers do not like to acquire installations which cannot be modified, perfected, or added to without applying to the firm that supplied it. On the other hand, the guarantees given are satisfactory.

The use of *medium pressure* gives results which are extremely favourable from the point of view we have studied above, and the installation of this type should be carefully considered when choosing a system of welding.

. . . .

The installations of *low pressure* are those which are the most numerous; using the gas and generating it at a pressure of a few inches of water. We have stated previously the considerations which are useful in the *choice of an acetyene generator*, but the choice of the blowpipe opens up the question again, and the type of installation becomes a question of great importance.

Many types of low pressure acetylene blowpipes are offered to the purchaser, and good quality can be obtained in all types.

Let us note, first of all, that each blowpipe has its particular function and aim. Existing blowpipes can be fairly clearly classified according to their logical use, and corresponding to the particular idea of their inventor, which frequently has nothing in common with the offers of their exploiters. There are blowpipes with fixed delivery, others with variable delivery, the good and the bad, the cheap and the dear, the light and the heavy, the long and the short.

The choice depends, first of all, on the use which is going to be made of it. Is it to continually weld identical pieces of work or welds requiring the same power of flame? If so, adopt the blowpipe of fixed delivery. On the other hand, do we wish to make all kinds of welds with the blowpipe? If so, choose the variable delivery type.

In indicating certain directions of choice between the two different types, of course particular conditions may vary the choice. Thus blowpipes of fixed delivery are always to be preferred as less fragile, if the cost of the series of different powers does not seriously enter into consideration. On the contrary, the small manufacturer whose expenditure on tools is limited should adopt the system of variable delivery, which offers him, so to speak, several blowpipes in one. Each one should consider his own particular case.

The weight of the blowpipe becomes of importance in its practical use. To listen to welders, the best blowpipes are those which feel "the best in the hand." But there, again, the choice depends on the work to be done and, as to the weight of the instrument, the duration of the work. If it is a question of repairs which have to be done quickly, the heaviness of the blowpipe is not a fault. On the contrary, if it is a question of construction work in which the weld to be executed is carried on for several hours without interruption, then lightness becomes an important quality.

The management, the regulation, and the maintenance have more or less to be considered according to whether the blowpipe is to be used by experts or by inexperienced persons.

We lay stress on these different points, because from our experience we know that types appreciated in certain cases are rejected in others, and if one searches for the exact motives, they will find that the questions of form, weight, solidity, lightness, etc., have come in to a large extent.

Now we arrive at the question of working and, what is more interesting, the consumption of the gases, subjects which have been greatly neglected until recently.

All blowpipes, needless to say, are not equally well constructed and regulated. The striking back of the flame into the interior, notably on the nozzle becoming heated, is a very serious defect, because the welder, in order to avoid it, increases the pressure of the oxygen. It is therefore an important quality of a blowpipe not to strike back or to *light in the interior* even after prolonged working. All the points we have given above should be carefully considered, and those which will be given later concerning the regulation of the flame.

The consumption of the oxygen in proportion to that of the acetylene, as we have seen, is a point of considerable importance both from the point of view of economy and the execution of good welds.

Let us take, for example, the case of the small workshop using autogenous welding on a moderate scale, say, 2100 cubic feet of oxygen per month. Suppose a bad blowpipe is used requiring 1·8 volumes of oxygen for 1 volume of acetylene, as is frequently the case. As the proportion of consumption of oxygen in good blowpipes only attains 1·2, the oxygen that should be used under these conditions is $\frac{2100 \times 1{\cdot}2}{1{\cdot}8} = 1400$ cubic feet. The loss is therefore 700 cubic feet, which at 1d. per cubic foot, say, represents a loss of practically £3 per month and £36 per year, which can be easily saved by using a good blowpipe. Moreover, in addition to this loss, the excess of oxygen gives rise to bad welding.

This illustrates the importance, from economical considerations, of inquiring as to the relative proportions of oxygen and acetylene, seeing that excess of oxygen brings about bad welds. This factor is more important than the economy of the gas.

Therefore in choosing a blowpipe system from the point of view of the consumption of oxygen, as explained previously, one should stipulate a guarantee from the constructors; for example, *the maximum proportion is* 1·3, *using the pressure of oxygen indicated.* This would be quite sufficient for normal conditions of working of blowpipes.

MAINTENANCE OF BLOWPIPES.

As we have said at the commencement of this chapter, blowpipes are instruments of precision. They are very delicate, and should be used carefully to avoid their deterioration.

If the blowpipe is carefully managed the wear is practically nothing, and they work after several years' use just the same as when bought. Their care consists in keeping in order the cocks and the joints of the movable pieces, and the cleaning of the exit nozzle from time to time.

This last operation is very delicate. In fact, *one must take care not to enlarge the orifice of the nozzle*, especially in the blowpipes for low pressure, because the slightest change in section produces derangement.

It is understood that, for the same blowpipe the section of the nozzle corresponds to a determined flow of oxygen, but the orifice for the flowing of the oxygen (the injector) remains unchanged, and any increase of the nozzle opening brings about a decrease of velocity at the exit, which provokes a return of the flame into the interior of the blowpipe.

The crusting of the nozzle by the oxides or particles of metal produces the following result: the delivery of oxygen being invariable and escaping under a greater pressure than the acetylene, the flame becomes *oxidising.* In effect, the orifice becoming too small for the passage of the two gases, it is the stronger, viz. the oxygen, that gets through in preference to the acetylene.

It is therefore necessary to watch that the orifice of the exit nozzle does not become encrusted, but it is more important not to enlarge it during the process of cleaning. *These recommendations are very important.* One should abstain from rubbing the extremity of the nozzle on the bricks of the welding table, or on metal, and more so from using a file. The decrusting of the orifice should be done by means of a *brass wire*, excluding altogether a steel tool or the tail of a file. *All widening of the nozzle or increasing the exit passage produces, as we have said, derangement of the blowpipe.*

Sometimes particles of dust contained in the gases are carried into the interior of the blowpipe, and can cause a partial obstruction. The working becomes affected owing to the gases passing along with difficulty. Some types contain a metal curtain which is supposed to keep back the dust, but this filter tends to become an obstruction itself, so the result is the same.

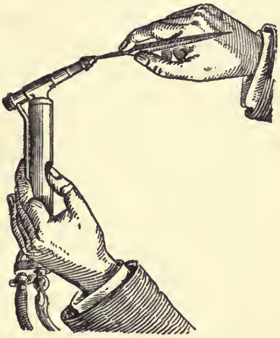


Fig. 60.—The scraping of the nozzle should not be done with a tool which might enlarge the nozzle.

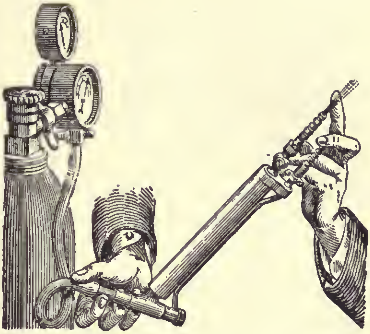


Fig. 61.—Cleaning the blowpipe by means of oxygen under pressure.

What is to be done? The remedy is very simple. It is sufficient to take off the tubing and to connect the nozzle of the blowpipe direct to the oxygen cylinder. Raise the pressure of the gas by means of the reducing valve (say to 10 lbs.), and send the current of gas in the reverse direction to that usually used. The acetylene cock on the blowpipe being open, close the orifice for the entrance of the oxygen with the finger, so that the gas under pressure sweeps out the acetylene passage; by playing on the exit with the finger the cleaning is facilitated. One can do the same for the oxygen passages, but the obstruction of this tube and the injector are very rare. The operation only takes a few seconds.

Blowpipes ought not to be dipped into water, because the presence of moisture in the interior causes the oxidation of the various delicate parts and produces obstruction and derangement. If in the course of the work it is desired to cool a blowpipe in which the flame strikes back on account of great heating, *care should be taken not to close completely the oxygen supply*, so that the flowing of the gas prevents the entrance of water into the orifice of the nozzle.

Fig. 62.—If the blowpipe is cooled by immersion in water, the oxygen should not be completely shut off.

Always abstain from greasing or oiling the interior of blowpipes, especially the oxygen tube or the mixing chamber for oxygen and acetylene. It is true that no oiling is necessary, but in oiling the cocks or joints the oil may flow into the blowpipe, and, in contact with the oxygen, especially on warming the blowpipe, the oil and grease oxidise and even catch fire, which produces an internal burning and ignites the rubber tube carrying the oxygen. This case is more frequent in new blowpipes in which the interior details are more or less oiled or greased.

Let us again point out that one should avoid as much as possible the taking of the blowpipe to pieces, as putting it together again generally requires some new regulation, which can only be done by specialists. In cases of bad working and the impossibility of its repair by the methods we have indicated, a speedy return to the maker is the best procedure, and usually the most economical.

Let us add that external cleanliness is generally an index of general care and good working, and let us finish by praising those workshops in which the blowpipes are treated as instruments of precision, ranged in good order, always polished, in a good state of preservation and good working, as all tools of precision deserve to be treated.

CHAPTER VII.

WELDING INSTALLATIONS.

We have studied acetylene generators, the cylinders containing the oxygen under compression, and oxy-acetylene blowpipes. An autogenous welding installation, especially one using acetylene at low pressure, comprises other details and accessories which one should know. What are they?

We have, first of all, to consider the *mains and service pipes* from the generator to the welding place; then the *safety valve*, which is indispensable for installations of low or medium pressure acetylene; the *oxygen reducing valves*; the *flexible tubes* carrying the gases to the blowpipe; the *welding benches* and their accessories; and, lastly, the special arrangements for certain kinds of work.

We believe that the security and good working of welding installations depends, in a large measure, on understanding these various details.

ACETYLENE PIPING.

In the majority of autogenous welding installations, which actually exist, the pipes which convey the acetylene from the generator to the welding place are of too small a section for the good working of the blowpipes with large delivery. This results in a serious *loss of pressure*, which prevents the acetylene arriving in sufficient quantity and under normal pressure to the blowpipe. The welder is compelled to increase the pressure of the oxygen to aspirate the acetylene, and often aspiration of air through the discharge tube of the hydraulic valve takes place.

The cross-section of the acetylene pipe should be in relation to the delivery, and *should provide for the maximum consumption, that is to say, for the largest blowpipe one is going to use.*

In fixing the size of piping one should look forward to a possible increase of the installation.

The loss of pressure for a determined delivery depends not only on the diameter of the pipe but also on its length, and one will admit that in a good system of piping it should not exceed $\frac{3}{8}$ inch of water; that is to say, that if the gas leaves the generator or the purifier at a pressure of 5 inches of water, for example, the pressure on entering the hydraulic valve should be $4\frac{5}{8}$ inches even during the working of the largest delivery blowpipe. This favourable result is, alas, too rarely obtained in consequence of the use of too small a piping.

See, for example, what happens with a tube of interior diameter $\frac{5}{8}$ inch: if the piping is 35 feet long, the delivery can attain 2300 litres or 81 cubic feet per hour without the loss of pressure exceeding $\frac{3}{8}$ inch of water; but for 50 feet it falls to 1900 litres or 67 cubic feet; then for 100 feet it is 1350 litres or 48 cubic feet; for 165 feet it is 1000 litres or 35 cubic feet, and for 330 feet it is 730 litres or 26 cubic feet.

If a welding installation should deliver 1400 litres or 50 cubic feet of acetylene per hour, a pipe of $\frac{5}{8}$ inch diameter, which is sufficient for a length of 80 feet, should be increased to $\frac{11}{16}$ inch for 165 feet, and to $\frac{13}{16}$ inch for 260 feet.

We give these examples to make clear that the diameter of the piping should not only depend upon the maximum delivery that may be required by an installation, but also on the length of the piping.

Here is a table that has been calculated, and enables one to find the necessary diameter of piping according to the length and the maximum hourly delivery. As the figures are obtained by theoretical calculation, in practice one should take into account unevenness of the pipes, leaky joints, etc., and should adopt a slightly greater diameter than that which corresponds to the immediate or future maximum consumption of the installation.

NUMBER OF LITRES AND CUBIC FEET OF ACETYLENE FLOWING PER HOUR IN A GIVEN DIAMETER AND LENGTH OF PIPING FOR A LOSS OF 0·4 INCH OF WATER PRESSURE.

Length of Piping in Feet.	Diameter of Piping in Inches.															
	$\frac{13}{32}$		$\frac{1}{2}$		$\frac{5}{8}$		$\frac{23}{32}$		$\frac{25}{32}$		1		$1\frac{3}{16}$		$1\frac{3}{8}$	
	litrs.	cub. ft.	litrs.	cub. ft.	litrs.	cub. ft.	litrs.	cub. ft.	litrs.	cub. ft.	litrs.	cub. ft.	litrs.	cub ft.	litrs.	cub. ft.
35	780	27·6	1500	53	2350	84	3140	111	4300	152	..	..	..	..	..	..
50	580	20·5	1140	40	1910	67	2590	92	3360	119	..	..	..	..	..	..
65	520	18·4	980	35	1650	58	2240	79	2900	103	5060	179	..	..	..	..
80	460	16·3	880	31	1480	52	1930	68	2580	91	4540	160	..	..	..	..
100	420	14·8	800	28	1350	48	1830	65	2360	83	4120	146	7060	250	..	..
130	360	12·7	700	25	1170	41	1580	56	2060	73	3580	126	6180	218	..	..
165	320	11·3	620	22	1040	37	1420	50	1820	64	3180	112	5460	193	7420	262
200	300	10·6	580	20	950	34	1300	46	1680	59	2940	104	5010	177	6810	240
230	280	9·9	520	18	880	31	1190	41	1540	55	2680	95	4600	102	6270	222
260	260	9·2	500	17·5	820	29	1110	39	1440	51	2540	90	4340	153	5680	201
295	240	8·5	460	16·4	770	27	1050	37	1360	48	2380	84	4060	143	5530	195
330	220	7·8	440	15·5	730	26	1000	35	1280	45	2260	80	3560	125	5245	185

The unions, joints, or cocks should have an area of cross-section equal or very little less than that of the piping; this from the generator to the safety valve, a detail with which we will deal presently. Needless to say, a piping of appropriate diameter becomes useless if the gas is throttled at one or more points.

In the majority of workshops using autogenous welding, the acetylene piping consists of iron tubes joined with unions, fixed to a wall or suspended. It is advisable to use *galvanised tubes*, because in the previous case the gas always being a little moist forms oxide of iron, which comes off in a powder and may accumulate in certain parts.

Our advice is that where the piping follows walls and there is no fear of crushing, the use of lead piping is preferable, because oxidation need not be feared, it is less subject to leaks, new branches can be made without difficulty, and in case of removal, due to increase of welding, for example, the metal practically preserves its value.

We admit, however, that in many cases the use of iron tubes, being more rigid and not affected by shocks, offers many advantages over lead.

Tubes of red copper are strictly prohibited, especially if the acetylene has not been purified, because it can form acetylide of copper, which is spontaneously explosible. The regulations forbid it. Brass is not subject to the same disadvantage, but it is useless to use this metal other than for cocks or unions for the piping.

The cocks should be carefully made. For large piping, one may advantageously use cast iron for the cocks.

The piping should be absolutely gas-tight, and should be tested after erecting, then verified from time to time. *The use of a flame in searching for leaks is dangerous*; in the absence of a compression pump for searching by the hissing, the odour or the use of soap and water should be depended upon.

SAFETY VALVES.

Mixtures of oxygen and combustible gases being in a high degree explosive, it is indispensable that all precautions should be taken to prevent their formation, especially when their inflammation is produced very easily, even by the propagation of the flame through wire gauze, small orifices, etc.

When acetylene is used under a much lower pressure than the oxygen, which is the case in all installations comprising an acetylene generator, the oxygen can return in the acetylene tubes and piping, and so mix with this latter gas, even to the generator. This is the case especially when there is a total or partial obstruction of the nozzle of the blowpipe or following a wrong manœuvre.

It is therefore indispensable to place in the acetylene piping, before taking the flexible tubes to the blowpipe, a perfect arrangement capable of immediately arresting any return of the oxygen in the acetylene piping.

To put it another way:—The function of the safety valve is to direct any oxygen which returns in the direction of the acetylene into the open air, and to prevent its flowing further into the piping of this gas. It is not a question of avoiding the return of the flame, but to prevent the formation of a mixture of the two gases, explosible by the return of the flame, or any other cause.

The efficacy of such an apparatus should be absolute, and one should rigorously reject all arrangements based on the movement of a valve which obstructs the drawing of the acetylene when the pressure is reversed. Not only may such an arrangement not work, but its tightness is uncertain, even when, by a mechanical artifice, the oxygen may be discharged into the open.

One should therefore use exclusively the hydraulic safety valve, in which from a layer of water emerge two tubes, one for the entry of the gas, the other open to the exterior, placed at different heights, constituting an absolute barrier to all return of the oxygen in the acetylene piping, without any possibility whatever of failure.

All other arrangements which are not based on this principle should be rejected.

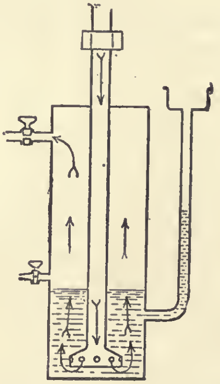


Fig. 63.—Hydraulic safety valve during the normal working of the blowpipe.

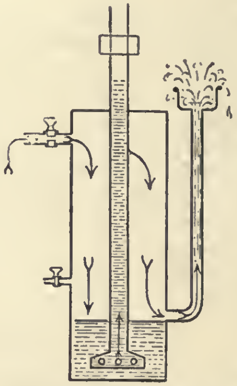


Fig. 64.—The hydraulic valve at the moment of the return of the oxygen.

The essential method of working is for the acetylene to bubble through a small height of water, but nevertheless sufficient for covering the tube leading to the exterior, this being between the surface of the water and the level of the escaping acetylene. If there is a return of oxygen, the pressure exerted on the surface of the water makes the liquid rise in the tube open to the air, forces it, if necessary, into the exterior, in such a way that this same tube eventually discharges the oxygen, the acetylene orifice meanwhile being protected by a seal of water.

The principle is not all that is required. It is further necessary that the construction should have been studied, and, in practice, one meets few hydraulic valves established under normal conditions of safety and good working.

It is necessary, first of all, to avoid too large a gas capacity in the valve, because, in case of the return of the oxygen and subsequent ignition, the explosion may be violent enough to break the valve and its parts. On the other hand, the diameter of the body should be sufficient so that the level of the water should remain fairly constant and the height large enough to avoid carrying drops of water to the outlet of the acetylene and so on to the blowpipe.

The tube leading the acetylene into the hydraulic valve should be of suitable cross-section for the maximum delivery of the blowpipe so as to avoid all loss of pressure. A tube whose diameter is too small provokes, on using a large blowpipe, a depression in the valve which *sometimes produces a suction of air through the open tube.* In ordinary welding places the tube should have a minimum diameter of $\frac{1}{2}$ to $\frac{5}{8}$ inch.

The bottom of the tube leading the acetylene to the water in the valve should, where possible, have a larger cross-section, and be notched or pierced with small holes in order to avoid the pulsation of the gas by the ascension of large bubbles.

The height of water between the acetylene exit holes and the surface of the liquid given by the level cock should be sufficient to allow the placing of the tube leading to the atmosphere without it being uncovered if the water level should be slightly lowered, and without the exit holes being uncovered in the event of the return of the oxygen, all this taking into account the differences of level which may follow the rising of the water, under the effect of pressure, in the tube in which the gas arrives or in that open to the atmosphere.

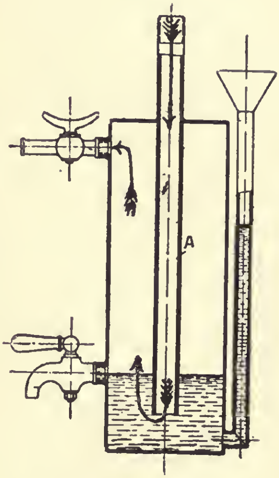


Fig. 65.—Hydraulic valve actually made, offering no safety, but, on the contrary, dangerous.

Nevertheless, one should avoid making the acetylene go through too great a height of water, so as to save, as much as possible, the pressure. A layer of $1\frac{3}{4}$ to 2 inches should be sufficient.

The tube leading to the outside should be placed half-way between the level of the water as fixed by the cock and the orifice or the holes from which the acetylene bubbles. It should be arranged in such a manner that the bubbles of gas passing through the water should not enter it. The cross-section should be as small as possible to avoid the lowering in the valve under the pressure of the acetylene, but large enough to allow for the rapid discharge of the water, or gas, in case of the return of the oxygen. A diameter of $\frac{3}{8}$ inch should be sufficient in ordinary cases.

The height of this outside tube depends essentially on the pressure of the acetylene, since the water rises in this tube as the pressure of the gas is increased. The height should be related to the change of level of the water in the valve, and should therefore be greater than that of a column of water corresponding to the greatest possible pressure that may be given by the acetylene generator.

Hydraulic valves are usually made for acetylene pressures varying from 4 to 5 inches of water, and the outside tube always has a height of 8 to 12 inches. For higher pressures it is necessary to increase this height, and to modify the valve in such a manner that the rising of the water in the tube should not lower too much the level in the valve.

The outside tube terminates in a chamber or funnel which serves for filling the valve with water. This is covered by a lid, which prevents the projection of water into the open in case of return.

The valves should be made of plate or strong tubes. Where possible, the bottom should be jointed and not welded, so that in case of ignition after the return of the oxygen, the deflagration, if very strong, breaks the joint.

We reproduce, quarter size, a hydraulic valve designed and experimented with by the *Union de la Soudure Autogène*, which fulfils all the necessary qualifications of technique and practice. The principle of the hydraulic valve, as in the one shown, is public property.

A good hydraulic valve does not get out of order. It is only necessary to verify the level of the water each day by means of the cock for this purpose. It is preferable that this operation should be done with the valve under working pressure, that is, with the acetylene arrival tube open.

It is advisable from time to time to empty the water, which gets dirty and contains sediment capable of obstructing, more or less, the orifices for exit of the gas. The bottom, joined simply and hermetically sealed, makes this operation very easy, and enables one to examine at the same time the various details and see if these are in a good condition.

In order to avoid badly designed or badly constructed valves, so frequently met in practice, one should see that the safety arrangements satisfy the conditions we have just given.

OXYGEN REDUCING VALVES.

In a special chapter we have studied oxygen and its storage in steel cylinders up to a pressure of 120 atmospheres per square inch. On the other hand, we see that the blowpipes receive the gas under a much lower pressure, generally from 14 to 28 lbs. per square inch. The pressure of the oxygen must therefore be reduced and, at the same time, regulated in such a manner that it remains automatically constant no matter what the pressure may be in the oxygen cylinder. This result is obtained by using special apparatus adapted to the oxygen cylinders, called *reducing valves* or *pressure regulators*.

It is *absolutely necessary* to use an oxygen reducing valve in autogenous welding or the cutting of metals. In fact it is important

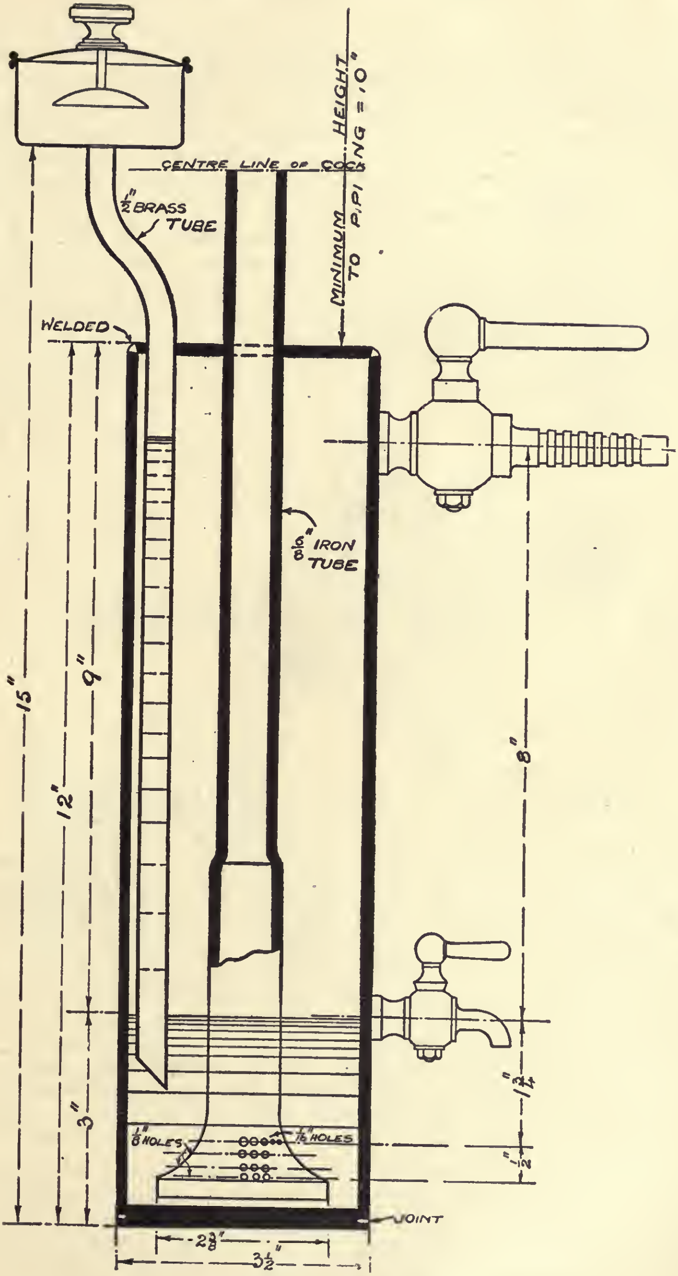


Fig. 66.—*Union de la Soudure Autogène* design of hydraulic valve.

(1) to use the oxygen under a pressure *automatically regulated*; (2) to know at any moment the value of this pressure. One should therefore reject all arrangements, designed for economical reasons or fraud, for measuring the pressure of the oxygen used in certain types of blowpipes, and especially those that use a simple micrometer screw, that is to say, a pointed valve. These instruments, which are sold to replace reducing valves (by bad or incompetent firms), give, in autogenous welding, deplorable results.

Reducing valves are very delicate instruments, but with correct ideas and care it is easy to keep them in perfect working condition.

We will not enter here into a detailed description because there exists a number of types which differ considerably in their construction but work on the same principle, which is as follows:—

The oxygen arrives from the cylinder by a straight passage, passes through a filter destined to retain any dust, transmits its pressure to a gauge placed in connection with the passage and which indicates the pressure in the cylinder at any moment; it is then directed into the principal part of the instrument, which is the automatic reducer.

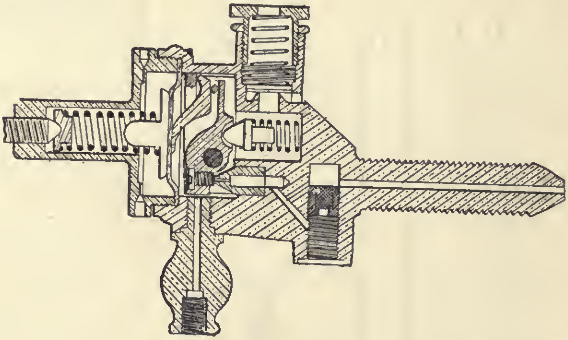


Fig. 67.—Section showing essential details of a reducing valve.

The reducing valve comprises a mechanism for opening and closing the gas passage by an ebonite seating controlled by a lever which, in turn, is controlled by a diaphragm which the pressure more or less deflects. A spring arrangement regulated from the exterior in a sense opposes the deflection of the diaphragm and serves to regulate the pressure to that required, a pressure which is indicated by a second gauge, called the *reducing gauge*, and which the welder consults for regulating the blowpipe.

The following is a description of the working of the apparatus: the gas presses against the elastic diaphragm until it reaches a determined pressure; the diaphragm is then deflected and moves the lever which controls the passage of the gas; if the pressure tends to fall the diaphragm ceases to move the lever, the orifice is opened progressively, and so on. In this manner an equilibrium is obtained which gives a constant pressure no matter what the delivery or what the pressure of the gas in the cylinder. The regulation of the valve is, as we have explained, controlled from the exterior by pressing on the diaphragm in an opposite direction to that of the gas, in such a manner that one obtains oxygen under any desired pressure.

A valve communicating with the atmosphere is connected to the reducing chamber, the function of which is to blow off the oxygen in case of bad working of the ebonite valve or other derangement by which the pressure in the reducing valve becomes too high.

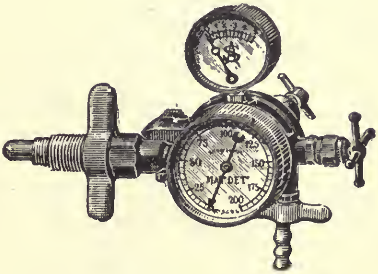


Fig. 68.—Reducing valve.

The reducing valves are fixed to the oxygen cylinders by means of a union screwed into the cylinder valve opening. These screws are standardised. Tightness is assured by simply tightening the ground faces. The practical operation is as follows :—

(1) Screw as far back as possible the movable part of the union so as to leave free the part which fits into the valve socket of the cylinder.

(2) Place the reducing valve as shown in fig. 69, and enter the union into the valve socket; screw the union until tightness is obtained.

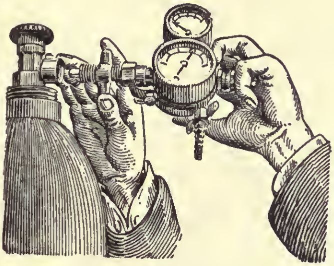


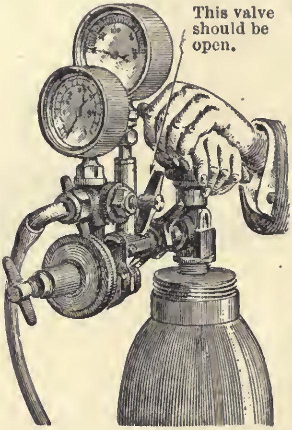
Fig. 69.—Fixing the reducing valve on the oxygen cylinder.

(3) Unscrew very slightly so as to be able to slope the faces of the gauges a little forward or on one side, according to the type, then fasten altogether with the hand, and lastly, complete the fastening by screwing with the aid of the reducing valve taken in both hands, but without using more force than is necessary. This latter operation places the gauges where they can be seen perfectly.

If it is not perfectly gas-tight one may further tighten it with the union or the reducing valve, but too much force must not be used.

As we have already mentioned in connection with the cylinder valves that it is dangerous to introduce oil or grease into the unions or details of reducing valves, welders should rigorously abstain from such a practice, because an ignition followed by an explosion in the reducing chamber and gauges may result.

The oxygen should always be opened as *slowly as possible* on to the reducing valve, which should have the regulating screw entirely *free* and the outlet for the gas *open*. In this manner, heating by quick compression is practically avoided. These instructions are important for the safety of the welder, and the preservation of the apparatus in a good working state, because sudden gusts of pressure on the diaphragm of the reducer produces derangement and quickly puts it out of order.



This valve should be open.

This screw should be quite free.

Fig. 70.—The valve on the oxygen cylinder should be opened very slowly.

After opening the cylinder it is only necessary to progressively screw up the regulating screw to obtain the required pressure; it is advisable at this moment to deliver to the blowpipe. The departure cock on the reducing valve should be opened wide, and this should not be used for regulating the gas to the blowpipe.

Thus treated and cared for, reducing valves do not suffer any great risk of derangement. One should always avoid, except when familiar with the repairing of them, taking them to pieces. If they are working badly, they should be returned to the makers.

FLEXIBLE TUBES—CONNECTORS FOR TUBES.

For management of the blowpipe the acetylene and oxygen are brought to it by *flexible tubes*, one coming from the hydraulic valve (or cylinder of dissolved acetylene when the gas is used in this form) and the other from the oxygen reducing valve.

These tubes can be of varying length according to the work to be done, that is, according to the degree of movement the welder is obliged to make. For ordinary work on the bench a length of 8 to 10 feet is sufficient, but this is a minimum, in order that the welder shall not be hindered in his movements.

The flexible tubes are usually made of rubber covered with canvas; they should be strong enough to resist the highest pressure used, and not easily deteriorated by friction, knocks, burns, etc.

In some places the regulations require that the tubes should be protected by an incombustible covering, and the tendency has been to use flexible metallic tubes or spiral tubes, sheathed with metal wire, etc. These types of flexible tubes are not to be recommended, because they deteriorate very easily, especially with sudden bends, or burns, such injuries not being easily noticed, which increases the danger.

In the interests of safety, we advise, in spite of any regulations, which are usually very lax, the use of good rubber tubing known as three-ply.

The use of flexible tubes of different diameters and different colours according to whether it brings oxygen or acetylene has been recommended. The idea seems excellent, but in practice it does not supply a real need, whilst it complicates the installation. It is much better to have one kind of rubber, so that the tubes can be interchanged or a reserve can be adapted to the connectors for the oxygen or acetylene.

This tends to the standardisation of the connectors for the gases on the blowpipe, on the hydraulic valve, and on the reducing valves. This standardisation is important, because the details which go to make a welding installation are frequently not of the same design, and when one comes to replace details with others possessing different size connectors, it becomes very inconvenient and sometimes impossible to make a joint.

The *Union de la Soudure Autogène* have taken the initiative in this reform, and determined the type (form and size) of connectors for the gases on the blowpipe, reducing valves, and hydraulic valves. Here is the decision adopted:—

Fig. 71.—Full size detail of standard connector, *Union de la Soudure Autogène.*

(*a*) The connector for the rubber tube on the blowpipe, hydraulic valve, and reducing valves should be standardised both in form and dimensions, and should be the same for the acetylene and for the oxygen.

(*b*) The forms and dimensions agreed upon are those given by the drawing (fig. 71), which represents the type adopted, actual size.

(*c*) The interchangeability of the connector for the rubber and the thread of its union remain optional.

This standardisation of connectors has been adopted by the majority of manufacturers of blowpipes and reducing valves, and one should adopt them especially for welding installations using 2000 to 2500 litres of acetylene per hour. The *Union de la Soudure Autogène* has not yet fixed the bore of the standardised connector; it should be as large as possible, depending in a degree on the exterior dimensions.

The flexible tubes should have a cross-section appropriate to the standard connector, so that it can be simply pushed on without fear of splitting. In case the dimensions do not agree, and to prevent leakage, tie up with twine and not wire. Certain firms supply arrangements which constitute a complete fastening attached to the rubber, which is covered by a wire network, and which is attached by means of a wing-nut.

The flexible tubes do not require any particular care beyond the prevention of burning, tearing, wear by friction, etc.; there should be no chafing in the interior, especially where it fits on the connectors, as the particles which become detached can obstruct the passages and organs of the blowpipe. *Never grease the rubber or the connectors for the gases in order to make them fit each other easily; if necessary, they should be moistened with water.*

TABLES FOR WELDING.

Whenever the work to be welded is not of too large a volume or too difficult to manipulate, the operation is best carried out on a *welding table.*

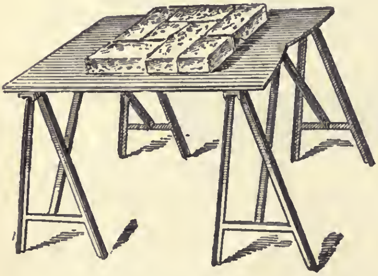


Fig. 72.—Table for welding small articles.

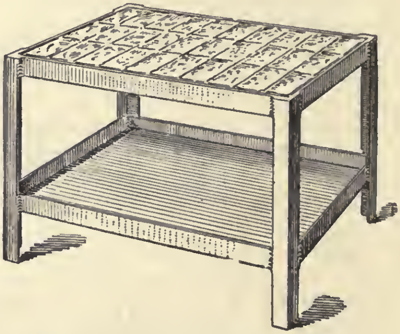


Fig. 73.—Welding table of angle iron entirely constructed with the blowpipe.

The tables for welding are in form and size adapted to the work to be done. They should be made entirely of metal, except the covering, which should be of fire-bricks simply placed one against the other.

Fig. 74.—Detail of execution of frames.

The simplest arrangement consists in placing on two iron trestles plates of $\frac{3}{16}$ inch thickness and covering them with fire-bricks.

The standard type of welding table is made in one or two hours by autogenous welding. It is both easy and interesting to make, and can be done by a beginner. It makes him familiar with the phenomena of expansion and deformation of pieces in welding.

One uses stock size of angle iron 2¼ inches × 2¼ inches × ¼ inch. First cut (with the blowpipe, for example) 4 lengths of 2¼ feet for the legs of the table, then 4 lengths of 3¼ feet for the long side, and

4 lengths of $2\frac{1}{4}$ to $2\frac{1}{2}$ feet for the short side, the tables generally being rectangular.

The joining of the 12 pieces of angle iron by autogenous welding is shown in the figures reproduced. One first proceeds to weld the two frames, which must be cut at the ends to angles of 45° in order to fit the pieces together; next join the two frames to the legs, one at the top and the other two-thirds down, welding the first on the top and sides and the second simply on the sides. Next fix a plate in each of the two frames, covering the top one with fire-bricks simply placed next to each other. The lower table serves for keeping tools, welding rod, etc.

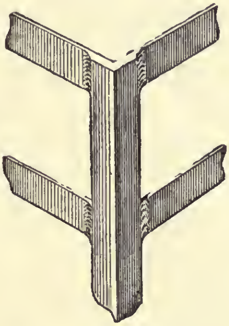


Fig. 75.—Welding of the frames to the legs.

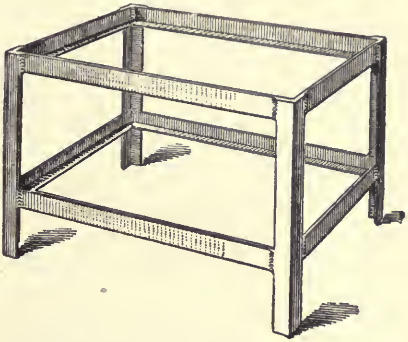


Fig. 76.—Table entirely welded.

It should be understood that the dimensions given can be varied according to the requirements of the welding shop; thus the tables can be higher or lower, much larger and much longer.

Other types can be studied or made which suit the particular work of a welder much better. Thus there are tables in which the top portion can be raised as required, inclined or turned circularly, movements extremely useful for the execution of certain welds.

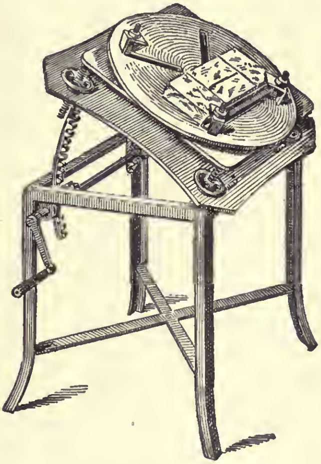


Fig. 77.—Welding table with adjustable top.

Tables can also be designed which contain a warming oven for preheating parts to be welded, made so as to take to pieces easily, and used for the repair of small pieces of cast iron, bronze, alloys of aluminium and analogous work which requires preliminary heating and slow cooling.

FURNACES FOR PREHEATING AND ANNEALING. HEATING AGENTS.

We shall see later on that for the repair of articles in cast iron, bronze, and alloys of aluminium, it is very often indispensable to have, previous to welding, a preheating of the article, followed, after welding, by a very slow cooling, in order to avoid the effects of expansion and contraction.

Further, the annealing after welding tends to remove *internal strains*, and it is always advisable to do this where there is no special difficulty to be overcome.

All welding workshops, and especially those concerned with the repair of articles in cast iron or castings of aluminium, are incomplete without an oven for the preheating and slow cooling of the articles, also, where necessary, the annealing of the welds.

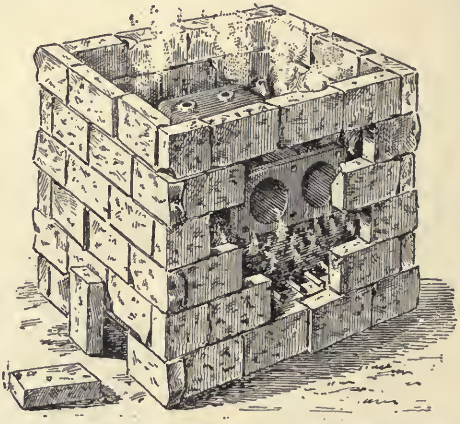


Fig. 78.—Preheating oven made as required for the repair of cast-iron articles.

In the absence of a special furnace, one always has at his disposal the elements for making one (fig. 78).

Certainly the question is complicated by the different sizes of the articles, and what is quite suitable in one case is either too large or too small in another.

Nevertheless, in those workshops which take orders for the repair of articles of the same kind—cylinders and gear-cases of automobiles, small articles of cast iron, etc.—the installation of a permanent oven has great advantages from the point of view of economy of fuel and the regularity of the preheating or cooling after welding.

We give, as an example, a diagram of an oven designed for the repair of automobile cylinders and gear-cases. The hinged cover is optional, but is useful for ensuring the slow cooling of castings.

For the ovens of which we have spoken the heating agent used is wood charcoal or wood charcoal mixed with coke.

These fuels have many disadvantages: their heat is generally badly utilised and given very irregularly to the articles to be repaired; further, the residue of combustion can be deposited in the cracks or bevel; and lastly, the articles being generally welded whilst in the oven, the heat and smoke inconvenience the welders.

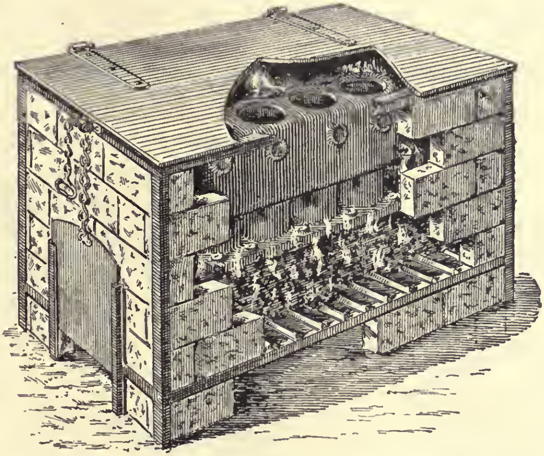


Fig. 79.—Workshop oven for the repairing and welding of articles of cast iron and aluminium.

It is only logical to inquire what other heating agents can advantageously replace charcoal or coke. We know that powerful lamps using benzol, petrol, or other heavy oils can be satisfactorily used as heating agents for the articles in the workshops of autogenous welding. The expense of the heating agent, when well designed for utilising the heat, should certainly be no higher than when using charcoal.

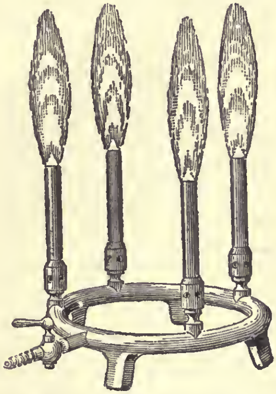


Fig. 80.—Group of acetylene bunsens for preheating.

Also, it very frequently happens that articles do not require to be preheated in an oven but have to be heated to a high temperature in the vicinity of the weld; and further, it is often useful after welding to anneal the line of welding. The lamps and arrangements for benzol, petrol, or heavy oils of which we have just spoken can be advantageously used in such cases. Certainly, one can carry out these operations with the blowpipe when it is a question of bringing it to a red heat and not to a melting heat. It is not economical to use the bought oxygen when one can obtain sufficient from the air to attain the temperature required. Advantage can be taken of using large *bunsens* of acetylene, which are sold for industrial heating, and which are arranged according to the requirements of the welder.

GOGGLES, BLOWPIPE LIGHTING, LIGHTING, ACCESSORIES.

Metals in fusion under the action of the blowpipe emit luminous rays, which considerably fatigue the sight of the welder and prevent him following the course of the work. It is important therefore for him to wear special glasses, smoked or coloured, which dims the brightness of the incandescent parts, protects the sight, and permits the following of the work. This precaution is absolutely indispensable. *Any welder who operates without glasses to shield the eyes is courting serious eye trouble.*

Fig. 81.—Glasses for welders, simple pattern.

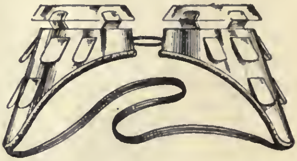


Fig. 82.—Goggles for welders, with air-holes at the sides.

The glasses also serve to protect the eyes from the projection of particles of oxide spurting out from the weld. One can see the incrustation of such particles on the front of the glasses.

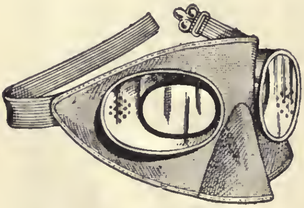


Fig. 83.—Goggles for welders, with mask.

It is difficult to indicate the exact colour of the glasses to be adopted, as this depends on the sight of the welder and the nature of the welds. The use of very large blowpipes obviously requires very dark glasses; the same applies to certain fluxes, which give a strong incandescence. The glass must be sufficiently dark so that the eyes are not fatigued, but not enough to strain the sight. Everyone must choose for himself the different tints.

The settings also differ. There are a number of different patterns to choose from, according to whether the glass is more or less distant from the eyes, the circulation of air round the eyes, etc.

For certain special work goggles have been designed to protect the neighbourhood of the eyes and the nose by means of a mask.

. . . .

A flame is necessary at the side of the welding place to light the blowpipe. A small flame of acetylene fixed, if possible, to the wall is generally used. Burners (jet or lighting) which consume 4 to 5 litres per hour are used. These burners have the advantage over lamps, candles, etc., in not being extinguished by the blowpipe.

The burner is generally fixed to a bracket which is screwed into the acetylene piping previous to it entering the hydraulic valve. The burner should be at least 8 inches in front, and not less than 20 inches from the hydraulic valve and at about the height of the welder.

. . . .

Acetylene constitutes a perfect method of lighting, especially for workshops. One profits by the generating plant and piping to obtain the perfect lighting of welding workshops. According to the case, one uses wall brackets, swivel brackets, etc., using Manchester or impinging burners consuming 25, 30 or 35 litres per hour.

Fig. 84.—
Jet burner.

Fig. 85.—Fish-tail burner,
Manchester type.

Fig. 86.—Fish-tail burner,
impinging type.

The piping and details required are exactly the same as for coal gas.

In cases of general lighting, incandescent burners are used where there is not too much risk of the mantles being deteriorated by shocks, dust, etc.

Those who use autogenous welding should not ignore the fact that acetylene is good for lighting, superior in many cases to coal gas, electricity, and in many cases more economical.

There are now 40,000 installations established in France exclusively for lighting, and consisting of 5 to 100 burners, and some even more.

. . . .

Autogenous welding installations also contain certain accessories used by the welder. These accessories vary according to the work to be done. Such as: the tongs for moving the warm articles, wedges, keys, hammers and mallets, clamps, etc.; also vices, anvil and accompanying tools; water vessel, waste, etc.

For welds of great thickness, and for welding articles in or on the ovens, the welder should have gloves and a table covered with asbestos; also plates of the same material to protect him from the radiant heat.

Lastly, there is the rack for the blowpipes and a shelf for the fluxes, welding rods, spare parts, etc.

Also a card containing advice and practical hints should be placed by the side of every welding place.

CHAPTER VIII.

WORKING OF WELDING INSTALLATIONS.

We have studied successively the gases used for obtaining autogenous welds and all the arrangements and apparatus forming an installation. The installation is complete and ready for use; how is it worked?

We will suppose it is a question of a low pressure acetylene installation, since they are by far the more numerous. The installations of medium pressure can be treated almost the same, and the use of dissolved acetylene only differs by replacing the generator with a cylinder of gas, which makes use of a special reducing valve in place of the hydraulic valve.

ERECTING AND TESTING THE INSTALLATION.

The acetylene generator is charged and ready to work. If it has just been erected or cleaned, the air should be driven out until a burner fixed on the installation gives a normal light.

The piping is charged with gas right up to the cock opening into the hydraulic valve, and shows no leakage. The oxygen cylinder, with the water which it might contain removed, and the valve, with all the dust removed, are placed in position. The reducing valve is placed in position as we have explained. There is no leakage; all is well.

The blowpipe of delivery appropriate to the work to be welded is chosen, and connected by means of the flexible tubes to the reducing valve on the one hand, and to the hydraulic valve on the other.

Do not confuse the tubes on the blowpipe. That which corresponds to the acetylene generally differs by having a cock which serves to regulate the gas.

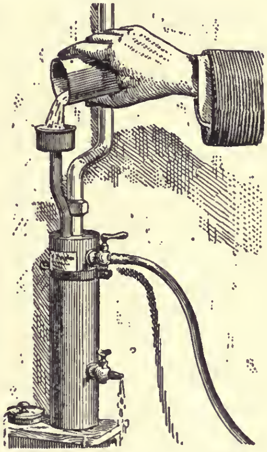


Fig. 87.—Testing of the water level in the hydraulic valve.

The adjustment of the flexible tubes being completed, it only remains to test if the hydraulic valve contains the quantity of water necessary for carrying out its function in case of necessity.

The testing of the water level in the hydraulic valve should be done at each welding bench, and at least once a day.

Here is the method of testing:—Open the gas cock leading to the hydraulic valve in order to put it under working pressure, then open the cock to gauge the level of the water. If any gas escapes, the water level is too low, and it is necessary to add more through the open tube; if only water escapes, then it is in excess, and one allows it to escape until the gas bubbles of acetylene appear. The following method is more positive and more sure:—(1) Pour water into the open tube so that it is in excess; (2)-charge the valve with gas; (3) take off the excess water by the gauge cock until the appearance of a stream of gases. The hydraulic valve being thus prepared to carry out its function, the installation is in starting order.

STARTING THE INSTALLATION.

Here is the method of working:—

(1) Open *very slowly*, that is, do not unscrew sharply, the valve of the oxygen cylinder; the regulator screw on the reducing valve being entirely free, and the outlet valve open, as we have previously explained (fig. 70).

(2) Open fully the acetylene delivery cock on the hydraulic valve.

(3) Open fully the acetylene delivery cock on the blowpipe.

(4) Light the blowpipe and at the same time screw up the regulator on the reducing valve.

(5) Continue to screw up the regulator until the reduced pressure, as shown on the gauge, corresponds to the normal working of the blowpipe, and which should be known.

At this moment the flame, which was at first sooty, still contains an excess of acetylene, which is shown by a streaky light about its centre, in the extension of the exit nozzle.[1] There still remains the *regulation of the flame*, an operation which we will describe.

Let us first remark that experienced welders do not always proceed in the way we have indicated. Some regulate the reducing valve first, others first proceed to open the oxygen, then the acetylene, and afterwards light the blowpipe. There is nothing against these methods when the operator is very experienced and knows very thoroughly the details of the welding installation. As a general rule, it is better to work as we have indicated, free to give the various movements almost simultaneously.

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[1] The variable delivery blowpipes in which the orifice of the oxygen ejector is controlled by a needle valve (Picard or Unic-Simplex blowpipes, for example) are managed slightly differently; the regulating screw of the reducing valve is *entirely closed*, the reducing valve is then set to the pressure required, next light the acetylene, open the needle regulator progressively so as to obtain a slight excess of acetylene. Then go slightly backwards to obtain the normal flame.

REGULATION OF THE FLAME.

The flame of every blowpipe started as we have described shows at first an excess of acetylene. All blowpipes which show otherwise with normal pressure of oxygen and the acetylene fully open are deranged or obstructed, and should not be used in this state unless the defect is one of obstruction either in the acetylene piping or the hydraulic valve.

We have therefore now a flame called *carbonising*, that is to say, with too much acetylene.

In order to render it neutral, that is normal, we partially close the acetylene cock on the blowpipe or that at the exit of the hydraulic valve, but preferably by the former.

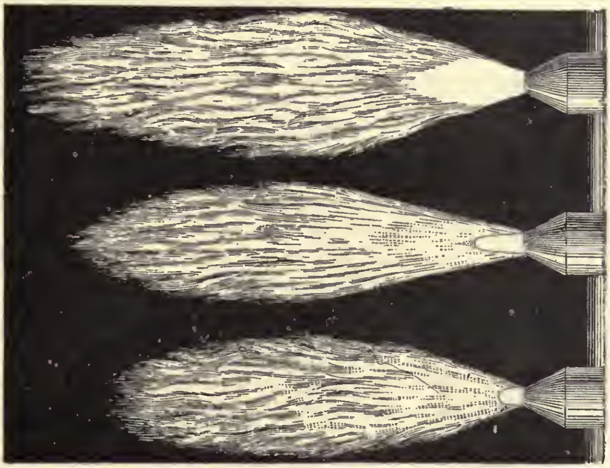

Fig. 88.—Regulation of the flame.
Top figure, excess of acetylene ; middle figure, normal flame ;
lower figure, excess of oxygen.

The streaky light disappears by degrees, and its place is taken by a white halo, which is extinguished in turn as the white jet becomes more and more pronounced. This is the normal flame.

If the acetylene is further reduced, the white jet diminishes in volume, and the flame becomes *oxidising*.

The flame of the blowpipe can therefore have an excess of acetylene or an excess of oxygen, and one must carefully avoid each of these in order to obtain good welds and economy in their execution.

The normal flame is obtained, as we have seen, by reducing little by little the excess of acetylene which is manifest at the starting.[1]

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[1] In those blowpipes regulated by a needle valve in the oxygen ejector the regulation of the flame is done by the control of the oxygen on the blowpipe, and not by the acetylene cocks, which must always be opened wide.

The reduction must be stopped the moment all the white halo has disappeared.

The flame is then characterised by a small violet-whitish jet of very clear outline. Its base is at the end of the nozzle, and for medium delivery blowpipes its length is only $\frac{1}{4}$ inch to $\frac{1}{2}$ inch. It is surrounded by a large bluish flame, in which the second phase of the combustion takes place. At the extremity of the white jet we obtain the highest temperature of the flame.

The regulation of the flame is in a way the regulation of this white jet. The white jet should be as large as possible, providing that its outline is very sharp, and that there is no whitish mantle round it. This precise point must be carefully sought after, readjusting several times if necessary.

MANAGEMENT OF THE BLOWPIPE.

It is very important that the flame should remain normal, that is, normally regulated. Now the flowing of the gas in almost all blowpipes for low pressure acetylene is modified in proportion to its heating. Thus the acetylene expands, arrives in a less quantity, and the flame becomes little by little oxidising.

It is to obviate this inconvenience that certain welders start with a very slight excess of acetylene, a scarcely visible halo round the white jet, which soon disappears as the blowpipe gets heated.

It is better to operate with the flame normal and remedy the variation, according to the heating, after a few seconds. *The important point is to remember to do it.* Good regulation of the flame is obtained by two or three different adjustments.

In obtaining certain kinds of welds the blowpipe becomes too heated, and, in spite of all possible regulation of the flame, the working, especially with certain types, leaves much to be desired. One may remedy it by plunging into water. But, as we explained in Chapter VI., it is necessary that the flame be extinguished and the oxygen slightly open in such a manner that the flowing of the gas opposes the entrance of the water into the orifice of the nozzle. *On the other hand, the acetylene should always be closed in order to avoid the formation of an explosive mixture above the water, and the blowpipe should never be plunged in alight.*

Defective regulation, bad condition of the blowpipe, too much heating of the nozzle, irregularity of the flame, projection of sparks can sometimes *return the flame or tend to return the flame into the interior of the blowpipe.*

This is indicated by sharp crackings, which in the case of large blowpipes sometimes produce a very loud noise. In the majority of cases the flame becomes normal again after these manifestations of the striking back into the interior; but if the detonations are renewed, it is best to remedy it by cooling the blowpipe as we have explained, and cleaning the extremity of the nozzle. Certain welders find it convenient to increase the pressure of the oxygen; this will obviously prevent the return of the flame, *but this practice is to be condemned, and brings about irregular working of the blowpipe.*

Sometimes there is a veritable persistent return of the flame, that is, the gas burns in the interior of the mixing chamber. This manifestation is accompanied by a hissing noise, more or less piercing and very characteristic; whilst the normal flame disappears, its place being taken by one usually smaller, reddish, and without power, from which escape black fumes. The gases should be cut off immediately, because this burning considerably heats the interior of the blowpipe, encrusts it, and may destroy or deteriorate its essential details. Therefore, when any return of the flame is persisted in one should close the acetylene and oxygen by the cocks that are nearest and most easily manipulated.

Beginners should not be alarmed by the detonations and hissing on the return of the flame, because there is no danger. Experienced welders are content to cut off the acetylene by bending the flexible tube which brings the gas to the blowpipe; and as soon as the internal combustion has ceased, for want of the combustible, they release the passage, and relight the blowpipe by contact with the red-hot metal. All other instructions on the manipulation of blowpipes proceeding from these recommendations will be found in Chapter VI., "Maintenance of Blowpipes."

STOPPING THE INSTALLATION.

We have two cases to consider: (1) The temporary extinguishing of the blowpipe, for permitting the welder to examine the part of the work executed, the adjustment of the piece or the preparation of another weld; (2) stopping the installation for a longer period, as, for example, between the hours of work.

In the first case, it is useless to close the oxygen cylinder or to touch the regulating screw of the reducing valve. One closes the oxygen by the conical valve at the outlet of the reducing valve, and the acetylene by the cock on the blowpipe, or by that on the hydraulic valve. We prefer the latter method, because if the blowpipe is changed one is not exposed to a leakage of combustible gas on taking off the flexible tube.[1]

For a definite stopping, the blowpipe is first of all extinguished, then, immediately after, close the valve on the cylinder, then the admission cock to the hydraulic valve. This done, the cocks on the blowpipe are re-opened so as to drive off excess gas stored by the pressure in the various details; finally, the regulating screw of the reducing valve is set free.

Notice if the gauge giving the pressure of the gas in the cylinder indicates that the valve has been properly closed.

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[1] Some types of blowpipe have a cock controlling the two different passages by the same seating—oxygen and acetylene. From certain points of view this arrangement is perhaps open to criticism; it is none the less very convenient for temporary stopping.

GENERAL ADVICE—SAFETY. MAINTENANCE.

The welder should always use a blowpipe (or a head-piece in the case of blowpipes of variable delivery) corresponding to the kind and thickness of the metal to be welded.

Increasing the power of the blowpipe by increasing the pressure of the oxygen is not good practice, and would not be indulged in by a conscientious welder.

Each type of blowpipe and each number of the same type corresponds for normal working to a pressure which cannot be increased without increasing the proportion of oxygen and oxidising the welds. This pressure is generally given by the makers in their catalogues; it should be summarised in a table fixed near the welding benches. Endeavour to lower the working pressure of oxygen indicated, but never raise it.

The welder should not blindly depend on the reading of the reducing gauge for obtaining the required pressure of oxygen; sometimes the pointer is in advance or behind; in case of doubt it is necessary to make a comparison with another reducing valve using the same blowpipe.

An experienced welder may not consult the reducing gauge for obtaining the required pressure of oxygen, but regulates by the flame, keeping the pressure as low as possible for a normal white jet, without too great a rigidity, and without any return to the interior.

An autogenous welding installation is perfectly safe, and should not cause any accident if it is installed, erected, and worked according to the conditions we have indicated. All ignition by leakage, blunders, or faulty manipulation produce no serious danger if one immediately closes the valve of the oxygen cylinder and the cock for the admission of the acetylene to the welding place. *Beware of oxygen leakages*, apparently of no consequence, which can provoke a rapid fire, for example, of the clothes, by a simple spark coming from the weld.

The advice on maintenance is that which we have already given for the different apparatus and details constituting a welding installation.

CHAPTER IX.

PROPERTIES OF METALS CONSIDERED FROM THE AUTOGENOUS WELDING POINT OF VIEW.

Although this book is meant principally for practical men, it is indispensable that they should understand and study the physical and chemical phenomena produced more or less in a metal in fusion under the action of the blowpipe, and which can leave such effects that the strength of the joint is seriously compromised.

We will treat the subject as simply and briefly as possible, and we believe it is essential that the welder himself should study it with us, digest it, and take it into account in the practice of his work. To understand the bad effects enables one to avoid them, or at least to provide a remedy.

We will now pass in review the different phenomena observed during the execution of welds without any attempt at classification.

MELTING-POINT.

One might say that autogenous welding consists in making the metals pass from the solid state to the liquid state, and in the new solidification their intimate union. Bodies always melt at the same temperature, called the *melting-point*; it is necessary that the welder should know its value for the different metals and alloys which he may have to join. Between the melting-point of lead at 325° C. and of iron which melts in the neighbourhood of 1500° C. the great difference is well known, but the difference between the melting points of cast iron, mild steel, copper or brass, etc., should be equally well known by the practical welder.

Melting-Point of the Principal Metals and Alloys.

	° C.	° F.
Iron	1500	2730
Mild steel	1450 to 1500	2640 to 2730
Hard steel	1400	2550
Grey iron	1200	2190
White iron	1100	2010
Nickel	1400	2550
Silver	950	1740
Red copper	1050	1920
Brass	950	1740
Bronze	900	1650
Platinum	1775	3230
Aluminium	650	1200
Zinc	410	870
Lead	325	630

TOTAL HEAT OF FUSION.

Apart from the intensity of heat required for melting, it is necessary to take into account the *total heat of fusion*; that is to say, the quantity of heat in calories or British Thermal Units absorbed in bringing a certain quantity of the metal to a liquid state, and which is more or less great according to the metal. Nevertheless, for clearness and simplification, we will only deal with this property in the most typical cases.

EXPANSION—CONTRACTION.

Bodies expand more or less under the action of heat with a consequent increase of volume, and in the case of solid bodies an increase of their linear dimensions. On cooling, they return to their original volume and dimensions.

Metals are particularly sensible to this phenomena; in other words, their *coefficient of expansion* is high.

If the temperature of a metallic body is raised progressively throughout the mass, or is lowered in the same way, the phenomena of expansion generally has no bad effects, such as breaking, deformation, etc., since its action is uniform. This is not so when the heat is applied at one point or part of the body. The metal tries to expand at this place, and, since no force can stop it, it breaks or deforms the part which opposes it.

No force, we repeat, can stop the expansion; it is absolutely useless to oppose it by clamping the parts in a vice, for example, as we have seen done.

It is necessary to obviate these effects, and in autogenous welding a hundred devices are at the disposal of an experienced welder, such as allowing for free play in preparing the work, warming the whole piece, simultaneous heating of opposing parts, artificial breaking, and the sprinkling of cold water in parts to create a force of contraction to counterbalance that of expansion.

No definite advice can be given, as the method of treatment varies with each metal and each piece according to the shape and dimensions.

It is well for the welder to reflect on these phenomena before commencing the work, and to arrange for overcoming these troublesome effects. Very rarely do cases arise for which there is no solution.

The effects of expansion are more or less to be feared according to the metal. Those which possess the property of *elongation*, or in other terms are *slightly breakable*, are only deformed with effort, and in the majority of cases can be put right with a suitable hammering. Those which do not possess sufficient elongation break like glass when heated at only one point, and it is necessary to take all precautions.

These effects vary according to the shape of the pieces. If the expansion can take place in all directions there is generally nothing to fear; on the contrary, if it is imprisoned by angles, casings, rings, etc., it exercises its efforts at the point which stops it and may break the metal at this part.

The contraction on cooling produces the opposite strains, and brings about the same results; these are overcome by similar methods to those used in overcoming the effects of expansion. It is, however, well to note that the effects of contraction are generally localised in the vicinity of the weld.

We explain elsewhere, for each metal, the importance to be attached to the phenomena of expansion and contraction, and explain how to avoid their consequences.

CONDUCTIVITY.

Metals do not conduct heat equally; copper, iron, and lead, for example, are *conductors* of very different degrees.

The property of conductivity which is more or less great should be taken into account in welding materials. Not only will the loss of heat be more or less according to the metal welded, but, moreover, the phenomena of expansion and contraction, of which we have spoken, extends itself over a greater or less area, and more or less rapidly, with obviously different consequences; lastly, according to the conductivity the neighbourhood of the weld is subject to more or less change in the mechanical properties, produced in certain cases by the increase of temperature above a certain limit.

It follows, then, from these remarks that the welder must take into acccount the greater or less conductivity of the metals which he has to join; thus, for example, because of the great conductivity of red copper he will take for the same thickness of weld a blowpipe of the same power as for steel, although the melting-point is much lower, and the welding will not be properly commenced until the surrounding parts are at a red heat, so that the metal in fusion shall not be too rapidly solidified owing to the drawing off of heat by conductivity.

OXIDATION.

Oxide is the body obtained by combination of the metal with oxygen. This combination is always more rapid with increase of temperature.

During the execution of the weld the metal can become oxidised, either by contact with the oxygen contained in the air, or by the presence of an excess of oxygen in the flame. *This latter point is very important.* Notice elsewhere that the presence of free oxygen is not necessary for oxidation; water vapour, for example, which contains oxygen in combination, can produce the same effects as oxygen itself.

Those bodies which tend to give up their oxygen are called *oxidising agents*; on the contrary, those which tend to extract it from the metal are called *reducing agents.*

The oxide of the metal is, according to the case, lighter or heavier than the metal itself, and consequently it may float on the molten bath of the weld or remain in the interior; the importance of this question in autogenous welding is obvious.

Again, the melting-point of the oxide can be lower or higher than that of the metal, which makes its elimination more or less easy during the execution of the weld.

Lastly, certain metals when molten dissolve more or less of their oxide, which, after cooling, is partly separated from the mass and sometimes in the state of a true alloy.

In the autogenous welding of materials it is therefore necessary, first, to avoid as much as possible the formation of the oxide; second, to avoid imprisoning the oxide in the mass; third, in case of necessity to dissolve or separate the oxide formed by the aid of a *reducing agent* or an appropriate *flux.*

The study of oxidation is of the highest importance, since it is to a great extent this phenomenon which brings about bad welds.

ABSORPTION OF GASES: BLOWHOLES.

The molten metal under the action of the blowpipe solidifies very rapidly, since it is no longer submitted to the high temperature required for melting. This rapid solidification does not always allow the gases present to rise, and they become incorporated in the mass near the surface, the imprisoned bubbles producing what are known as *blowholes.*

In other cases metals are inclined to absorb the gas in solution, and give it up on cooling, that is to say, at the moment it changes from the liquid to the solid state,—this likewise results in blowholes being formed in the mass.

The welder can, for each metal or alloy, avoid the bad consequences of this incorporation or dissolving of gas in melting the metal, but there again he should understand the causes in order to apply the remedy with knowledge.

VOLATILISATION AND COMBUSTION OF THE ELEMENTS.

Incorporated in certain metals during their manufacture are elements destined to modify their properties for certain applications: carbon, silicon, manganese, etc.

Now, these bodies, which, as a rule, are only present in small quantities in these alloys, can be volatilised or burnt under the action of the high temperature of the blowpipe. For example, the volatilisation of zinc in brasses is known by welders who more often note the consequence of the phenomenon and not the phenomenon itself.

These elements which can oxidise directly, or through the *reduc-*

tion of the oxide of the metal in fusion, may be considered as undergoing true combustion during the course of welding.

In each case *impoverishment* of the line of welding is produced by volatilisation or burning, and consequently a change in the nature of the metal in relation to the rest of the article follows—this should be avoided.

According to the alloys, the welder can avoid this volatilisation or burning of the elements, or remedy it by using, for example, a welding rod containing an excess of the element which tends to disappear and thus replace it by an equal portion.

CARBONISATION—DECARBONISATION.

The steels and cast iron are alloys of iron and carbon, the proportion of the latter element being 0·05 per cent. (extra mild steel), 1·5 per cent. (extra hard steel), and can attain 4·5 to 5 per cent. in the cast irons.

The carbon can burn either directly by contact with oxygen or by the reduction of the oxide of iron; in each case there is a *decarbonisation* of the metal, and the phenomenon is similar to that just studied in the preceding paragraph.

There can also take place *carbonisation* of irons and steels, that is to say, addition of carbon to the metal, since carbon tends to be taken up. In fact, if the flame contains an excess of acetylene, the carbon content can be added to, that is to say, it will unite with the iron at the high temperature. This is so true that one can carbonise mild steel with the aid of an oxy-acetylene flame containing an excess of acetylene.

The welder should remember these phenomena of carbonisation and decarbonisation in all cases where he is working with the blowpipe on iron or its alloys.

SEGREGATION: SEPARATION OF THE ELEMENTS.

When certain alloys are raised, under special conditions, to a definite temperature, the phenomenon known as *segregation* or *liquation* occurs in which the elements separate one from the other.

This property, which has to be carefully considered in the manufacture of welding rods because the elements incorporated must be distributed equally throughout the mass, is not frequently met with in autogenous welding; it is produced so rarely that we need only mention it.

MODIFICATION OF MECHANICAL PROPERTIES.

The mechanical properties of metals: tenacity, hardness, ductility, malleability, strength, etc., vary according to their temperature, their molecular constitution, and the *internal strains* localised at certain points of the articles considered.

It is important to note that the tenacity of certain metals, however strong, becomes practically *nil* when raised to a temperature which is still below the melting-point; for example, in the case of copper. Breaks on cooling are much more common in these metals than in others, and one is able to avoid them on knowing that at a certain temperature their tenacity diminishes very rapidly.

The texture of a metal considerably influences the mechanical properties; one knows the influence of *hammering*, *tempering*, and *annealing* which can modify the structure of the *grain*, that is to say, the crystallisation or uniformity of the metal.

Again, the portion of metal which has become melted under the action of the blowpipe, even under the best possible conditions, rapidly cools, and is generally more or less different in mechanical properties than the rest; the parts surrounding the weld may have been influenced by the heat and no longer be in the physical state they were before the application of the blowpipe.

Lastly, the internal strains on contraction, though insufficient to cause breaks, are not on this account non-existent, and the line of welding and its neighbourhood remain permanently strained and endanger the holding power of the joint.

In many cases these modifications have little or no consequence; the strains to which the weld will have to be exposed are not of such a nature as to put it to a very severe test of its homogeneity and mechanical properties.

In others, on the contrary, it is absolutely essential that if autogenous welding is to be advantageously applied, the line of welding must possess mechanical properties similar to the metal, there must be no internal strains, and the joining of the parts must be homogeneous.

In addition to the precautions which can be taken during the operation of welding, mechanical and thermic treatment, such as hammering, tempering, and annealing, can be applied.

Every welder should know the influence of these treatments on each metal or alloy, so as to apply it judiciously when possible or necessary.

CHAPTER X.

METALS AND MATERIALS ADDED.

GENERAL NOTIONS.

In the study of the welding of different metals and alloys we will examine the metals and products advantageously added in each case. The practical welder should have certain knowledge of this question, which is certainly one of the most important. The aim of this chapter is to furnish this.

NECESSITY FOR ADDING SPECIAL METALS AND MATERIALS.

It suffices to have studied the phenomena produced during the melting of the metal under the blowpipe, a study to which the previous chapter was devoted, to admit, without hesitation, the necessity for introducing into the bath of fusion elements capable of combating these phenomena and avoiding their bad consequences.

Unfortunately, the practical man will not admit their need unless it is impossible to proceed with the work or unless the advantages are very obvious; that is why all welders believe in a cleaning flux for aluminium, because the metal obstinately refuses to be welded without its presence.

On the contrary, iron, cast iron, copper, etc., unite without special metals or products, and since it is difficult on first examination to understand the value of the weld, they deride the elements which actually improve it. The welds thus produced are far from *autogenous*; they are covered with oxide or blowholes, lack certain constituents; in brief, they are of poor quality and safety.

It might appear superfluous to insist on this point, but we are persuaded that the time is still far off when every welder will admit the general principle of the necessity of adding special metals and products for the perfect realisation *of all welds.*

PURITY OF ADDED METAL.

The principal quality which one should require of the metal to be added is that it should be as pure as possible, that is to say, exempt from foreign elements detrimental to the mechanical properties of the welded part.

The metal of the parts which the welder has to join is not generally free from impurities.

Obviously metal of the same nature could be added when there is no risk of lowering the quality of the parts to be joined. But generally this is not the case; and to add to the line of welding a metal which is purer, more sound, in a word better, improves the holding power of the joint.

Suppose it is a question of welding iron, that is to say, practically extra mild steel: we know that the mechanical property of *elongation* is considerably lowered in the line of welding. We also know that the purer the iron the less foreign elements it contains, such as phosphorus, sulphur, slag, etc., and the more it possesses the property elongation. It therefore follows that in order to increase the elongation of welds in soft steel, a quality they lack as a rule, one should employ as an adding metal an iron which is as pure as possible; for example, Swedish iron made with wood charcoal, or, better still, electrolytic iron.

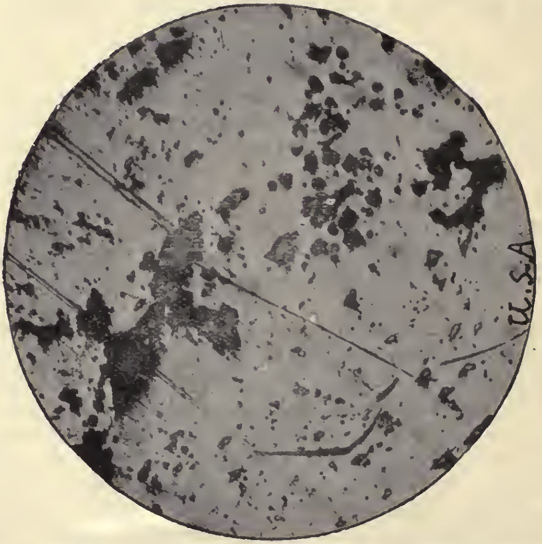


Fig. 89.—Microphotograph of a sample of welding wire (soft iron) containing slag and oxide (magnified 100 diameters).

This is just an example, but it is the same for all metals, and sometimes the absence of impurities is of still greater importance; it is for this reason that welding rods for cast iron, copper, brasses, bronzes, etc., should only be made with *new* metal of first quality, the purity controlled where necessary by competent specialists.

MATERIALS ADDED TO THE WELDING METAL.

In all cases where the operation is industrially possible, and as the technique of autogenous welding advances, one adds to the welding rod materials destined to combat the undesirable phenomena produced by the blowpipe and to counterbalance their effects, silicon for cast iron, phosphorus for copper and bronze, aluminium for brass, etc.

We will examine more closely the function of these materials when we study the welding of each of these metals, but it is necessary that they should be added in definite proportions and uniformly distributed throughout the mass, so that their presence is favourable; on the contrary, their excess may cause very grave disadvantages.

These materials should only be added to the welding metal when one has full knowledge of their action and the difficulties of incorporation, their tendency to disappear whilst in the crucible or on being poured, and their action on the impurities which the welding metal may contain, etc.

MANUFACTURE, CONTROL, AND GUARANTEE OF WELDING METALS.

It follows from what we have just explained that the manufacture of welding metals containing special elements, deoxidisers, or others, is extremely delicate, and necessitates rigorous supervision and control.

Manufacturers who utilise autogenous welding are by no means disposed to analyse or to examine micrographically, which is necessary to recognise the quality of the welding metal on which the good holding of the joint and execution depend in a very great measure. What will the welds be like if they are using a welding metal which should contain certain materials and which, due to bad manufacture, management or control, contains too little or too much?

One should therefore require of the manufacturer the maximum competence and guarantees, the control exercised by a laboratory specialist, such as the Autogenous Welding Association of each country for example, intervening and supervising the manufacture and control of these products.

POWDERS AND VARIOUS MATERIALS USED FOR THE EXECUTION OF WELDS.

It is not always possible to incorporate in the welding metal itself those elements most favourable for combating the oxidation of the welds, and the loss of certain constituents, etc. Further, certain products, notably fluxes, are employed previous to fusion of the metal, and having a different object than the welding metal; it is these considerations which justify the use of powders, liquids, or pastes.

The powders and products used do not do away with the necessity for a special welding metal; they are, in the majority of cases, cleaning and deoxidising fluxes destined to prepare the edges of the weld and eliminate, by way of combination, the oxide which is formed during welding.

These compositions require equally great care in the preparation. Although their use in greater or less quantity has generally no effect on the composition of the metal, their defective manufacture tends to produce inconveniences when they are used, and in consequence the bad execution of the weld.

CHAPTER XI.

PREPARATION OF WELDS.

GENERAL NOTIONS.

A WELD well prepared is half done, because the facility of execution depends in a large measure on the arrangements made by the welder in the preparation of the parts to be joined.

In detail, this preparation varies notably with the nature of the metal, thickness of weld, and, above all, the form and position of the parts to be welded; but it follows general rules which serve to indicate the methods to be applied in each particular case.

Although we will indicate later the different rules to be followed for each metal, it appears to us useful to draw attention to the principal considerations relative to the preparation of the parts, and then profit by giving or repeating later the essential information.

BEVELLING.

Bevelling means cutting to form an angle, or slope, or chamfer.

Bevelling the edges to be welded is to facilitate the execution of the work and to make sure of melting the metal throughout the thickness of the weld. It offers equally the advantage of enlarging the line of joining, that is to say, it avoids the consequences of too great a localisation of the defects, and, lastly, it allows the addition of a much greater quantity of metal of better quality and containing the required deoxidising materials.


Fig. 90.—Bevelling for pieces from $\frac{1}{8}$ inch to $\frac{3}{16}$ inch in thickness, angle of bevel 45°.

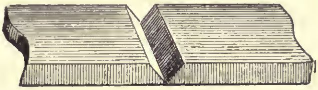


Fig. 91.—Bevelling for thicknesses exceeding $\frac{3}{16}$ inch, angle of bevel 90°.

However, it is admitted that bevelling is not practised below a thickness of $\frac{1}{8}$ inch on parts to be welded. From $\frac{1}{8}$ to $\frac{3}{16}$ inch a slightly open bevel is sufficient, the inclined faces forming an angle of 45°, for example. From $\frac{3}{16}$ to $\frac{3}{8}$ inch one increases the angle up to 90°; it is not necessary to go beyond this even with great thicknesses.

The bevelling is obtained, according to the case, by chisel, file, or grinding machine; the cutting should be regular, especially at the bottom, so as not to produce holes or excess thickness at the bottom of the bevel.

Rolled plates (tubes, etc.) offer, at their junction, a bevel which only requires retouching. In the joining of angle irons, plates at angles, etc., the bevelling necessary for the good execution of the weld is also obtained without cutting, because the edges are arranged so as to practically form an angle of 90°. We shall see later that this method of joining is not always to be recommended.

The necessity for bevelling exists, whatever the metal to be welded—steel, cast iron, copper, aluminium, etc. Those welders who obstinately weld edge to edge, without bevelling, thicknesses from $\frac{3}{16}$ to $\frac{3}{8}$ inch always obtain bad results, such as bad penetration, *adhesion*, or *overheating of the metal.*

These defects, even when only local, present great disadvantages. Moreover, bevelling is a guarantee that the weld has taken place throughout the thickness of metal in those cases where verification is impossible.

The separating of the edges to be welded does not replace bevelling. This practice, on the contrary, should be carefully avoided.

For welds exceeding $\frac{3}{4}$ inch in thickness, and the material iron or steel, the bevelling can be done with a *cutting blowpipe*, especially in the case of repairs.

CLEANING.

The edges to be welded and their immediate neighbourhood, that is to say, where fusion takes place, should be cleaned until the metal is bright. According to the state of the surface of the metal this mechanical cleaning is done with a grindstone, file, scraper, or simply with sheets of emery. The oxide which is detached, and all particles from the bodies used, must be removed from the line of welding, and especially from the bottom of the bevel.

In the absence of mechanical cleaning one uses chemical agents which at a high temperature slags the oxide on the edges of the weld at the same time, that is to say, during the realisation of the weld.

The fluxes generally used work well, but it is preferable to precede their use by a mechanical cleaning.

ADJUSTMENT BEFORE WELDING.

Before commencing the welding, it is advantageous to adjust and arrange the parts to be joined, so that during the welding they remain perfectly in position. Too often welders fail to take sufficient precautions to get this preliminary adjustment, and the solidity of the joint, as well as the progress of the work, suffers. The deviation of the lines of welding arising from the phenomena of expansion and contraction, of which we will speak later, are the chief difficulties to be overcome, and it is necessary to avoid these faults and others of the same kind which arise from want of adjustment.

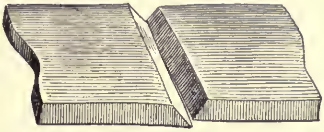


Fig. 92.—Overlapping of the bevel, which should be avoided.

The welder should therefore see that the angles of the bevel, or the edges to be joined, are maintained exactly at the same level. In cases of repairs to non-malleable pieces, for example toothed wheels, parts of machines, etc.. the adjustment before welding should be very carefully done.

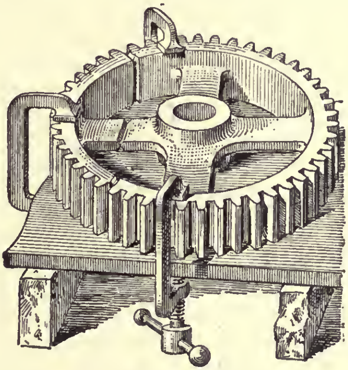


Fig. 93.—Adjustment before welding of a non-malleable metal article.

According to the metal, the thickness of the parts, one varies this preliminary adjustment. The maintaining in position of the parts to be joined, during the advancement of the welding, is obtained by using wedges, keys, clamps, iron wire, etc.

PRECAUTIONS IN VIEW OF THE PHENOMENA OF EXPANSION AND CONTRACTION.

We have already drawn attention to the importance of these phenomena in the case of autogenous welding, which can produce the following effects :—*Deformation, breaks or cracks, internal strains.*

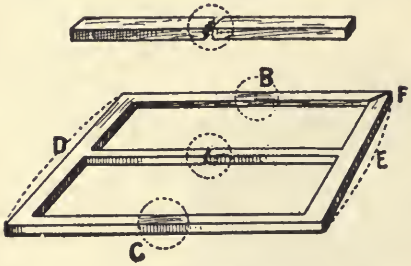
If the whole of the pieces to be welded can be raised to a high temperature, somewhere near the melting-point and uniformly cooled after welding, no serious results following expansion and contraction need be feared, and for the repair of certain articles of cast iron or alloys of aluminium one is obliged to adopt this process. But, as a general rule, it is possible to overcome the effects of local heating by foreseeing the manner in which they will manifest themselves, and so controlling them to the extent that they have no bad results.

Let us state, first of all, that expansion and contraction cannot be overcome by force; the phenomena manifest themselves whatever one does, and it is perfectly useless to try to oppose them. The method is to avoid or limit their consequences.

Let us take a general example:—Here is a weld to be executed in the middle of a long bar (fig. 94). The dimensions are not important. No bad effects of expansion or contraction are to be feared when it is free to expand or contract. No precautions are necessary to overcome the expansion and contraction in this case.

On the contrary, the *same bar*, having the *same break*, and in the *same place*, is now situated, for example, in the middle of a frame (fig. 95). What is now the position?

No bad effects of *expansion* need be feared, since, on heating to fusion the edges to be welded, the expansion takes place and the edges to be welded approach each other, the metal in fusion offering practically no resistance to this expansion.



Figs. 94 and 95.

But the weld is completed, and the metal commences to cool and *contract*. Now the bar which was free to expand does not offer the same freedom to contraction, since the two extremities of the bar are fixed solidly to a frame which was not previously heated and consequently is unchanged.

If the metal is ductile, elastic, the contraction of the parts heated will not produce a break, but simply a *deformation* or strain corresponding to the linear value of the contraction. This would often be the case, for example, with mild steel. If the piece was of cast iron, cooling would probably produce a break, probably in the welded portion.

A break will frequently occur in those metals which are *ductile* at ordinary temperatures but whose strength when hot is extremely low—copper, for example; it takes place during cooling in that part which remains at the highest temperature.

The realisation of welds in such metals is possible. All that is required is reflection and adjustment.

One could raise the whole piece to a high temperature before welding, and thus produce expansion in the entire mass, and in this way equal contraction. But, as a matter of fact, complete heating is not necessary. It is sufficient to heat, simultaneously with the operation of welding, the parts B and C of the frame and thus obtain equal expansion to that of the broken bar; then, on cooling, the contraction is of equal importance in the case of the two parallel bars and the repaired bar. Therefore there is no strain in the metal or break.

Suppose it were impossible to heat the frame at B and C. Other methods are at the disposal of the welder; for example, a slight separation of the two bars D and E by bending separates the two edges to be welded. This done, proceed to weld, and at the end of the operation, that is to say, as soon as contraction commences, due to cooling, remove the keys, wedges, or screw jacks from between the sides D and E. The return of the bent bars to their original position annuls the effect of contraction in the welded bar, and thus welded it should be free from strains, deformations, or breaks.

Another method is, although the success depends upon the thickness of the metal, to cut the frame at F, execute the weld of the bar, and then weld at F, the effects of contraction being least to be feared at this part. That is to say, sometimes we have to break a piece in order to repair it.

This example, taken from a hundred, shows the importance which the welder should attach to foreseeing the effects of expansion and contraction during the execution of the weld and on cooling. And this is evidently part of the "preparation of pieces," since it is not possible to guard against the consequences of these phenomena once the welding has commenced.

The devices to be followed vary in each case. We will study them in greater detail in the chapters devoted to each metal, but it is useful to emphasise that the phenomena of expansion and contraction are enemies of the welder; that in all welds means must be devised to prevent their effects and avoid their consequences by means of such methods as we have indicated.

THIN PIECES.

The welding of thin pieces requires a certain amount of skill, and beginners require a great deal of practice before they are able to do it well.

The welding of thin plates under $\frac{1}{16}$ inch is particularly difficult on account of the separation or warping produced by expansion; also the least excess of heat tends to produce holes which are difficult to avoid when the metal is very thin.

The welder should carefully watch that the edges to be welded do not overlap each other; if one can bend them up a small height, $\frac{1}{16}$ inch for example, the execution of the weld becomes much easier; the metal bent over serves as a welding rod, and, after welding, the line of welding is equalised with a hammer.

For very thin plates, aluminium amongst others, grooving the edges to be welded can be done, then afterwards unite in fusion the four thicknesses of metal, equalise afterwards by hammering, as in the previous case. This method, which is practised by our German friends, does not seem to us to be absolutely recommendable, on account of the possible interposition of oxide between the folds of the metal.

THICK PIECES.

When the thickness to be welded is over $\frac{3}{4}$ inch it is advisable, where possible, to bevel the two sides and weld on both sides. If the joint is important, one uses two blowpipes of the same power, travelling parallel on either side.

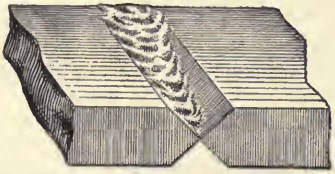


Fig. 96.—Bevelling and welding of thick pieces.

For very thick welds, one has to apply the welding rod in two or more successive layers, for example $\frac{3}{8}$ to $\frac{1}{2}$ inch thick, taking care to obtain fusion of such layer before adding the new welding metal, and thus avoid adhesion and interposition of oxide. This method appears to us defective. We prefer working *in steps*, which allows the welding of all thicknesses without leaving the metal to cool.

The different methods of operating must be reasoned out for each case in the course of preparing the pieces.

WELDING PIECES OF DIFFERENT THICKNESSES.

Autogenous welding is not easily applied to the joining of pieces varying appreciably in thickness.

In fact, the melting of the two edges is not equal and does not take place at the same time, since the blowpipe is too powerful for the thin piece or too weak for the thick piece.

Of course, a clever welder could manage his blowpipe so that the heat given to the two edges is proportional to the thickness of metal; but if the difference is very great, for example a plate of $\frac{1}{16}$ inch to be joined to a plate of $\frac{1}{4}$ inch, the joining is not easily obtained. The melting of the thick edge does not permit the management of the thin edge.

All the same, nothing is impossible in autogenous welding, and experience has produced *manipulation* which enables such welds to be done. Thus one can manage to join a thin plate to a thick plate by using two blowpipes, the one powerful, which raises to a red heat the thick plate, and the other of appropriate power for the thin plate, which weld together the two plates. Another method consists in laying under the thin piece, under the line of welding, a thick piece of metal of high conductivity (red copper, for example);

the metal absorbs the excess of heat and, with a clever welder, makes the welding possible.

It is by such artifices many welds are made possible.

EXAMPLES OF THE PREPARATION OF PIECES.

In closing this chapter we think it useful to indicate, especially with illustrations, some general examples, both good and bad, of the preparation of pieces to be welded, principally referring to current practice.

These examples not only apply to mild steel but also to all ductile metals and alloys such as copper, brass, aluminium, etc.

We have grouped our drawings in plates referring to the different work and the special arrangements for the execution of the same work; we think the reader will easily recognise and use them in studying the chapters which follow.

. . . .

The effects of expansion often act in such a manner that the edges to be joined separate and approach each other alternately.

If one wishes to join two plates by autogenous welding and the edges have been arranged parallel, when the weld has commenced one first observes a widening at the other end of the plates (fig. 97).

If the welding is continued, the deviation quickly stops and the opposite movement is produced, that is to say, the edges approach each other (fig. 98).

On continuing the operation, expansion leads to the *overlapping* before the completion of the weld (fig. 99).

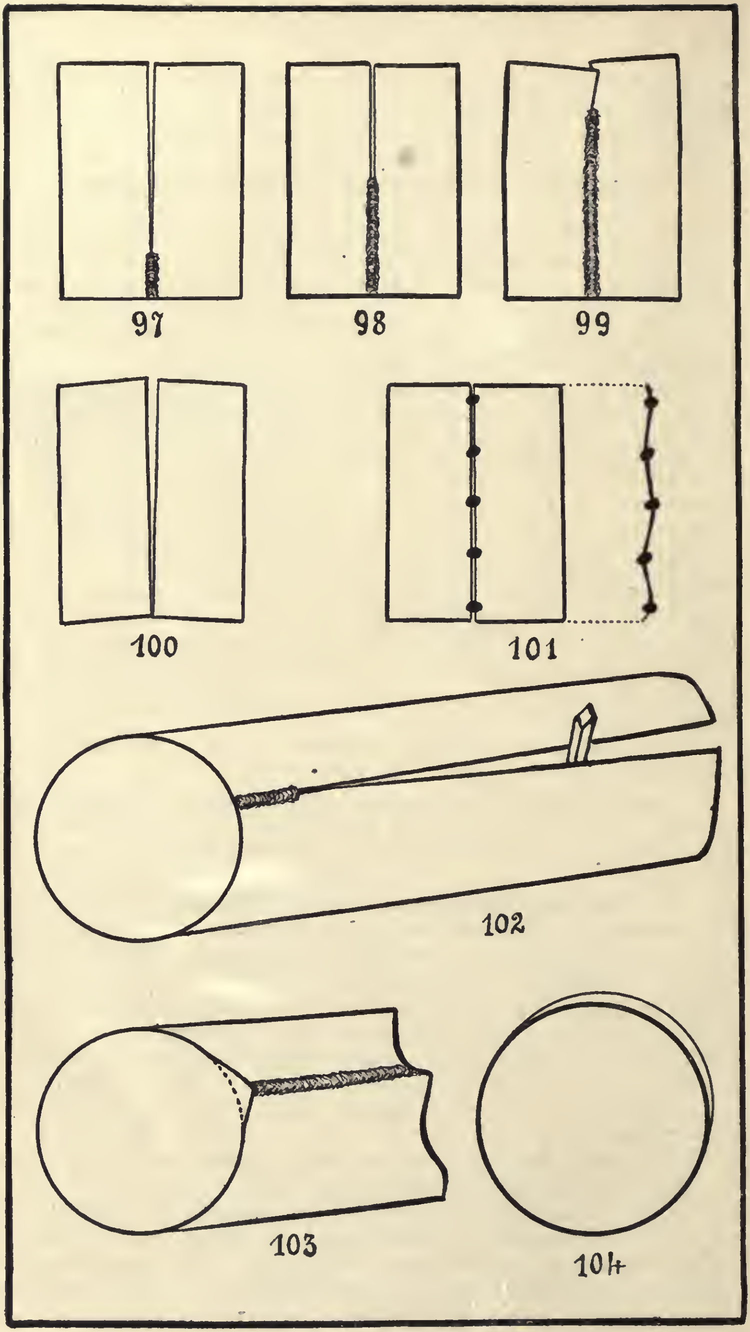
In order to overcome this final overlapping two methods are possible: either by separating the edges before commencing to weld (fig. 100), or by *tacking* the line of welding, as shown in fig. 101.

In the first case the separation should vary from 4 to 8 per cent. of the length to be welded; it depends, of course, on the thickness of the metal and the size and shape of the pieces. This method is applied in repetition work, for after two or three trials the welder knows exactly what separation to give in order to bring the two edges together exactly at the end of the operation.

In the case of tacking, the expansion cannot act laterally as in the previous case, and this brings about bending, as shown in fig. 101. In the majority of cases it is easy to bring the plates back to the original position.

These deformations are more or less important according to the thickness of metal, the size of the plates, etc.

For the welding of cylindrical bodies separation is obtained by means of a wedge of appropriate size placed either two-thirds along or at the extremity of the line of welding (fig. 102) As soon as the weld is commenced the wedge is gradually raised so that the edges can approach as the work proceeds.



Figs. 97 to 104.

The welding of cylindrical bodies previously tacked produces the deformation shown in fig. 103.

This can be avoided by commencing to weld away from the ends, returning to the extremities for the end of the operation.

The fastening of bottoms to cylinders produces deformation of the circumference of the plate (fig. 104), especially if the weld is completed without interruption. This can be prevented by tacking the bottom strongly but rapidly, or by welding opposite portions, so that the effects of expansion in each sector is counterbalanced by that produced immediately after.

It is difficult, of course, to give definite instructions on the subject, because the deformations vary with the nature of the metal, thickness, form and size of the bottom to be welded.

. . . .

The welding of very thin pieces produces great difficulties on account of the metal in fusion under the action of the blowpipe being too extensive; this produces holes.

If the edges of each plate can be flanged (fig. 105) the work of welding is greatly facilitated. The metal can afterwards be hammered level.

We have already pointed out that for very thin pieces the grooved joint shown in fig. 106 has been used, the extra thickness of metal making it less sensible to the action of the blowpipe. This method does not appear favourable to us, on account of the interposition of oxide between the metallic parts.

The overlapping of the edges shown in fig. 107 is equally faulty. From our point of view, it should never be used, and more especially if the joining is formed as shown in fig. 108.

If the metal is not thick enough to prevent the formation of holes, one may be able to form the edges as shown in fig. 109. In case the angle is very acute (fig. 110) no preparation of the edges is necessary.

Up to a thickness of $\frac{1}{16}$ inch the edges of the weld can be simply brought together (figs. 111, 112, and 113).

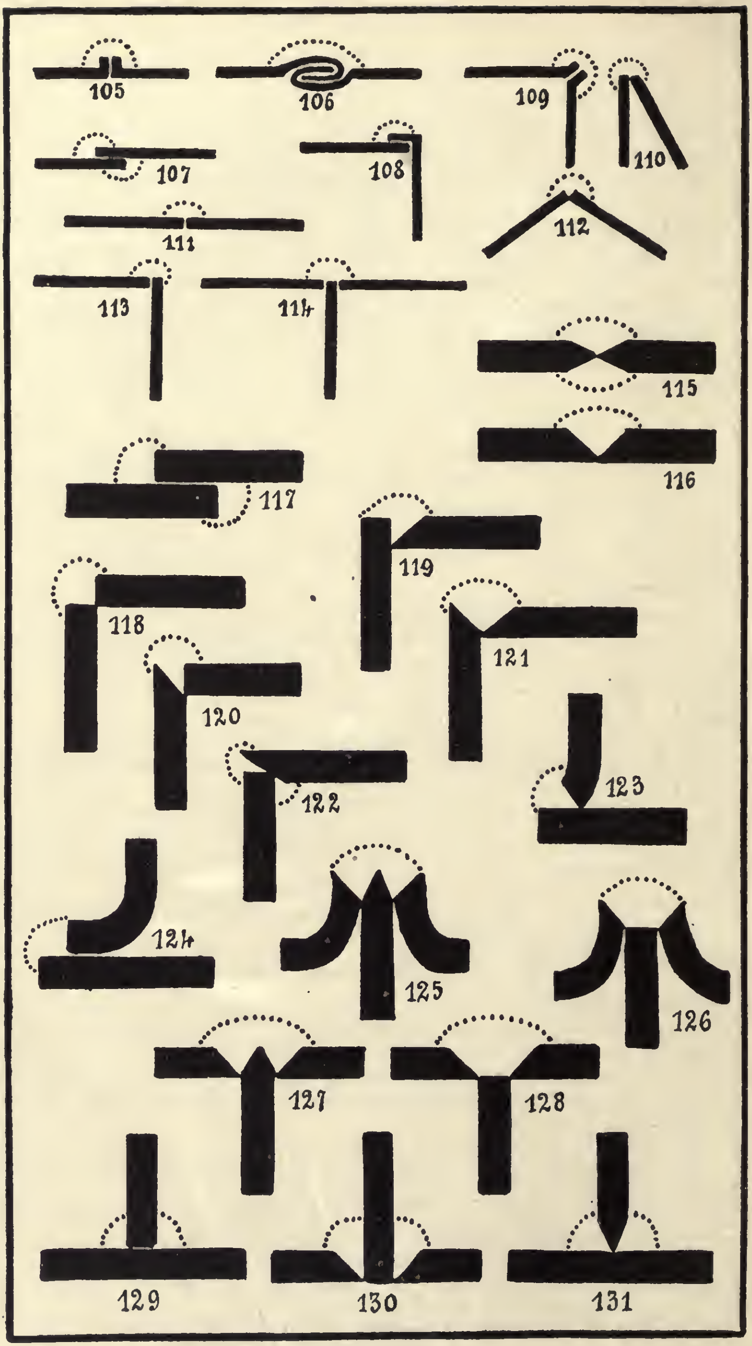
The joint shown in fig. 114 can be used if the melting takes place throughout the whole thickness.

We have already said that for thicknesses over $\frac{1}{8}$ inch the edges should be bevelled to an angle not less than 45° and not more than 90°. The double bevelling (fig. 115) should only be used for thicknesses exceeding $\frac{5}{8}$ inch or $\frac{3}{4}$ inch. Up to that a simple bevel should be made (fig. 116).

Joining by overlapping of the plates should never be done in autogenous welding, even when welded on both sides (fig. 117). One should absolutely avoid this method of welding.

In joints at right angles, the angle for welding is obtained without bevelling by simply arranging as shown in fig. 118.

Nevertheless, the preparation shown in fig. 119, though more costly on account of cutting, is clearly preferable.



Figs. 105 to 131.

The preparations shown in figs. 120 and 121 are less recommendable.

Fig. 122, being welded on each side, gives bad results, and it is surprising that some authors recommend it.

The preparations shown in figs. 123 and 124 are little to be recommended.

The joining of three pieces by autogenous welding can be done in different ways. The arrangement shown in fig. 125 is excellent, but the cost of the preparation of the pieces is high.

The joint shown in fig. 126 requires too much welding rod. The same is true of figs. 127 and 128.

The joint, fig. 129, which requires no bevelling, is bad when the thicknesses to be welded exceed ⅛ inch, because the penetration is doubtful.

The arrangement given in fig. 130 is very favourable, but the welding is very difficult.

Lastly, the joint shown in fig. 131 can only be obtained by expert welders, because the simultaneous melting of the plain parts and that of the two bevelled faces can only be obtained by skilful manipulation of the blowpipe.

. . . .

The preparation of welds of bottoms to cylinders and to vessels of all kinds depends on the destination of the piece, that is to say, the strain the metal has to support.

If the vessels have to contain gases or liquids under pressure, the line of welding should be so arranged that the strain is one of tension and not bending.

The preparations shown in figs. 132 and 133 do not fulfil this condition, and they should not be used in cases where the strain on the bottom is high.

The preparation, fig. 134, on the contrary, satisfies the condition we have stated, and is excellent.

The arrangement shown in fig. 135 is expensive and not favourable to the good holding of the joint. We give it as an example to be avoided.

The joints figs. 136 and 137 are still less to be recommended. It is surprising that some authors recommend them.

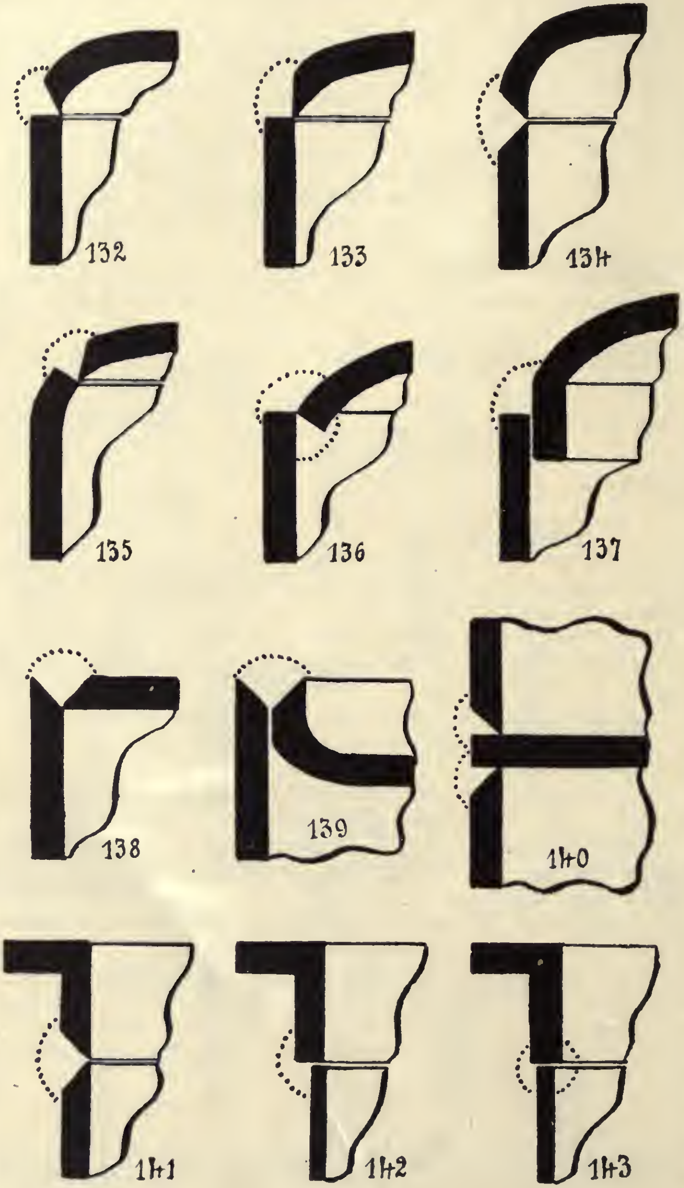
Where the bottom does not have to support a great strain the preparation can consist of forming an angle, fig. 138 for example.

A joint for concave bottoms, an excellent arrangement for small cylinders destined to contain gases or liquids under pressure, is shown in fig. 139.

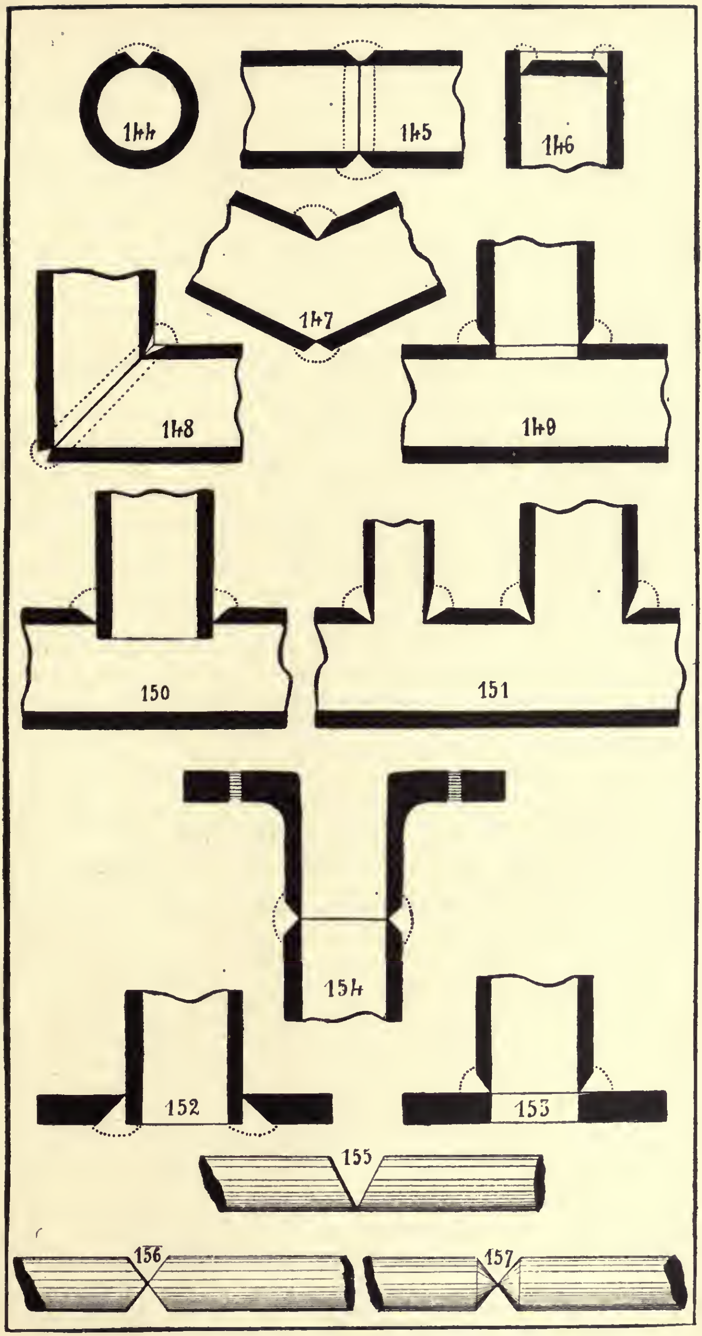
The welding of a partition in a cylindrical body is very rare. The piece is prepared as shown in fig. 140.

To weld angle iron rings to cylindrical bodies when the thicknesses are approximately the same, both edges must be bevelled as shown in fig. 141.

For thin plates to thick angle iron the joining is as shown in



Figs. 132 to 143.



Figs. 144 to 157.

fig. 142. In carrying out the weld, strongly heat the edges of the angle iron in such a manner that the blowpipe simultaneously melts the two pieces.

The arrangement shown in fig. 143 consists of welding each side, and is to be less recommended for pieces of different thickness.

. . . .

In the joining of pipes and tubes rolled from plates (fig. 144), the bevel for the line of welding is obtained without cutting the edges.

For joining welded portions, or the joining end to end of tubes, bevel as shown in fig. 145.

For welding a bottom to a tube one operates according to fig. 146.

Figs. 147 and 148 show the preparation for bent pipes or tubes.

The joining of branches is shown in figs. 149, 150, and 151. We prefer that shown in fig. 151.

The fixing of flanges to tubes by autogenous welding is a difficult operation because of the different thicknesses, and the joints generally have to withstand strains of all kinds.

The preparation shown in fig. 152 is convenient. The preparation fig. 153 is not so good, but the operation of welding is much easier. In the two cases, the flange, being of greater thickness than the tube, should be first heated in order to obtain simultaneous fusion.

Special types of flanges have been made for autogenous welding, so that the thickness of the tube and the portion of the flange to which it is joined correspond (fig. 154). The use of these special flanges is to be recommended.

The welding of round rods is carried out in the same way as for plates, the two edges being bevelled (fig. 155). When the diameter reaches $\frac{5}{8}$ inch to $\frac{3}{4}$ inch the bevelling is as shown in fig. 156.

One sometimes sees the preparation of round rods by turning the extremities to points recommended (fig. 157). This method is deplorable, because the metal in fusion necessarily flows to cold parts and brings about adhesion.

CHAPTER XII.

GENERAL NOTIONS ON THE EXECUTION OF WELDS.

The welding shop is furnished and arranged as explained in a previous chapter. A blowpipe is chosen (as we will explain later) according to the thickness and nature of the metal to be welded. Lastly, the pieces are prepared according to the principles explained in the previous chapter. We will suppose it is a question of trying to weld two pieces of metal of equal thickness, and of mild steel, as is usual to commence with.

We know that the edges of the weld should be clean and bright, bevelled if necessary, so as to make the *penetration* easy. The two pieces are arranged edge to edge, not flat on the welding table, *but raised so that the under side of the line of welding is not closed up.* The blowpipe is lighted and the flame regulated. How is the execution to be carried out, and what tends to produce failures in the case of a beginner?

POSITION OF THE WELDER. HOLDING AND DIRECTION OF THE BLOWPIPE.

The welder generally stands upright. Nevertheless, for the work of long duration he can arrange to work sitting, and neither the welds nor the speed of welding are likely to suffer.

The blowpipe is held and directed with the right hand, except in the case of the welder being left-handed. According to the type, form, length, weight, one holds the handle more or less forward, so that it is well balanced in the hand during welding. The flexible tubes generally serve to maintain equilibrium.

The blowpipe should be simply held and directed by the hand; holding it with the fingers tends to produce trembling. Let us say, with reference to welders whose hands tremble, they never become good welders of thin materials, up to $\frac{1}{8}$ inch, for example.

The blowpipe is held as near as possible in the direction of the edges to be welded, and not perpendicular to the line of welding. Experienced welders sometimes prefer the latter method, but generally it is dangerous, because there is the risk of not regularly attacking the two edges.

One welds by pushing the blowpipe, and not by pulling it.

The flame is held in a *slightly inclined* forward position. If the inclination is too great, the molten metal is blown forward, and *adheres* to the edges of the weld, which are much cooler.

If the inclination is perpendicular to the metal, the heat of the non-welding part of the flame is not used for preheating the bevel, and does not tend to the realisation of good-looking welds. Nevertheless, in certain cases, especially in great thicknesses, the perpendicular direction of the flame is preferable. With careful observation the welder soon obtains the best inclination according to the work to be executed.

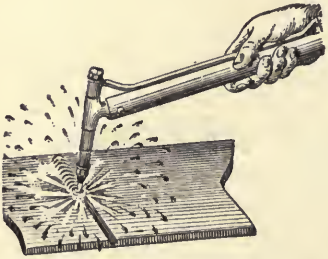


Fig. 158.—Wrong method of holding the blowpipe. The blowpipe should be held as near as possible in the direction of the edges to be welded and not perpendicular to the line of welding.

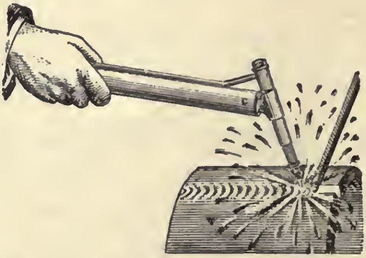


Fig. 159.—Method of holding the blowpipe, and normal direction of the flame.

MOVEMENTS TO GIVE TO THE BLOWPIPE.

In proportion to the execution of the weld, that is to say, to the joining of the edges by melting the metal, the blowpipe must be moved more forward, very slowly and with great care in order to obtain a continuous and regular weld.

It is an advantage, of course, to give the blowpipe a movement such that the two edges to be welded are attacked by the flame in such a manner as to bring about simultaneous fusion. The movement, therefore, should be frequent and regular.

The best movement is to make the small white cone describe a circular movement, the diameter corresponding to the molten bath obtained, according to the thickness to be welded, so that this movement, combined with the advancing one, gives a series of elliptical curves, the locus of their centres being in the direction of the line of welding.

One can also, especially for thick pieces, proceed in half-circles, or play the flame regularly from one side to the other, regulating the rapidity of the movement according to the melting and the bath of liquid metal obtained. All the same, the circular movement is the one that produces the smoothest and most regular welds.

Except in the cases where the two edges touch each other completely, and for thin pieces (tubes, for example), a movement from side to side is indispensable. According to the metal, its thickness and shape, the welder should give a regular and careful movement.

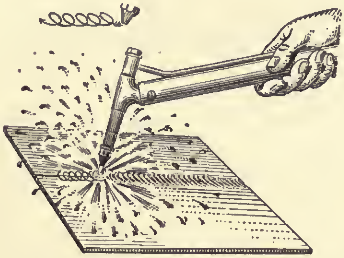


Fig. 160.—Circular or gyratory movement of the blowpipe during the execution of the welds.

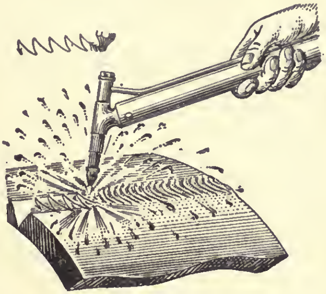


Fig. 161.—Oscillatory movement for the execution of welds of great thickness.

POSITION OF WELDING ROD.

SIMULTANEOUS MELTING.

The welding rod is held and directed by the left hand of the welder. If it is a question of a thin flexible rod, it should be bent or curved so that the flexibility does not cause vibrations or deviations at the end.

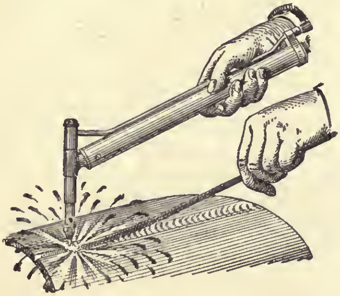


Fig. 162 —Normal holding of the welding rod.

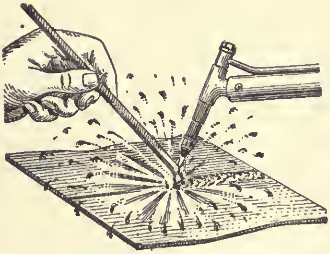


Fig. 163.—The metal added must not fall drop by drop into the weld.

No definite instructions can be given with regard to the inclination; the direction depends on whether it is in the form of a rod or thin wire, and this depends on the thickness of the weld and the welders. As a general rule, the rod is held inclined for thin welds, and more nearly perpendicular as the thickness to be welded increases.

The size of the welding rod should be in proportion to the thickness welded. We give later the necessary sizes for each metal.

The melting of the welding rod and the edges of the weld must take place at the same time, so as to make the two metals alloy immediately with each other.

If the welding rod flows between the edges of the weld before they are melted, the joint is bad; it is an adhesion and not a weld.

This fundamental principle, which it is so necessary to observe, is often neglected by so-called experienced workers.

It is a question, then, of the welder so conducting the work as to make the welding rod melt at the same time as the bevelled edges, the rod being brought progressively in the welding portion of the flame without any special dis placement of the flame.

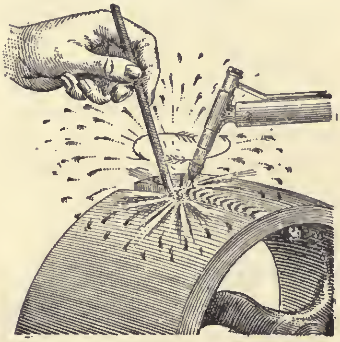


Fig. 164.—For great thicknesses the rod is plunged into the molten bath.

The welding rod as it melts should never fall in drops on the weld in course of execution.

When the proper moment arrives to apply the rod, it is lowered so as to bring it in contact with the molten metal in the weld, and then the heat is directed so as to produce melting of the extremity.

For great thicknesses the end of the rod is plunged into the molten bath, whilst the small white jet of the blowpipe is played right round; the end of the rod is thus protected from the air and the gases of the blowpipe.

The welder applies the welding rod so as to produce a good appearance, no humps or hollows. The lines of welding should be overcharged, that is to say, slightly thickened, especially if they are to be hammered. If the weld is required smooth, this is done with the hammer, grindstone, chisel, etc., according to the case.

A *flat* weld always has small holes or punctures even when properly welded, but these do not extend throughout the thickness.

EXECUTION OF WELDS.

The information which has just been given on the position of the welder, the holding, direction, and movement to give the blowpipe, the melting of the welding rod, etc., constitute in themselves the principles for the execution of welds. Together with reflection, attention, and a little practice, their application presents no special difficulty.

Welding is but a regular succession of *molten baths* joined one to the other so as to form a homogeneous line. There are, certainly, manipulations to be learnt, but these are relatively easy to acquire, and are better obtained by practice than by reading.

The beginner either does not melt enough and the welding lacks penetration, or he melts too much and so makes holes. It is evidently necessary to find the happy medium, and, above all, to work regularly.

Holes are particularly the despair of a beginner, because in trying to mend them he generally sees them increase, which shows bad instruction. Let us give him the job of reconstructing the partition which the supply of too much heat has caused to fall in. The flame should be inclined so as to be almost parallel to the surface of the hole, that is, to the line of welding. In this position approach the edges to be rejoined and make the sides in a plastic state, that is, without excess of heat; at this moment the wire or welding rod is interposed, and a little metal is welded, and so on until the hole is closed up. One forms in this way a partition of metal approximately equal to the thickness before the hole was formed. During the latter part of the operation the blowpipe is progressively raised so as to obtain the normal position of the flame. Then commence to obtain a regular and homogeneous weld, taking care not to repeat the error.

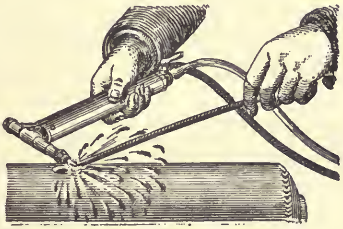


Fig. 165.—Position of blowpipe for the filling in of holes.

The simultaneous and regular melting of the two edges of the weld and the welding rod is the most important advice to welders.

Beginners generally direct the flame so that one of the faces of the bevel is *attacked* more than the other, thus producing adhesion. Many good welders possess this same fault, and on examining internally their welds one finds that portions of the sides have scarcely been melted; the work which has otherwise been well executed possesses these grave local defects.

The beginning of a weld is always slower and the end more rapid because the temperature of the piece is increased as the work goes on; it is therefore necessary to advance the blowpipe regularly and without hurry at the beginning and not too slowly at the end.

Let us recall, lastly, that all the advice given elsewhere for the regulation of the flame, the distance between the white jet and the molten metal, etc., should be carefully observed.

GENERAL DEFECTS OF WELDS.

We have shown in Chapter IX. what are the principal phenomena which come into question in the metal during the obtaining of welds.

We will not go back to this subject, but think it useful before proceeding to the study of the welding of different metals to draw particular attention to what might be called the *general defects of welds.*

The first is *lack of penetration,* commonly called in the workshop "not gone through." This takes place, above all, when the edges of the weld are not bevelled; the heat has not been sufficient for the fusion to go right through the whole thickness of the piece. Not only is the solidity of the joint diminished, but also the section not welded constitutes a *starting-point for a break* (fig. 166).

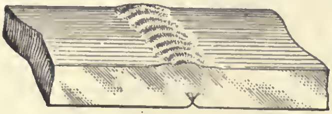


Fig. 166.—Weld not penetrated.

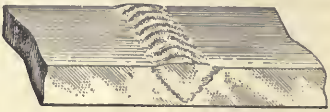


Fig. 167.—Adhesion.

To avoid this defect one must not go to the other extreme and go *too far through;* this produces holes, loss of heat and time, and assists oxidation.

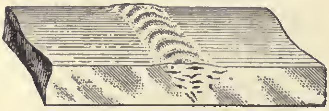


Fig. 168.—Interposition of oxide.

Next there is *adhesion.* This very significant term is difficult to explain. *One obtains adhesion* in different ways, either by not attacking sufficiently the edges of the weld or doing so unequally; also by the flowing of the molten metal on to parts not yet melted, and again by the interposition of oxide in the welded seam. Welders should give constant attention to their work and avoid this "adhesion,"—it is not rare to find this defect, localised it is true, in the welds executed by experienced welders. *The molten metal flowing from the edges of the weld into the bottom of the bevel brings about adhesion if this part itself is not melted.* This defect is so important and so frequent that even the best welders should never lose sight of it.

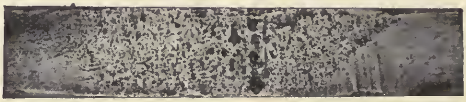


Fig. 169.—Blowholes in a weld of copper, exposed by the corrosion test.

There are sometimes *bad joins* due to the interposition of a layer of oxide between the metal and the added metal; this is generally due to a supply of molten metal on metal already solidified or to lack of liquefaction in the molten bath constituting the weld.

Blowholes equally constitute great defects; they are sometimes numerous or of large size, and the solidity of the joint suffers considerably.

We must mention, lastly, the welds that are *insufficiently filled*, that is, whose level does not reach the surface of the piece; also those *too highly charged* or *badly finished*, that is to say, filled with peaks and valleys.

Fig. 170.—Line of welding, showing hollow due to lack of added metal.

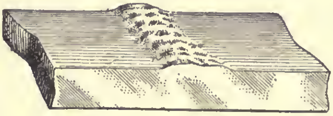


Fig. 171.—Weld normally charged, especially for hammering.

TESTS FOR WELDS.

The majority of the defects of which we have spoken are hidden in the body of the metal, and the welder himself is often ignorant of them. The latter therefore requires to know whether his welds are good or bad, so that he can estimate his attempts, correct his faults, and thus perfect himself.

True enough, it is not usual in practice to break the joints in order to measure their strength or examine their internal constitution, but the welder can carry out trials on similar metal to those he has worked with, and then submit the *test pieces* to the various tests of which we are going to speak. We will not ask him to make a test of the resistance, elongation, or hardness with the aid of special apparatus mainly used by specialists, but will show him how, by very simple methods, he can judge more or less the quality of his welds.

We will give brief instructions in three methods — *corrosion, bending, and hammering.*

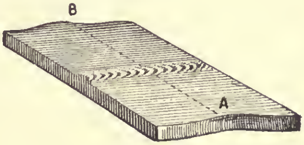


Fig. 172.

The test by corrosion, also called the *micrographic* test, is applied to all metals, providing the thickness welded is not less than $\frac{3}{16}$ to $\frac{1}{4}$ inch.

It consists in cutting the weld perpendicular to the line of welding (fig. 172), polishing one of the faces and then attacking it with the aid of a suitable corrosive. The corroding liquid, or etching fluid as it is called, first attacks the oxide, exposes any *adhesion*, *blowholes*, and places where there is *lack of metal* in such a way that it is sufficient to examine the weld to recognise its defects. The welder can see, at the same time, from the aspect of the metal if the weld has been burnt.

The most delicate part of the operation consists in perfectly polishing the face of the welded test piece. This is done by filing with a "rough" file, then with a "smooth" file, and finally with a "dead smooth" file. The marks from each file should be across those made by the preceding file, and so obliterate them.

The filing is followed by a series of polishings with emery papers of increasing fineness. Start with "No. 1," and finish off with "No. 0," "No. 00," and "No. 000," so as to obtain a distinct polish.

Avoid touching the surface with the fingers, which are more or less greasy, and immediately commence the corrosive attack.

Neither the cutting of the part welded or the polishing disclose anything; on the contrary, one always has the impression at this moment that the weld is perfect. But as soon as the attacking liquid is applied one commences to see the defects. If welders apply this kind of test from time to time, they rapidly perfect themselves and speedily adopt the best methods.

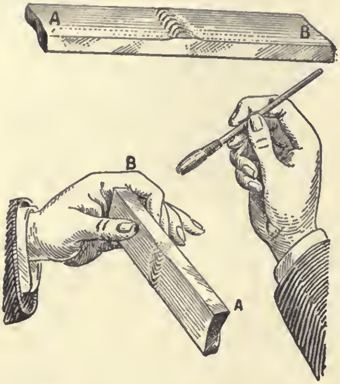


Fig. 173.—Tests of welds by corrosion; on top, the weld polished; below, applying the etching solution.

Composition of different corroding or etching liquids used:—

(1) **For iron and steel.**

Iodine solution	Water	10 parts.
	Potassium iodide	2 ,,
	Iodine	1 ,,

The solution is applied with a brush immediately the polished cut is ready.

The structure almost suddenly develops, and in a few minutes the corrosion is sufficient.

Wash with running water, dry with alcohol, and cover with a layer of transparent varnish if the test is to be preserved.

Sulphuric acid solution for slow attack	Sulphuric acid	25 parts.
	Water	75 ,,

The test piece is entirely plunged into the solution and taken out from time to time for examination and washing to detach the crust. In about one and a half hours the attack is completed.

To preserve the test piece it is washed in running water, and when sufficiently dry it is varnished.

(2) **For copper, brasses, and bronzes.**

The solution used is as follows:—

Nitric acid	25 parts.
Water	75 ,,

The attack is fairly rapid. According to the case, it can last several minutes or a quarter of an hour. It suffices afterwards to wash, dry, and varnish.

(3) **For aluminium and its alloys.**

Hydrochloric acid . . .	10 parts.
Water	90 ,,

The maximum time for the attack is a quarter of an hour.

To obtain distinct micrographic sections great care must be taken to attack the metals with the solutions indicated above, avoid touching the surface with the fingers, or the use of emery paper that has been in contact with oil or grease. In fact, the least layer of grease can prevent the etching solution attacking the metal.

. . . .

The bending test is applied to test pieces of ductile metals such as iron, mild steel, copper, and brasses.

A sufficiently long test piece is used to facilitate bending. After welding, hammering, and annealing the welded part, the test piece is placed in the vice so that the line of welding is just above the edge of the vice.

A hammer is applied to the *opposite side* to which the metal was added, so that the latter is in the folds of the bend.

As soon as a satisfactory angle is reached, the bending is completed by a press or by other means which avoids a sharp shock; it is sufficient to observe the angle where the weld commences to crack.

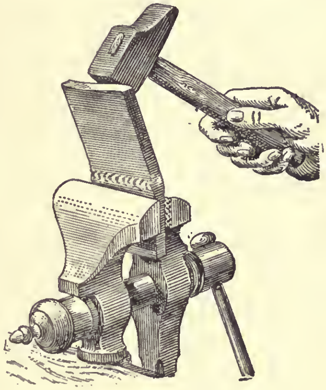


Fig. 174.—Test for welds by bending the welded line.

Welds of mild steel hammered and annealed and perfectly executed should bend completely over without showing cracks.

. . . .

The hammering test is of greatest value for autogenous welds of copper and brasses. It gives information as to the ductility of the welded parts. After annealing the weld, the metal is beaten thin with a hammer, taking the precaution to reheat from time to time to prevent hardening.

With red copper or brass perfectly welded it should be possible to hammer down to extreme limits of thinness without showing cracks.

We repeat that welders, in order to know their aptitude and their defects, should frequently make use of these tests, especially that of corrosion, on welded test pieces. In correcting their defects, after proper verification, they are rapidly able to produce work as perfect as is possible.

CHAPTER XIII.

AUTOGENOUS WELDING OF IRON AND MILD STEELS.

Mild steel is the material that is most used in metallic construction, and in the joining of this metal by autogenous welding there is a vast field of exploitation; it is for this purpose that oxy-acetylene blowpipes are most used. We will therefore devote a chapter as detailed as possible to this subject.

To speak technically, iron no more exists in commerce as an element in metallic construction; it is always *mild steel* or *extra mild steel*; that is to say, an alloy of iron and carbon, obtained by melting, the percentage of carbon being very small, and the properties of which approach closely that of the iron itself.

We will therefore treat in common *iron*, *extra mild steel*, and *mild steel*, even including *half mild steels*, observing, in passing, that its welding commences to present difficulties which we propose to deal with in the next chapter, on the welding of hard steels.

STUDY OF IRON.

Iron is certainly the metal most widely distributed in nature. One meets it in the form of oxides, sulphides, carbonates, phosphates, silicates, etc.

The principal ores of iron which are worked are the following:—Magnetic oxide of iron, found principally in Norway and Sweden; crystallised ferrous carbonate or spathic iron ore (English mines, French and German mines, etc.); crystallised ferric oxide or specular iron ore (occurs in Devonshire, Elbe, and the Vosges); hydrated ferric oxide or brown hematite (occurs in England, France, Spain, and Germany, etc.).

Amongst the ores used in the metallurgy of iron we find magnetic oxide of iron or "magnetite" Fe_3O_4, and the ferrous carbonate or spathic iron $FeCO_3$. The greater part of the good irons of Sweden are prepared from these ores, which in the majority of cases are absolutely free from phosphorus and sulphur. If we add that the carbon employed in their metallurgy in Sweden is in the form of charcoal, which is also absolutely free from phosphorus and sulphur, the iron itself prepared in this manner must also be free. It is on account of this total absence of sulphur and phosphorus that the irons of Sweden obtain their reputation. These two substances render the metal brittle even when present in minute proportions.

Physical properties.—Iron is a greyish-white metal, ductile and malleable; after nickel it is the most tenacious of the ordinary metals.

The density is generally fixed at 7·7. Other authors adopt the figure 7·86 as the average density of pure iron.

The iron obtained by fusion melts at about 1500° C.; the melting-point of electrolytic iron can be fixed at 1600° C.

Iron, of all bodies, possesses in the highest degree the property of magnetism. This property disappears when the metal is heated to 800° C. We will recall this phenomenon later in dealing with the reheating following hammering after welding.

The crystalline structure of cast iron is so much the coarser according to whether the cooling is slow; this makes the metal brittle. The crystallisation can be modified by a process of hammering while hot. The development of the crystals can take place in the cold by purely mechanical phenomena. After hammering, rolling, or drawing, the structural changes produced necessitate annealing so as to render the metal as flexible as it was originally.

The heat conductivity of iron is not very high. Represented by the number 16 for cast iron and 18 for forged iron, the corresponding number for silver is 100.

Iron can withstand great elongation before breaking. The elongation before rupture exceeds 32 per cent. The metal is very tenacious. An iron wire 0·079 inch diameter ($\frac{5}{64}$ inch) only breaks under a load of 550 lbs.

Chemical properties.—Chemical symbol of iron is Fe; atomic weight is 56; the molecular weight, double the atomic weight, is represented by 112.

Iron can unite directly with the non-metals—oxygen, sulphur, phosphorus, arsenic, carbon, silicon, etc. It is more or less attacked by the majority of acids.

At ordinary temperatures iron does not change in dry air; in moist air it is transformed into rust, hydrated oxide of iron, arising from what we have called at the beginning of this work slow combustion.

Heated to redness iron rapidly oxidises in air; in a molten state this oxidation is exceedingly intense and practically produces a veritable combustion, which is also the case when the metal is heated to the melting-point in the presence of pure oxygen; this is the principle of cutting blowpipes.

The oxide of iron melts at about 1200° to 1300° C. It dissolves in the molten metal up to the proportion of 1·1 per cent., which corresponds to the point of saturation.

The absorption of gases by pure iron in fusion is very small, but is generally increased with the proportion of carbon contained in the metal. For mild steel it can attain twenty times the volume of the mass in fusion, except in the case of sudden cooling, when the dissolved gases escape from the molten iron before solidification.

STUDY OF STEELS.

Ordinary steels are alloys of iron and carbon, other elements only exist in relatively small proportions.

Steel is prepared by decarbonising cast iron, which gives mild steel, or, for small pieces, by carbonising iron, which gives cementation steel. The welding of this quality of steel is difficult.

The proportion of carbon contained in steel varies from 0·05 per cent. (extra mild steel) to 1·5 per cent. (extra hard steel).

Increasing the carbon diminishes the ductility and malleability of the alloy; whereas, on the contrary, the breaking-point, elastic limit, and the hardness, by tempering, are rapidly increased.

We indicate in the following table an example of the classification of dephosphorised steels which we have borrowed from the metallurgist, M. G. Charpy :—

Scale of Hardness. Numbers.	Breaking Stress in Lbs. per Sq. In.	Per Cent. Elongation at Rupture.	Chemical Composition.			
			Carbon. Per Cent.	Silicon. Per Cent.	Phosphorus. Per Cent.	Manganese. Per Cent.
1-hard	106,000 to 99,600	12 to 14	0·30 to 0·50	traces	0·08 to 0·10	0·72
2-hard	99,600 to 92,400	14 to 16	0·26 to 0·30	,,	0·08 to 0·10	0·64
3-half hard	92,400 to 85,300	16 to 18	0·22 to 0·26	,,	0·08 to 0·10	0·62
4-half hard	85,300 to 78,200	18 to 20	0·18 to 0·22	,,	0·08 to 0·10	0·54
5-mild	78,200 to 71,100	20 to 22	0·15 to 0·18	,,	0·07 to 0·09	0·51
6-mild	71,400 to 65,400	22 to 24	0·10 to 0·12	,,	0·06 to 0·08	0·46
7-very mild	65,400 to 59,700	24 to 26	0·09 to 0·10	,,	0·06 to 0·08	0·45
8-extra mild	37,000 to 40,000	26 to 28	0·08 to 0·09	,,	0·05 to 0·08	0·39
9-special	40,000 to 45,000	28 to 32	0·06 to 0·08	,,	0·03 to 0·06	0·32

The extra mild steels are difficult to cast, and the hard steels are reserved for the manufacture of special objects, particularly tools. The steels used for casting are generally mild and half mild.

The density of steels is about the same as that of iron. It diminishes very slightly as the proportion of carbon is increased.

The heat conductivity likewise diminishes, but only slightly, in proportion to the increase of the carbon content.

The melting-point of extra mild, mild, and half mild steels is in the neighbourhood of 1450° C. and 1500° C. This temperature diminishes in proportion as the proportion of carbon is increased in the alloy.

We find, therefore, from the chemical point of view, apart from the proportion of carbon which enters into composition in these steels, almost exactly the same conditions as for iron, and we have the phenomenon of oxidation indicated previously.

We have already remarked that the "irons of commerce" are generally constituted by extra mild or mild steel. In consequence, we will make no division, in the continuation of this chapter, between iron and soft steels, and we use indifferently one or other of these terms.

DIFFICULTIES WHICH OCCUR IN THE AUTOGENOUS WELDING OF MILD STEEL.

The welds on mild steel, which apparently are the most easy to obtain, are, in reality, those which require on the part of the welder the most thought and care.

True, if it is a question of pieces where the line of welding has no serious strain to support, which is fairly frequent in current welding practice, the joining with the blowpipe is always an advantage and requires no special precautions; it is evident that, for such work, autogenous welding of iron can be considered most easy to execute.

It is otherwise when one requires of the weld mechanical properties approaching that of the metal to be welded; in other words, autogenous.

Except in the case where the process is applied with a knowledge of the technique, the strength of the metal and, above all, its elongation are considerably lowered; in short, the operation of welding can lower, in the line of joining, the principal qualities of mild steel which are particularly required in metallic construction, notably in boiler work.

The misfortune is that the autogenous welding of mild steel is apparently so simple and gives results sufficient for joints to be passed without trouble. Welders who are often ignorant of the phenomena produced during the melting of the metal under the blowpipe believe their welds are perfect because they look well; they become self-satisfied, never doubting their ability, and undertaking with a light heart welds which require precisely those qualities of the metal which are lost in fusion. Hence the failures, even accidents, which may occur a long time after the work is done, through defects in the welds.

The various companies and administrations that have the control of steam plants are often right in not trusting to the apparent good joining of iron by autogenous welding, and reserve to themselves the right to sanction or forbid the process. Autogenous welding, when well applied, constitutes an excellent method of joining, but when applied too soon, that is to say, before the time is ripe, it suffers considerably.

Thus iron, which is so easy to unite by melting under the action of the blowpipe, loses its qualities and acquires defects during the course of the operation. Let us study the phenomena which manifest themselves, and examine the correct methods to avoid their effects.

Fig. 175.—Weld of mild steel executed without bevelling; adhesion and interposition of oxide (photograph after corrosion test).

The principal enemy of welds on iron and steel is *oxidation.*

We have seen that iron when heated to redness, and even more so when melted, oxidises. This oxidation is caused by contact with the oxygen of the air, or the presence of water vapour coming from products of combustion.

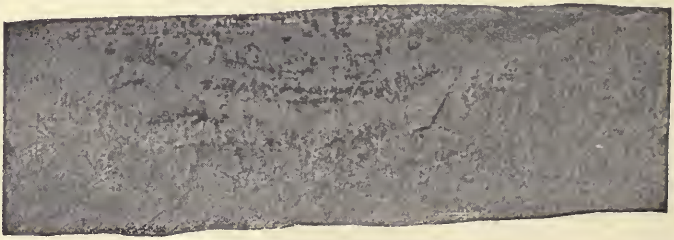


Fig. 176.—Interposition of oxide and burning of the metal in a weld of mild steel (photograph after corrosion test).

The contact with the air cannot be avoided, because the flame is surrounded by it.

Water vapour is produced whatever welding flame is used. True enough, acetylene produces it in the least quantity, but it exists none the less, and the molten iron oxidises in contact with it.

There is always formation of oxide of iron at the surface of iron or steel melted under the action of the blowpipe.

We have previously said that this oxide, more fusible and less heavy than the iron, rises to the surface of the welds and eliminates itself either by being moved from the surface or by forming a non-adherent superficial crust which can be detached after the operation.

Things do not go so well as this. Another phenomenon intervenes — *the dissolving of the iron oxide in the iron itself*, and the dissolved oxide remains well imprisoned in the metal after cooling.

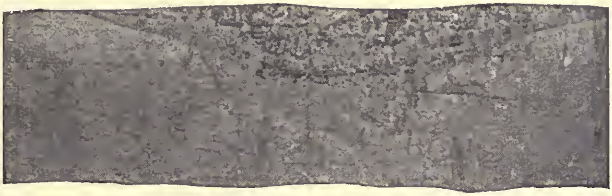


Fig. 177.—Burnt metal in the upper part of a weld (photograph after corrosion test).

Iron in a molten state dissolves 1·1 per cent. of oxide, and this proportion is always attained whenever one melts this metal, or mild steel, by the aid of the blowpipe.

Thus even the best welds executed (except those done with a knowledge of the technique, which we will give shortly) always retain the oxide of iron dissolved in the molten mass, and this is sufficient to prevent the joint having the strength and elasticity of the original metal—qualities particularly required.

Let us go still further. The oxide of iron which is diffused in the molten mass reacts with the carbon or the manganese which is contained in steels and destroys these elements. In the matter of welding mild steels this is not of great importance, but it is useful to mention all the consequences of oxidation. Notice, in addition, that the dissolved oxide destroys itself in destroying the elements mentioned above, is immediately replaced in the mass, which is constantly found saturated with a kind of carbon and burnt manganese, so that these elements cannot play the useful rôle of reducing agents.

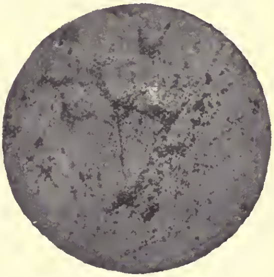


Fig. 178.—Microphotograph showing a track of oxide of iron in a weld of mild steel (magnified 50 diameters).

Lastly, the oxide of iron can be *interposed* in the weld, which frequently happens even in work done by experienced but thoughtless welders. One finds layers of oxide either at the bottom of the line of welding, or on the edges, bevelled or not, or even in the middle of the molten metal when the operation has been badly done. True, the defect can be avoided, but who is the welder who can say that he is completely free from it?

To continue—*adhesion* is common in the welding of mild steel, because the high temperature necessary for uniting the edges brings about melting of the welding rod before the sides are ready, as that is more in contact with the flame and more fusible than the piece being welded. Adhesion is, moreover, generally accompanied by a thick layer of interposed oxide.

The *dissolving of gases* is not a serious disadvantage when the welders are experienced, as they give the metal time to give them up to the atmosphere by progressive solidification.

There remains, lastly, the *internal structure of the metal*, which does not possess, in the coarse welds, the necessary qualities for obtaining good mechanical properties. The abrupt passage from one molecular structure to another between the line of welding and the metal of the piece is sufficient to constitute a *heterogeneous* joint, which can considerably lower its strength. We shall see that we can overcome this disadvantage by *hammering* and *annealing* after welding, operations which are indispensable for welds that will have to withstand deflections, tension or shocks.

One sees, then, that the obtaining of *good welds* in iron or mild steel offers serious difficulties. Certainly it might be thought that we had painted the picture black, but things are just as we have indicated. We shall see that all these evils possess remedies, and when well applied the process is capable of giving all that the welder can require of it.

It is understood that the methods which we are about to indicate apply to the realising of the most perfect welds possible; pieces that have not to support strains or shocks can evidently be welded with less precaution, but even in the latter case it is useful for the welder to work with normal care, because it is difficult to get rid of bad habits contracted in doing work requiring little care.

And, lastly, let us state that the technique of the autogenous welding of iron and mild steel, so long neglected, is scarcely outlined yet. Meanwhile one obtains results sufficiently satisfactory for applying the methods on a vast scale, and with sufficiently large guarantees. We foresee, however, the rational extension of present applications, and it is under this title that we develop certain passages in this book which will indicate probable methods, which, up to the present, have not yet been made exact. Leave to the technical specialists, and notably in particular the laboratory of the *Union de la Soudure Autogène,* the task of establishing these methods.

PREPARATION OF WELDS.

A large number of the indications given in Chapter XI., "General Notions on the Preparation of Welds," and especially the latter part of the chapter, apply to the preparation of pieces of iron and mild steel.

Let us recall that above ⅛ inch the edges of the weld should be bevelled under the conditions which have been indicated.

One takes care to get perfect adjustment, and to take the precautions necessary to overcome the effects of expansion—tacking the pieces or separating them in the form of a "V."

Iron and mild steel being very ductile, breaks on cooling are not greatly to be feared. However, there are cases in which they can be produced, notably in going over the line of welding after the first melting.

For all that concerns these questions we refer the reader back to the chapter specially designed to deal with them.

CHOICE OF BLOWPIPE.

The blowpipes destined for welding iron and mild steel, for obtaining homogeneous and strong joints, should be chosen from among the best. The quality of the blowpipe has a direct influence on the quality of the welds.

It has long since been asked why the welds done with dissolved acetylene are superior to the welds obtained with acetylene under low pressure. The reasons are now known, and are as follows:—Dissolved acetylene gives a normal flame with an equal volume of oxygen, whereas in the other blowpipes the proportion of oxygen to acetylene varies from 1·2 to 1·8; this oxygen in excess contributes to the oxidation of the welds.

On the other hand, dissolved acetylene is always purified, an operation which is not the common practice in low pressure installations.

Lastly, the small white jet in blowpipes using dissolved acetylene is without rigidity, and does not sweep the molten metal. This point is of considerable importance, because the interposition of oxide in the welds is, above all, due to the rigidity of the flame. It is therefore necessary to obtain blowpipes for acetylene under low pressure which possess the same working qualities as those used for dissolved acetylene, *i.e.* consumption of oxygen approaching as near as possible the theoretical value, a flame which is not rigid, and which does not sweep the molten metal. Let us add that the acetylene produced from generators should be freed from the impurities it contains, especially phosphorus and sulphur, which are so detrimental to irons and steels.

Of course the blowpipes should possess all the other qualities usually required—easy regulation, stability of flame, conveniently employed, etc., etc.

Here are the approximate powers to be used according to the thicknesses to be welded:—

Thickness of Metal.	Delivery of the Blowpipe. Acetylene per Hour.	
In Inches.	In Litres.	In Cubic Feet.
$\frac{3}{64}$	75 to 100	2·6 to 3·5
$\frac{5}{64}$	150 to 200	5·3 to 7·1
$\frac{1}{8}$	300 to 350	11·5 to 12·4
$\frac{5}{32}$	350 to 425	12·4 to 15·0
$\frac{13}{64}$	450 to 525	16·0 to 18·5
$\frac{1}{4}$	525 to 575	18·5 to 20·0
$\frac{9}{32}$	575 to 625	20·0 to 22·0
$\frac{21}{64}$	625 to 700	22·0 to 24·8
$\frac{23}{64}$	750 to 800	26·5 to 28·2
$\frac{13}{32}$	1000	35·0
$\frac{15}{32}$	1200	42·5
$\frac{19}{32}$	1500	53·0

Let us recall in connection with this that when the deliveries are not engraved on the blowpipe, it is a good plan to fix up a table near the welding bench indicating the deliveries for each blowpipe or each nozzle where these are interchangeable or of variable delivery.

REGULATION OF THE FLAME.

The regulation of the flame should be perfectly assured and maintained during the course of the execution of the weld. In fact, if the flame contains an excess of acetylene, carbonisation of the metal takes place. On the contrary, excess of oxygen produces intense oxidation. (This defect of regulation is much more common.)

Those blowpipes in which the flame is not seriously put out of order, by heating during welding, have a marked superiority. In any case, the welder should see that the flame is always perfectly regulated, that is, presents the characteristics indicated in the preceding chapters—the small white jet as large as possible, provided the edges are sharp and clear; that is to say, there is no excess of acetylene.

A too rigid flame which brings about intense oxidation and sweeps the molten metal is often due to the use of too great a pressure of oxygen. *We repeat that the pressure of oxygen should be as low as possible, and it is good to well digest all we have said on this subject.*

WELDING ROD.

The welding metal used for the welding of iron and mild steels should be a wire of soft iron, as far as possible Swedish iron of the first quality. The choice of a good welding metal is very important. We have seen that the welding of iron and steels produces defects which are difficult to overcome; it is therefore necessary to add to the line of welding a metal of first quality able to counterbalance, to a certain extent, the loss in mechanical properties due, notably, to oxidation.

The welding metal should be particularly free from phosphorus, sulphur, and slag, and should be homogeneous.

Workshops do not attach sufficient importance to the choice of a good welding metal. It seems to welders that the higher price of Swedish wire is an obstacle to its use. Nevertheless, the difference when put in its right place is relatively insignificant, and is an infinitely small proportion of the cost of the work, gases and labour for example. If those who use autogenous welding for iron and steels would only take into account the improvement brought about by using a welding metal of first quality, the ordinary irons, actually used in the majority of workshops, would immediately be rejected.

The welding metal is used in the form of round wire or rods, or in flat or square rods. We give here the diameter of rod to use for various thicknesses to be welded:—

Thickness of Welds in Inches.	**Diameter of Welding Rod in Inches.**
$\frac{3}{64}$	$\frac{3}{64}$
$\frac{5}{64}$ $\frac{1}{8}$	$\frac{5}{64}$
$\frac{5}{32}$ $\frac{13}{64}$	$\frac{1}{8}$
$\frac{1}{4}$	$\frac{5}{32}$
$\frac{9}{32}$ $\frac{21}{64}$ $\frac{23}{64}$	$\frac{13}{64}$
$\frac{13}{32}$ $\frac{15}{32}$ $\frac{19}{32}$	$\frac{13}{64}$, $\frac{13}{64}$ to $\frac{1}{4}$.

Afterwards, $\frac{9}{32}$ inch for all thicknesses above those given.

Previously rods of *plaited* wire with two, three, or four strands were used. This method has been abandoned, and with good reason. In fact, a welding rod thus constituted offers, during he melting, a very large surface for oxidation, the very fault one endeavours to avoid.

The *Union de la Soudure Autogène* has carried out researches on a welding metal which contains a deoxidiser capable of eliminating the oxide of iron according to its dissolution in the mass in fusion. Such a welding rod is of great importance for the perfect execution of welds on iron and steel.[1]

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[1] The researches of the *Union de la Soudure Autogène* on this point have been completed, and a satisfactory welding rod for iron and mild steel has been produced.

Until these are completed one should use a welding metal as pure as possible, made, for example, of Swedish iron of first quality, which gives, when all the other points are followed, very acceptable results, often better than are required.

CLEANING FLUX.

We have said that the oxide of iron, apart from that dissolved in the metal, generally floats on the surface of the molten bath, but, as we have remarked, there is often an interposition of oxide either at the bottom of the bevel, on the sides, or in the metal itself.

The use of a *flux*, that is, a product capable of *slagging* the oxide, is therefore indicated.

Until recently welders have not troubled about the application of such a flux, and the good appearance of the welds has proved sufficient for them. If they had carried out corrosion tests and bending tests as we have advised, they would see that their welds have not always the qualities which they assume they have given them, and that they are not exempt from layers of oxide.

Many fluxes for the autogenous welding of iron and mild steels have been proposed. They give good results from certain points of view, but, on the other hand, they present certain defects which should be avoided.

A good flux should give a very fusible slag, very fluid, and very light; it should be without action on iron or carbon, of homogeneous application, and easily employed.

The *Union de la Soudure Autogène* has actually studied a product which seems to possess all these desiderata, and the method of use will be published shortly after the appearance of this work as soon as the tests are concluded.

EXECUTION OF THE WELDS.

All the useful details, relative to the execution of welds, which we have given in Chapter XII., and the instructions which it contains, apply very particularly to the autogenous welding of iron and mild steel.

The preheating of the edges to be welded is not generally practised, because the effects of the phenomena of expansion and contraction are little to be feared on account of the elasticity of the metal. Let us notice, however, that if it is a question of great thicknesses, a preliminary heating obtained by the use of ovens or a flame burning the oxygen of the air, is of economical application, since it supplies heat towards the melting of the metal.

The welder should take the precautions which we have given to avoid overlapping or deformation of the edges during the execution of the weld.

The flame of the blowpipe is made to approach the metal until the *extremity of the small white jet licks the metal and produces melting*,[1] this without too much exaggeration. The blowpipe is held in the position we have indicated, and given a circular or oscillatory movement (see figs. 160 and 161). As for all welds, the edges to be united should be melted before bringing the welding rod in contact. The welds should be done without haste, but without going back or stopping.

To conclude, we give relative indications of speed of working for welds on steel plates. The figures are only approximate.

Thickness of Plates in Inches.	Speed of Working per Hour.	
	For one Hour (in Feet).	Average Per Hour for a Day's Work (in Feet).
$\frac{3}{64}$	30 to 33	23 to 26
$\frac{5}{64}$	20 to 21	16 to 20
$\frac{1}{8}$	15 to 16	13
$\frac{5}{32}$	13 to 15	10
$\frac{13}{64}$	10 to 12	9·0
$\frac{1}{4}$	9 to 10	7·5
$\frac{9}{32}$	8 to 9	6·5
$\frac{21}{64}$	7 to 7·5	5·8
$\frac{23}{64}$	5·5 to 6·0	4·9
$\frac{13}{32}$	4·25 to 4·5	3·25
$\frac{15}{32}$	3·25 to 3·6	2·6 to 3·0
$\frac{19}{32}$	2·25 to 2·5	1·6 to 2·0

The speed varies rather considerably according to the shape and dimensions of the pieces, because of the loss of heat by conductivity.

We repeat that the figures given above are only approximate and apply to the welding of plates.

Preliminary heating permits the increasing of the speed of working or diminishing the power of the blowpipe.

TREATMENT AFTER WELDING.

We have seen that the metal melted under the action of the blowpipe consists of a crystalline mass whose texture differs distinctly from that of the neighbouring metal. The *grain* is much larger, almost a hundred times more than that in the adjacent portion of the weld, which is, on the contrary, very fine, due to a veritable *annealing* in the vicinity of the line of welding during the operation. The joint lacks homogeneity.

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[1] The small white jet should be in contact with the metal, because the melting-point for iron and steels is very high. In the welds on cast iron, copper, brasses, bronzes, aluminium, etc., the small white jet, on the contrary, should be held slightly away, as we shall explain later.

Further, the effects of successive expansion and contraction produce, as we have already shown, *internal strains* which the metal can stand, thanks to its tenacity, but which are, nevertheless, unfavourable to the strength of the welds.

Lastly, one recognises the advantages which result from mechanical treatment, such as rolling or hammering. The line of welding constituted of the metal which has been melted requires that it should be thus *worked*, and the properties required in a good joint are not obtained except by this condition.

Fig. 179.—Microphotograph showing the grain of the metal, the weld unannealed (magnified 50 diameters).

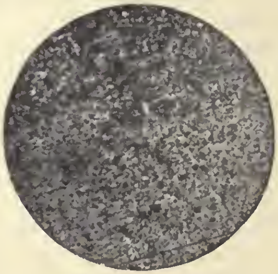


Fig. 180.—The grain of the same weld after annealing (magnified 50 diameters).

These properties are obtained, then, by a double treatment of the welds after their completion—annealing and hammering.

Fig. 181.—Fissure in a weld through hammering at too low a temperature (magnified 50 diameters).

The hammering and annealing can be done immediately after welding, thus taking advantage of the heat in the metal. If it is a question of welds of great thickness, it is advantageous to have a workman following the welder and who, with the aid of a blowpipe and appropriate hammer, performs these operations immediately after the welding.

Hammering and annealing should only be applied at a high temperature, in the vicinity of 950° *C., that is, at a bright cherry red.* Hammering at too low a temperature, even on good welds, can bring about the formation of fissures or cracks in the added metal. Annealing at too low a temperature after hammering increases the size of the grains instead of making them finer, and makes the line of welding excessively fragile. Welds have been known to break to pieces under an insignificant shock, the effect of bad annealing.

With regard to the process of annealing, the operation should be conducted in the following manner:—The line of welding and its immediate vicinity should be raised to a *bright cherry red*, by the aid of a welding blowpipe or any other process of heating. The use of a more powerful blowpipe than that used for welding the joint is advisable. Distribute the heat so that the temperature is uniform in the parts submitted to the treatment, and avoid all contact between the small white jet and the metal. When the temperature is obtained, allow it to cool normally.

For small pieces, where the greater part reaches cherry red, tempering after annealing is advisable, because the sudden cooling gives the metal a still finer grain.

If the weld is to be hammered, the metal round about should be raised to a white heat. The hammering is stopped as soon as the temperature falls to that of dull red. A new heat must be applied if the hammering is not completed.

The exact appreciation of the temperature at which to stop hammering is a delicate matter for workmen not used to working at the forge.

In order to know it, advantage can be taken of the magnetic properties of iron, of which we have previously spoken. In reality, the magnetism of iron, which is very intense at 770° C., becomes *nil* at 800° C. The magnet constitutes an excellent indicator of temperature for hammering welds, since the hammering should be stopped a little below 800° C., that is, as soon as the magnet is attracted the hammering should cease.

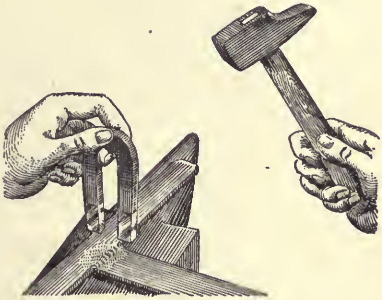


Fig. 182.—The hammering of a heated weld of mild steel should be stopped as soon as the magnet is attracted.

Hammering and annealing considerably improve the mechanical properties of the welded lines. If the operation of hammering cannot be done, one should not forget that simple annealing with the blowpipe, so that the metal is brought to a bright cherry red, gives excellent results, since it raises the elongation 5 to 15 per cent. in the welded part.

RESULTS OF TESTS.

A very large number of mechanical tests, both official and private, have been carried out on welds on mild steel, and it would be difficult to give the papers here or even a summary.

The principal defect of the welds is the lack of elongation, especially when they have not been hammered and annealed.

The joints obtained under average conditions of execution and having been submitted to hammering and annealing give qualities which are sufficient from the point of view of elongation, and which are highly acceptable for a great number of applications, even important ones. The elongation obtained for ordinary mild steel has an average value of 12 to 18 per cent., a number which is not obtained by any similar process of joining.

The numbers for strength are equally favourable, since the breaking stress varies, for welds of average quality, from 48,000 to 51,000 lbs. per square inch.

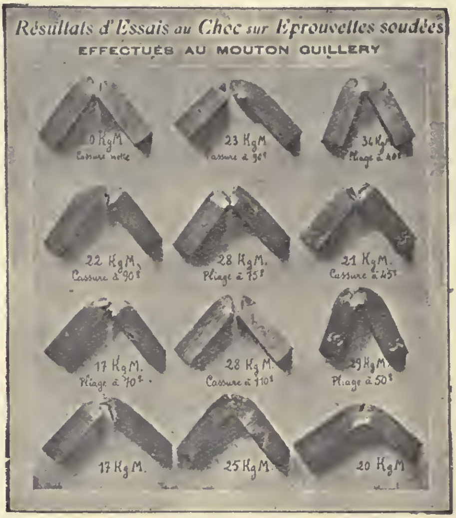


Fig. 183.—Results of tests by shock on welded test pieces.

Shock tests give equally satisfactory results.

It is certain that, thanks to the improvements which will shortly enter into the current practice of welds on mild steel, *i.e.* the use of a special welding rod and cleaning flux, these results will be still further improved, but, at the present, one might say that the process is sufficiently advanced to be applied to a multitude of jobs, even where good quality of joining is particularly desired.

APPLICATIONS OF AUTOGENOUS WELDING TO IRON AND STEELS.

We would require the entire volume in order to enumerate the jobs in iron and steels which can be done advantageously by autogenous welding. We will just mention a few examples, taken from a thousand, without too much delay in describing the method of execution of the welds, which we have already dealt with in this or in the preceding chapters.

Apart from the special qualities which are obtained in the joining by autogenous welding, the economy of the process is the principal factor which appeals to manufacturers.

We have given all the elements necessary for fixing the cost of welds, *i.e.* consumption of oxygen and acetylene, price of these principal materials, speed of execution, etc., so that it is easy, our figures being rigorously true, to fix the cost compared to other methods of joining, and see what economy results from autogenous welding. One finds that, in a very large number of cases, this economy is considerable. We will leave each one to find it out according to the kind of work to be done, the jobs being so varied that any particular example might be misleading as an element of comparison.

Fig. 184.—Art ironwork executed by autogenous welding.

Let us choose, haphazard, some jobs from amongst those which are generally executed.

We have, first of all, the thousand and one joins which practically have to support no serious load, and which one can execute readily without any special precautions.

Art ironwork, a large variety of pieces of ironmongery and lockwork, and a large variety of household articles.

There are also some simple objects which are easily constructed by autogenous welding, and which are manufactured on a vast scale—buckets and similar vessels made from mild steel plates, elevator buckets, garden seats and metal tables, pieces of armour, freezing moulds, etc.

The manufacture of certain other objects is more interesting, because it entails a process of manufacture which is quite new, and consists of joining by welding two stamped plates so as to form a hollow body, and which could not previously be done so easily, advantageously, and satisfactorily—sheaths for swords and bayonets, handles for knives, walking sticks or umbrellas, parts of radiators for central heating, various hollow bodies, etc.

The same process is applied to pieces which require much greater strength, bicycle frames, for example. This manufacture is similar to the manufacture of pipes and tubes by welding rolled plates together. When the joints are well executed one obtains absolutely homogeneous pieces of equal value to that obtained by drawing.

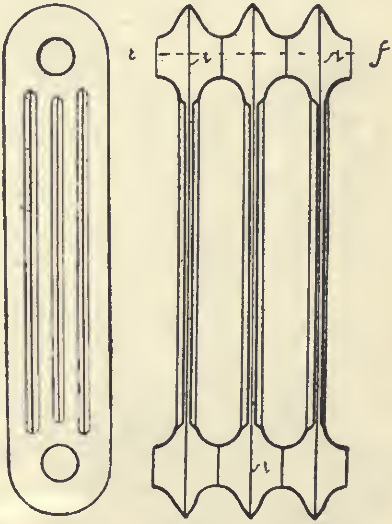


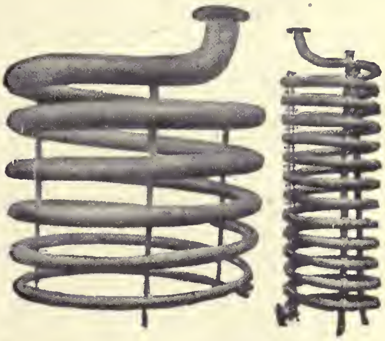
Fig. 185.—Radiator elements for central heating, made from plates of mild steel autogenously welded.

The manufacturers of cycles, automobiles, and aeroplanes can make great use of autogenous welding both for the construction of details and their joining. On the Continent, bicycles in the majority of cases are made entirely by autogenous welding. This work is executed by welders who have specialised in it and who can manipulate the blowpipe without burning the metal.

In the automobile and aeroplane industry the oxy-acetylene blowpipe is applied on a vast scale. It has even been proposed to manufacture the entire motors with it—cylinders, pistons, etc., in the double aim of lightness and strength.

We have already mentioned the manufacture of pipes and tubes. One obtains, by welding, tubes of all forms and of all diameters, which would be very costly if made by the old process. We mention here coppersmithing, and this requires us to mention the manufacture of vapour receivers, casing and details for water circulators, superheating tubes, tube systems for blast furnaces, recovering furnaces, steel works, coal mines, coils of all forms and of all dimensions, etc.

The manufacture by autogenous welding of vessels destined to receive liquids or gases under pressure has been greatly developed. Let us also mention vessels or vats with double bottoms or a double envelope for use with chemical products; also the manufacture, entirely by welding, of boilers for central heating and vertical multitubular boilers.



Figs. 186 and 187.—Coils made by autogenous welding.

The coppersmith trade can make very extensive use of autogenous welding, and already its applications are very numerous.

The openings are equally important in the locksmith trade and constructional work in metal. A multitude of permanent joints can be economically obtained, and solidity assured by autogenous welding.

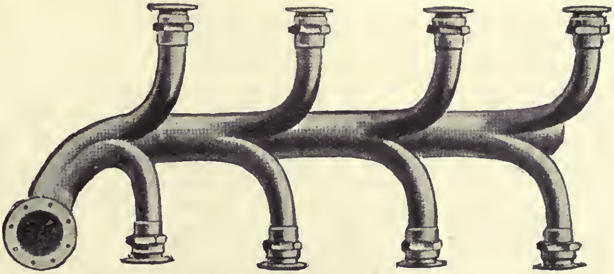


Fig. 188.—Arrangement of tubes for aviation motor, manufactured by autogenous welding.

The process has given rise to the manufacture of pieces which previously were not given to this industry, for example, window frames entirely in metal.

In loom construction, autogenous welding is equally capable of numerous applications. The cases are so numerous that one cannot attempt to enumerate them.

The combination of the cutting blowpipe and the welding blowpipe enables one to obtain articles formerly very difficult and costly to manufacture by the forge. Thus one can obtain, by cutting and welding successively, plates, angle irons, and iron of various profiles, and details of all forms entering into metal construction.

Fig. 189.—Vapour collector made by autogenous welding. Tested hydraulically the plates closing the branches were fractured but the welds unaffected.

We will cease enumerating the new pieces that can be obtained by autogenous welding, and conclude with *repairs.*

Fig. 190.—Repair of crank-shaft.

It will be seen that autogenous welding can be advantageously applied to a multitude of cases of repairs to iron or mild steel. It is often the only process which allows the recovery of broken, deformed, or worn-out details.

Let us mention, first of all, the use of the blowpipe for filling in blowholes and pits in articles of cast steel. If the operation is well conducted it is possible to reconstitute exactly the metal of the article by the added material.

Castings of mild steel often have cracks which can be repaired in a perfect manner.

The repairs by autogenous welding on iron and mild steels can be done on all kinds of construction, and in the majority of cases they offer, as we have shown, exceptional advantages.

It is obvious that not only those manufacturers who make a speciality of repairs, but also all those who make use of machinery, etc., such as sugar refiners, chemical manufacturers, distillers, etc., should have at their disposal a welding plant.

Fig. 191.—Repair of stern-post of steamer.

Fig. 192.—Repair of rudder of steamer.

Marine repairs by autogenous welding, and especially those that interest boilermakers, constitute a speciality, and should not be undertaken unless the welder is perfectly acquainted with their execution.

Space cannot be spared in enumerating the numerous jobs which can be executed by autogenous welding. One can simply say that, well applied, the process can be of considerable use in all kinds of constructions and repairs, and can well replace in many cases other methods of joining. It is sufficient to apply it with a full understanding of the conditions.

CHAPTER XIV.

AUTOGENOUS WELDING OF HARD STEELS.

We will condense, in this chapter, the particulars relating to the welding of hard steels. The technique of the treatment of these metals by blowpipe welders is still little developed, and they should be considered, for the moment, as very imperfectly weldable.

The preceding chapter was devoted to mild steels, and we have shown that we included in that category the *half mild* steels which, although not behaving so well as the first mentioned, can be treated, for the moment, in the same manner.

It remains for us to examine the steels called *half hard*, *hard*, and *extra hard.*

We will give a few notes on special steels at the beginning of Chapter XVIII., which deals with the autogenous welding of various metals and alloys.

CLASSIFICATION, PROPERTIES, AND USE OF THE HARD STEELS.

Hard steels are divided into four classes according to their carbon content, viz. *half hard*, *hard*, *very hard*, and *extra hard.*

We give, in the following table, the composition and principal mechanical properties of each kind :—

Material.	Per cent. of Carbon.	Ultimate Tensile Strength in Lbs. per Sq. In.	Elastic Limit in Lbs. per Sq. In.	Per cent. Elongation.
Half hard steels .	0·40 to 0·6	78,000 to 92,000	45,000 to 54,000	18 to 22
Hard steels .	0·60 to 0·7	92,000 to 107,000	54,000 to 64,000	15 to 18
Very hard steels .	0·70 to 0·8	107,000 to 121,000	64,000 to 71,000	8 to 15
Extra hard steels	0·80 to 1·2	121,000 to 142,000	71,000 to 78,000	5 to 8

The elongation, which is in the neighbourhood of 30 per cent for extra mild steels, falls to about 20 per cent. in half hard steels, and 5 per cent. in extra hard steels.

The elastic limit and the tensile strength, on the contrary, increase with the percentage of carbon, the respective figures for the two extremes being 34,000 to 78,000, and 57,000 to 142,000 lbs. per square inch.

The density of hard steel is slightly lower than that of mild steel. The melting-point is lowered according as the proportion of carbon is increased. The following is the melting-point for each of the classes :—

Half hard steel	1430° C.
Hard steel	1380° C.
Very hard steel	1360° C.
Extra hard steel	1350° C.

The heat conductivity likewise decreases as the proportion of carbon is increased.

The principal applications of the hard steels are :—

Half hard steels. — Castings, axles, transmission shafts, piston-rods, etc., slide-blocks, ploughshares, boring bars for mines, ordinary cutlery, armour pieces, dies, pincers, edge tools, tyres, springs, etc.

Hard steels. — Castings, springs, rails, wire for cables, paper guillotines, edge tools, quarry wedges, hammers, cutlery, dies, tyres of great resistance, boring bars for soft stones, fish plates, shares and mould-boards for ploughs, reaping hooks, various tools, files, tools for stone and earth, etc.

Very hard steels.—Tools, springs of great resistance, files, saws, balls for grinding mills, punching tools, pruning-bill, sécateurs, milling cutters, fine cutlery, etc.

Extra hard steels.—Tools, spinning-mill pins, saws, files, miners' drills, rolls for rolling mills, cable wire of great resistance.

DIFFICULTIES ENCOUNTERED IN THE AUTOGENOUS WELDING OF HARD STEELS.

The present technical knowledge of the autogenous welding of hard steels is not very encouraging; the obtaining of homogeneous welds by fusion with the blowpipe is reserved for the future. If the process offers any interest for the welding of certain articles of half hard and hard steel it is, on the contrary, practically inapplicable to extra hard steels, and it is not very probable that the improvements which may be introduced will render weldable the two latter qualities.

The difficulties encountered are extremely serious; the molten metal under the action of the blowpipe always suffers considerable *decarbonisation.* Interposition of the oxide is very common on account of the melting-point of the metal not exceeding that of the oxide formed. Lastly, the most serious defect is in *the burning of* *the metal adjacent to the line of welding*, and it is this disadvantage which, without doubt, one will never be able to avoid, since it takes place not in the molten mass, but in the parts which surround it. There is produced a *segregation* of *cementite*, sometimes accompanied by the formation of voids ; this tends to produce an intense oxidation in the joints of the cells.

We will not enter further into the description and the explanation of this phenomenon, which belongs to more advanced metallurgy. It is sufficient to state that it exists, and is very difficult to avoid. *In consequence it is better, at least for the moment, to abstain from using the blowpipe for welding very hard and extra hard steels.* The half hard and hard steels can be treated as we will indicate. It is well to abstain as much as possible from welding the latter, except in special cases, or where the strength of the joints are not important.

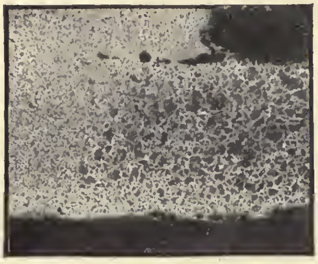


Fig. 193.—Decarbonisation of hard steel in a weld.

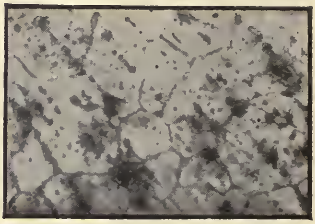


Fig. 194.—Burning of the metal in the neighbourhood of a weld on hard steel.

METHODS OF WELDING.

The welds on *half hard* steel are prepared in the same way as for mild steel. For the same thickness of metal a slightly more powerful blowpipe is used than for the latter.

The welding rod to be used is iron or mild steel of good quality.

One uses for a cleaning flux a base of carbonate and bi-carbonate of soda, as used for the welding of cast iron. The flux used for the welding of mild steel gives results which are not quite so good.

The weld should be done as rapidly as possible, then annealed at about 800° C. (cherry red). In view of the rapid execution of the weld, reheating of the line of welding is advisable.

Although welds on half hard steel begin to have the disadvantages we have mentioned, yet they can be considered as practicable and sufficiently good for the purposes required in a great number of cases, if the conditions of realisation which we have indicated are observed.

The welds on *hard steel* are, as we have said, only to be undertaken in special or extreme cases. Here is the best method of working we can indicate:—Use a blowpipe of much higher power than for the same thickness in mild steel, and first heat the whole of the edges to be welded to a cherry red. Execute the weld *very rapidly* with the aid of a welding rod made of half hard steel, and use the cleaning powder used for cast iron. After welding, hammer at 800° C., afterwards anneal at about 950° C.; after cooling, anneal a second time to redness (650° C.).

CHAPTER XV.

AUTOGENOUS WELDING OF CAST IRON.[1]

The oxy-hydrogen and oxy-acetylene blowpipes were not applied immediately after their introduction to the welding of cast iron. It was declared at that time that the repairing of pieces of cast iron by autogenous welding was *impossible*, the reason given being that the metal under the action of the blowpipe became as hard as flint, and in the majority of cases the article broke on heating or on contraction. Obviously the technique of autogenous welding at that time was not very advanced, or the welding of cast iron would not have been declared *impossible*. With certain welders at the present day the good welding of cast iron is supposed to be unrealisable. These simply lack the necessary technique and, above all, reflection.

As a matter of fact, the welding of cast iron is the easiest of all, or rather that which gives the best results, in the sense that the piece repaired is, in the case of good workmanship, generally of a superior quality to the rest of the piece. To require more than this would, in truth, be an excessive demand.

When everything is taken into account, the difficulties to be overcome are neither numerous nor insurmountable. The first welders complained of the hardness of the welds and the breaks on contraction. We shall see how easy it is to apply infallible remedies to these two faults.

GENERAL PROPERTIES OF CAST IRON CONSIDERED FROM THE AUTOGENOUS WELDING POINT OF VIEW.

The generic name of cast iron or *castings of iron* is applied to alloys of carbon and iron in which the proportion of carbon is between 2·5 and 6 per cent.

Cast iron cannot be forged, and consequently articles in this metal are obtained by casting.

In the large majority of cases the cast iron used for castings contains from 3 to 4 per cent. of carbon. The carbon can be present in very different states: either combined with the iron or dissolved

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[1] A note on the autogenous welding of malleable iron and the joining of iron to cast iron appears in Chapter XVIII.

in the metal to which it communicates great hardness; or in the free state, in the form of particles of graphite disseminated in the mass.

In the first case, carbon combined or dissolved makes the metal very hard and difficult to work; in this case it is an alloy known as *white cast iron.*

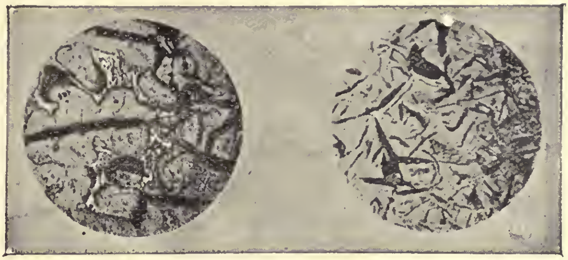

Fig. 195.—Microphotographs of two samples of grey cast iron; notice the particles of carbon in the free state.

In the second case, most of the carbon is in the free state, the metal is soft and easy to work, and is known as *grey cast iron.*

Since the majority of welds in cast iron should be capable of being worked, it is indispensable that the line of welding should be constituted of **grey iron.** The majority of castings are in grey iron.

Fig. 196.—On the left, microphotograph of white cast iron; on the right, malleable cast iron. In the latter one can follow the progressive decarbonisation of the cast iron.

The obtaining of welds of grey iron depends solely on the state of the carbon in the metal; it is necessary to study the causes which facilitate or prevent its precipitation in the form of graphite.

The rapid cooling of the metal in fusion tends to bring about the combination of the carbon and the iron, that is to say, the formation of *white iron.*

On the other hand, slow cooling or reheating tends to bring about the precipitation of the carbon, and thus produces a softer iron.

Silicon introduced into cast iron in the form of ferro-silicon takes the place of the carbon, which tends to alloy with the iron and compels it in some way to take the form of graphite, and thus facilitates the formation of grey iron.

Manganese, on the other hand, opposes the precipitation of graphite, and leads to white iron.

These important effects being known, it is easy to state the general conditions to be observed for the formation of a line of welding in grey iron, that is to say, one easy to file and workable by tools:—

(1) *Slow cooling.*

(2) *Introduction of silicon in the welding rod.*

(3) *Absence of manganese*, which element is often present in cast irons in sufficient quantity to produce the formation of white iron during the process of welding.

It is much more necessary to observe these conditions, than the local fusion and consequent rapid cooling of the metal, the phenomena of oxidation, decarbonisation and volatilisation, of which we will speak, all conducive to the formation of white iron.

According to the proportion of carbon which the cast iron contains, the melting-point varies from 1050° to 1200° C., a temperature at least 300° C. lower than the melting-point of iron. The melting-point of the cast iron which welders mostly deal with is about 1150° C.

The oxide of iron formed melts at about 1350° C., and therefore cannot, as in the case of iron or steel, be melted and swept away by the flame, but forms an agglomerate in the form of crusts surrounding each part exposed to the air.

It is therefore necessary to destroy this oxide, which prevents the combination of the molten metal and also burns the carbon, and thus is conducive to the formation of white iron.

The excessive heat of the welding flame can bring about an alteration of the metal during welding, notably its decarbonisation and the volatilisation of the silicon. We shall explain the methods to prevent these changes in the metal.

The *quantity of heat required to melt* cast iron is great, that is to say, the quantity of heat necessary to melt a certain weight of cast iron is greater than that required to melt the same weight of aluminium or iron for example.

Cast iron can be classed amongst the bad conductors of heat; it is devoid of elasticity and elongation before rupture.

It is therefore always necessary to foresee that in the case of welding cast iron the phenomena of expansion and contraction can bring about breaks if the shapes of the pieces oppose free play of the metal on heating or cooling, and it is often necessary to take very special precautions to avoid the same.

DIFFICULTIES ENCOUNTERED—DEFECTS OF WELDS.

The difficulties encountered depend almost exclusively on the phenomena just mentioned; the hardness of the metal melted by the action of the blowpipe making it impossible to work on it with tools, and producing cracks or breaks either in the line of welding or elsewhere during the welding or on cooling.

These difficulties are avoided, as we have said and as we will explain better later, by using a welding metal of good quality, free from manganese and containing a high percentage of silicon, also a suitable cleaning flux. The effects of expansion and contraction are overcome by preheating every part of the object, or by any other treatment bringing about the same result.

We will recall that the lack of elasticity renders cast iron particularly sensitive to the effects of expansion and contraction, especially when the heat is localised, as is the case when autogenous welding is done without special precautions. If these effects are not foreseen and provided for, breaks on cooling are almost inevitable.

Certain difficulties in working are sometimes trying to welders; for example, the fluidity of the metal when melted does not allow the realisation of vertical welds, and it is therefore necessary to arrange the line of welding as nearly horizontal as possible, which with certain shapes and sizes of pieces is difficult.

The fluidity of molten cast iron makes it necessary, in certain work, to surround or hold up the edges to be welded in order to prevent the metal from flowing away.

The necessity of welding for a long time over a preheating oven renders the work difficult and tedious, but the welder soon gets used to holding the blowpipe with arms outstretched and in this position making perfect welds.

Apart from cracks due to expansion and contraction and the hardness of the line of welding, the welds can have the following faults: lack of penetration, bad joining, interposition of oxide, blowholes, sinking of the surfaces to be joined. The instructions which we are about to give enable these to be avoided.

PREPARATION OF WELDS.

The edges of the weld should be bevelled as for iron and other metals as soon as the thickness exceeds $\frac{1}{8}$ inch. Welders who attempt to execute welds on $\frac{5}{16}$ inch to $\frac{7}{16}$ inch thicknesses without bevelling are sure to obtain bad welds; in order to penetrate the metal they push the molten metal with the rigid white jet; this brings about an alteration in the metal and a partial *adhesion*. Also, it is good to introduce into the line of welding as much of the siliceous iron as possible, and bevelling facilitates this introduction.

In a number of pieces of cast iron to be repaired by autogenous welding in which the repair is a crack and not a break, bevelling can only be done by means of a hand grinder. This should be well done, notably the penetration should be regular and not excessive, so that there are no openings at the bottom of the line of welding.

If an extension of the crack is feared by the expansion of the metal during preheating or during the execution of the weld, a hole should be drilled a short distance from the end of the crack and in the direction it would naturally take if it extended.

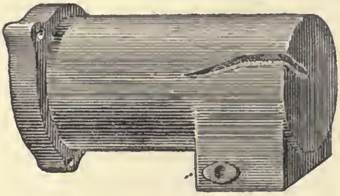
Fig. 197.—Cast-iron object bevelled previous to welding.

The majority of the instructions given in the first part of Chapter XI., "General Notions on the Preparation of Welds," apply also to cast-iron welding.

The most important point consists in studying the effects of expansion and contraction during and after welding, and avoiding the results of these phenomena. In the examples on repairs which will be given later, sufficient hints will be given to avoid failure, which is unfortunately still too frequent in the workshops of non-specialists.

WELDING ROD.

We have already mentioned the characteristics of the welding metal to be used for the welding of cast iron: cast iron of first quality, free from manganese, and containing a large quantity of silicon.

Let us again recall that the manganese favours the combination of carbon and iron, and consequently the formation of white iron. On the contrary, the silicon enables one to obtain grey iron, soft and workable.

This element renders other services: it destroys the oxide of iron, prevents blowholes, and the decarbonisation of the metal; it cannot be replaced, and without it the autogenous welding of cast iron would be difficult to realise.

A high percentage of silicon is necessary because a quantity of this element disappears in the course of welding, acting the part of a deoxidiser. Practically it is incorporated in the welding rod specially made for the welding of cast iron, the quantity being 3·5 to 5 per cent. The welds are then very workable, especially if the article is not cooled too quickly and if the welder keeps the small white jet of the blowpipe sufficiently separated from the molten metal.

An excess of silicon in the welding rod produces welds that are too soft. It is therefore important that its manufacture should be uniform. It should be made of pure cast iron of first quality free from manganese.

The welding rod for the autogenous welding of cast iron is supplied in round rods about 20 inches in length, and from $\frac{1}{8}$ to $\frac{1}{2}$ inch in diameter.

CLEANING FLUX.

We have seen that a flux is necessary to destroy the oxide, which is less fusible than the metal, and which interposes itself in the welds and prevents the perfect joining in the molten bath of metal; the flux acts as a melter to the oxide of iron and economises the silicon, which tends to destroy the latter.

The cleaning flux is most appropriate in the form of a powder formed by mixing equal parts of carbonate and bi-carbonate of soda, to which is added from 10 to 15 per cent. of borax and 5 per cent of precipitated silica. This product is supplied commercially at a price so low that welders have no necessity to prepare it for themselves.

Other recipes for cleaning powders have been proposed which offer no special advantage and sometimes have great faults. Certain welders are content to use borax, which as a cleaning flux is insufficient. In fact, the powder of which we have given the formula equalises decarbonisation of the cast iron by a corresponding carbonisation—a quality borax does not possess. The silicon of the welding rod, in effect, liberates the carbon contained in the alkaline carbonates, and thus the metal can regain from the flux so constituted the carbon which it loses by oxidation.

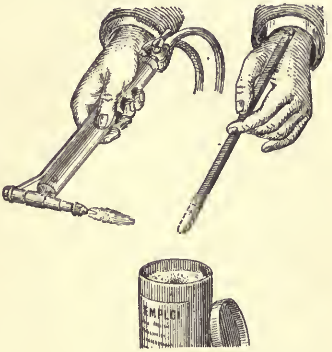

Fig. 198.—The extremity of the welding rod, previously heated, is dipped into the cleaning flux.

The cleaning flux has also the advantage of protecting the molten metal from excessive oxidation, thanks to the slag which floats on the surface.

The flux is used by plunging the extremity of the welding rod into the box or bottle, the rod having previously been heated, but not to excess. Avoid throwing the powder into the molten metal whilst executing the weld; the supply from the welding rod is always sufficient.

EXECUTION OF THE WELDS.

The execution of welds in cast iron presents no special difficulty when the parts have been properly prepared, preheated to redness where necessary, and using the proper welding rod and cleaning flux.

In many cases the welds are done with the article partly or wholly in the preheating oven. The welder protects himself from the heat by using plates of asbestos or simply plates completely round the part to be welded. Currents of air must be avoided during welding which can bring about rapid cooling and cause breaks or cracks in the article.

For articles which do not require preheating, it is advisable to take the chill off the metal, at least round the weld, by playing on it with the blowpipe previous to welding.

If a local heating is necessary at a different part of the article to oppose the effects of expansion or contraction, it is better to do this with a second blowpipe or group of bunsens, benzol lamp, etc.

The total heat of fusion of cast iron being high, it is necessary to use a blowpipe with a greater calorific power than for the same thickness of welds on iron.

Sometimes, when the melting-point of the cast iron is notably lower and the conductivity less, a more powerful blowpipe is not used. For a thickness of $\frac{3}{16}$ inch, for example, a blowpipe of 750 litres (26·5 cubic feet) would be necessary if the article has not been heated to redness by an oven or flame. In the case of preheating, a blowpipe with a delivery of 500 litres (17·5 cubic feet) of acetylene would prove sufficient.

The blowpipe is played on the edges to be welded until melting of the iron just takes place; the regular gyratory or oscillatory movements are of less importance here on account of the behaviour of the metal on melting. It is important that the two edges to be joined should melt at the same time.

As soon as the first fusion is obtained, the welding rod powdered with the cleaning flux is applied, in the manner indicated, in order to avoid oxidation.

The melting of the welding rod should take place as much as possible in the molten bath in the bevel by the plunging in of the rod and then playing the blowpipe all round. This method should always be used for great thicknesses. In the case of thin pieces the welding rod is melted by sweeping over the molten metal. The point to remember, which applies to all welds, is never to let the metal of the rod fall drop by drop, or to hold it too far away from the molten bath.

We have already said that to avoid adhesion due to blowing the molten metal along the line of the weld which is not yet at a high enough temperature to receive it, the blowpipe should be held so that the flame strikes the metal almost perpendicularly. A very inclined position of the flame invariably produces trouble and bad results.

The white jet of the blowpipe should never be in contact with the metal; the point should be kept at a distance varying from $\frac{3}{16}$ to $\frac{3}{4}$ inch, according to the thickness. This recommendation is very important, as cast iron under the very high temperature of the oxy-acetylene white jet can be degraded by the subsequent oxidation and decarbonisation.

If, in repairing certain articles, the molten metal has a tendency to flow away from the line of welding, it can be maintained by the aid of plates arranged before welding. The use of clay or refractory earth, as a rule, is conductive to the formation of blowholes, and consequently this practice should be avoided. Any experienced welder can melt in such a way that this flowing of the metal is avoided.

The plunging of the welding rod into the cleaning flux should not be forgotten as each supply of metal is added; on the other hand, excess of powder is detrimental.

The welding rod containing the element silicon, which is indispensable for obtaining a workable cast iron, should be supplied regularly along the line of welding. Avoid going over the welds after solidification without adding fresh silicon metal. The danger to be feared is the destruction of the silicon in the line of welding; this tends to produce white iron, or at least the formation of hard grains making it difficult to work.

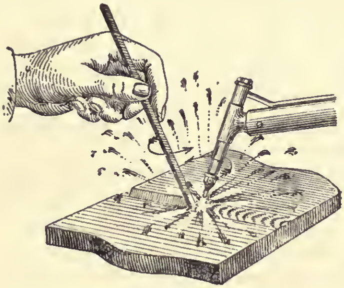

Fig. 199.—The welding rod is plunged into the molten bath and the white jet is played round it.

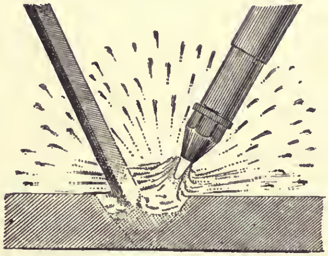

Fig. 200.—The white jet should not enter into contact with the metal.

For the same reasons, the welds should be rapidly executed without prolonged melting of the metal with the blowpipe.

TREATMENT AFTER WELDING.

As we have previously explained, the cooling of cast iron just welded should be as slow as possible.

For articles which have been preheated it is useful to replace them in the oven which has been used and cover them completely so as to avoid local cooling.

Many articles of cast iron, properly welded, break or crack in cooling, either in the line of welding or elsewhere, owing to lack of precautions in view of local contraction.

When a coke or charcoal fire has been used for preheating, the piece welded should be completely covered with cinders or charcoal; refractory bricks or sheets of asbestos should be placed on the sides and underneath so as to avoid all draughts of cold air, and the article should be left until it is *completely cold*. Sometimes it is necessary to take twenty-four hours for cooling.

For articles which do not require complete preliminary heating, it is sufficient, after welding, to play the blowpipe on the part heated and remove it progressively. Next cover with warm cinders, asbestos, or any other badly conducting non-fusible material so as to ensure slow cooling.

After complete cooling the welds can be worked with the file, grindstone, chisel, etc., until all the unevenness is removed. Thus an absolute uniform surface can be obtained in which it is impossible to recognise traces of the breaks and repairs.

Certain welded articles pass as new, which they are in reality.

RESULTS OF TESTS.

The welding rod specially made for the autogenous welding of cast iron is of very good quality. It follows, then, that when the work has been well done the line of welding is generally more sound than the metal of the article. The grain is finer, and the homogeneity perfect.

A number of tests on cast-iron welds have been made in large metallurgical establishments concerned with the strength of welds.

The figures for mechanical tests in compression give a strength of 21,400 to 24,209 lbs. per square inch. Shock tests on welded test pieces give the same results as those obtained with the original material.

The oxy-acetylene flame, when properly managed, does not alter in any way the welded pieces of cast iron; on the contrary, the fusion and rapid solidification gives a fine and compact structure to the added metal, which explains why the metal in the welded part is often much less fragile than the rest of the piece.

APPLICATIONS.

The applications of autogenous welding to cast iron are innumerable and very varied.

The process can be employed not only for the repair of all castings broken or deteriorated by use, shocks, vibrations, etc., but also for the putting in order new pieces which have defects, such as blowholes, pits, flaws, and fractures.

The process is not yet well known in many foundries which in the near future will make great use of it. It should be recalled that with a weld, if well done, the article treated can be considered as new, since the metal added is at least of as good quality as that of the article, and when joined to it is perfectly homogeneous. Those founders who hesitate from conscientious motives to apply autogenous welding to the repair of pieces leaving the foundry have only to reproach themselves in obtaining defective welds. Even badly applied, the process is a hundred times preferable, from the moral point of view, to the use of cements for hiding blowholes and sometimes flaws and cracks in articles leaving the foundry.

Foremen charged with the maintenance of works or the works themselves, find in autogenous welding a valuable process for the rapid repair of cast-iron parts broken during working. Not only is the economy realised, in not having to purchase a new piece, of great importance, but also the rapid return to service of the damaged object is, in many cases, of considerable value.

It would be necessary to mention all the articles made of cast iron used industrially in order to give all the examples where autogenous welding has been successfully applied. For example, the repair of flywheels, pulleys, toothed wheels, benches, and frames of machines, parts of machines of all kinds, stamps, punching machines, etc.; automobile motors, cylinders of steam engines, vessels of all kinds and all dimensions, cast iron used in buildings, all kinds of objects and utensils in cast iron, etc.

Let us mention, to close, a few cases of interesting repairs constantly met with in the practice of autogenous welding on cast iron.

Repairs to automobile cylinders.—Automobile cylinders surrounded by their water jackets frequently have cracks due to freezing, heating, shocks, internal strains, etc. The workshops and garages in large towns frequently use autogenous welding for their repair.

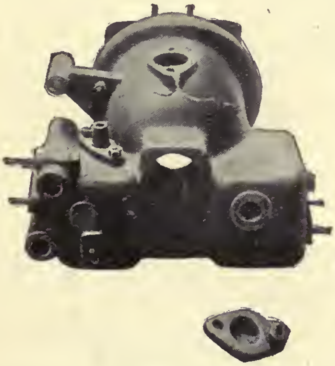

Fig. 201.—Damaged motor cylinder only repairable by autogenous welding.

Fig. 202.—The same cylinder after repair by autogenous welding.

It is necessary before commencing to weld to preheat the cylinder completely by placing it in a coke or charcoal basket or in an oven until it attains a red heat.

The cracks are first bevelled and prepared as already explained. After welding cool *very slowly*.

The majority of such cracks appear on the exterior surface of the water jacket, or on the flanges or corners.

If the cylinder itself is damaged, the repair is more difficult, because the welding can never be done from the interior. The method is to remove a portion of the water jacket above the crack, then proceed to weld in the usual manner, and, immediately after welding, weld the portion removed in position again.

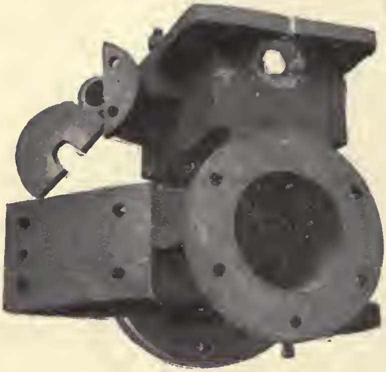

Fig 203.—Another motor for repair.

The success of repairs to automobile parts or similar articles depends, above all, on good preheating of the article and the very slow cooling after welding.

Repairs to flywheels, pulleys, etc. — Autogenous welding is frequently applied to the repair of cast-iron flywheels and pulleys. Their execution is more or less easy, depending on the position of the break, the shape and dimensions of the article, and the thickness of the metal in the different parts.

Certain flywheels are easy to repair, because the expansion and contraction of the cast iron can take place without tending to produce breaks. Others, on the other hand, present difficulties which an inexperienced and thoughtless welder cannot overcome.

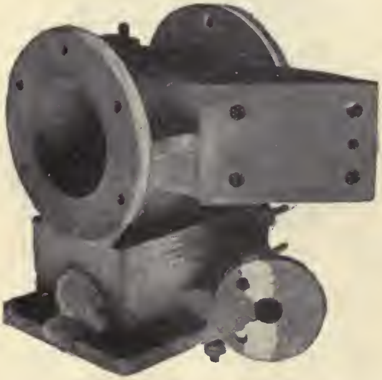

Fig. 204.—Same after repair.

Fig. 205.—Repair on a motor cylinder executed on the interior surface. A piece has been cut from the water jacket opposite the crack, and will afterwards be replaced by welding.

When the dimensions of the articles allow complete preheating of the whole body and very slow cooling, breaks or cracks are not greatly to be feared; but when the size of the articles makes it impossible to raise to red heat the entire body previous to welding, it is necessary for the welder to exercise thought in overcoming the effects of

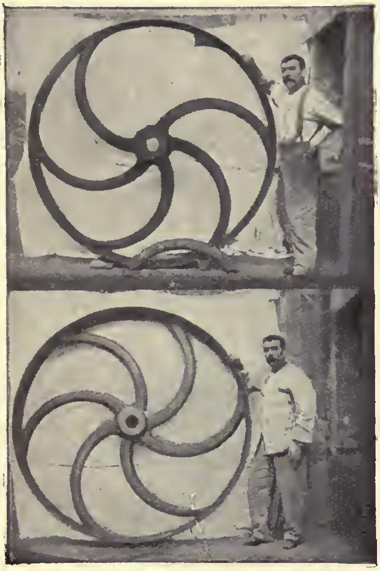
Fig. 206.—Repair of a cast-iron flywheel by autogenous welding.


Fig. 207.—Repair of a punching machine.


Fig. 208.—Locomotive cylinder badly damaged. Replacing it would have cost £160.

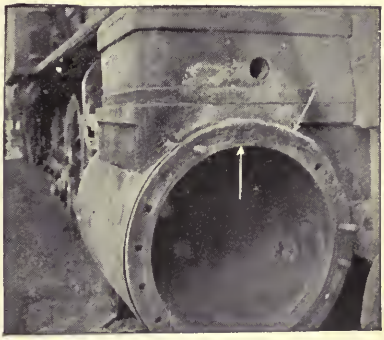
Fig. 209.—Repair by autogenous welding cost £3, 10s. It only remains to smooth the weld.

expansion and contraction during the execution of the weld, either by working in such a manner as not to have the heated part closed in by parts which are not sufficiently elastic, or by heating certain other parts of the article in order to compensate for expansion and contraction, as we have had occasion to explain in a previous chapter.

Fig. 210.—Repair of cast-iron vat whilst on the fire.

Seeing the excessive variation in dimensions, shape and thicknesses of flywheels, pulleys, or wheels in cast iron, we prefer not to give examples easy or difficult to repair; the slightest displacement of the break in the rim in its relation to the arm, or on the arms themselves, often necessitate quite a different treatment in view of the phenomena of expansion and contraction. The welder must exercise his own judgment in the presence of each article to be repaired.

Repair of large articles.—In the majority of cases large articles cannot be wholly preheated, and in these cases it is necessary to judge in advance how expansion and contraction will act during the execution of the weld and on cooling. Sometimes the breaks are in such places that the repair if not impossible is very laborious, and in many such cases it will pay better to dispose of the metal.

Repair of toothed wheels.—The teeth of cast-iron wheels often get broken, which puts the wheel out of use. It is easy to repair them by autogenous welding. One proceeds by replacing the broken tooth by simply adding metal to the base of the tooth, rejecting the piece broken off. A certain amount of skill is necessary in building up the weld without too much flowing on either side and in keeping the joining of the metal perfect.

Various examples of adding metal.—Autogenous welding is frequently employed for adding metal to worn parts of cast-iron articles. The operation is the same as for building up teeth of wheels, taking care that perfect joining of the metals is obtained.

If the surface of the article thus repaired has to withstand friction, it requires to be constituted of hard cast iron; to obtain this it suffices to use a non-silicious welding rod or one that is only slightly silicious. One should not reckon on working such a line of welding after being welded; the surface is made even by a wide melting during the operation. Of course, it is understood that if the surface of the article has to be perfectly uniform the process is not applicable.

Fig. 211.—Repair of a hawse-hole of a steamship. In order to avoid wear by friction a welding rod without silicon is employed so as to obtain a hard metal.

The type of work in cast iron which can be autogenously welded is excessively varied, and necessitates on the part of the welder much thought and ingenuity. The few examples given above and the instructions given in the previous chapters should enable him to succeed with the majority of jobs brought to him.

CHAPTER XVI.

AUTOGENOUS WELDING OF COPPER, BRASSES, AND BRONZES.

UNTIL recently the autogenous welding of copper, brasses, and bronzes was in a very imperfect state. Pure and simple fusion of these metals under the action of the blowpipe produced strong oxidation and numerous blowholes, and to avoid these disadvantages a welding metal was used of a more fusible composition and which produced a true brazing; and since the metal was prepared for joining end to end, the joints offered no cohesion, little resistance, and no elongation. They were *heterogeneous*, and the *autogenous* welding of red copper, brasses, and bronzes did not exist, technically speaking.

The discovery of the methods for the autogenous welding of these metals has been a great honour for the *Union de la Soudure Autogène*. The remarkable work of M. Amédéo allows one now to apply, in a perfect manner, autogenous welding of copper and its alloys to a host of jobs which could not be undertaken formerly. True, the process must be studied and then applied with all the technique possible; but, after all, it is very simple for those that have the will to understand and follow a method of work scientifically established.

It should be noted that the autogenous welding of copper, brasses, and bronzes, properly executed gives better results than the welds on iron and steel, which are considered more simple. In fact, not only is the molten metal absolutely clean, but also the thermic and mechanical treatment which are generally so easy to apply to copper and its alloys, enables the welder to improve the qualities of the welded zone to such an extent that perfect homogeneity between the metal of the weld and the rest of the piece is obtained.

We divide this chapter into three distinct parts, devoted respectively to *red copper*, *brasses*, and *bronzes*. It will be seen, on reading, that the technique of these welds is easily acquired and observed in the industrial treatment of these metals for their joining by fusion.

RED COPPER.

GENERAL PROPERTIES OF COPPER CONSIDERED FROM THE AUTOGENOUS WELDING POINT OF VIEW.

Copper is a metal of a reddish colour; the fracture shows a rose tint. Metal which contains the oxide in a dissolved state is more yellowish.

Copper is a hard metal, elastic and tenacious. Its density is about 8·9.

The presence of sulphur, antimony, or lead in the metal makes it brittle. Small traces of phosphorus do not affect the mechanical properties. *Copper oxide incorporated in the metal causes it to lose a large number of its qualities.*

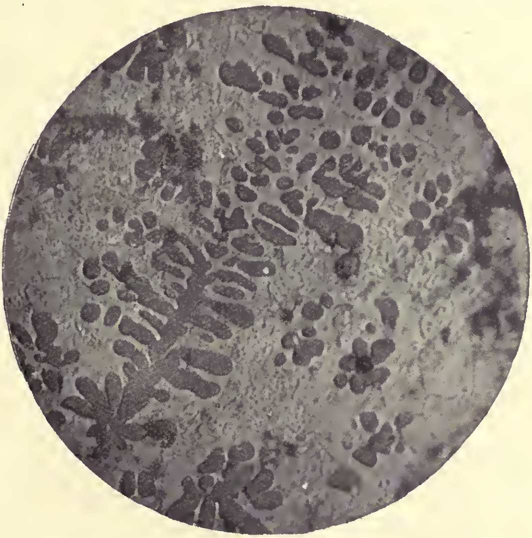

Fig. 212.—Microphotograph of weld showing copper oxide (magnified 100 diameters).

The tensile strength, which is about 33,000 lbs. per square inch at ordinary temperature, decreases rapidly under the effect of heat. At 500° C. it is only about 14,000 lbs. per square inch. We shall return to this lowering of tenacity when heated when dealing with fractures due to contraction during the cooling of welds.

The conductivity for heat is very high, and this property is troublesome in autogenous welding, not only because of the rapid dispersion of heat from the blowpipe, but because it produces rapid local cooling after welding, therefore a rapid contraction which acts along the line of welding still hot. The tenacity of hot copper being very low, as we have already mentioned, this can produce fractures.

Copper in a state of fusion oxidises rapidly in contact with air, and this oxide is very soluble in the metal; it forms with it a veritable alloy, which crystallises in the mass on cooling either as islets of oxide or in tree-shaped form which, when examined under the microscope, have a very pretty appearance (fig. 212).

The melting-point of copper containing the oxide is appreciably lowered: from 1090° C., which is that of pure copper, it can fall to 1068° C. for the alloy "copper-oxide in copper" containing 4 to 5 per cent. of the oxide.

The melting of copper is accompanied by the phenomenon of absorption of gas. Hydrogen and carbon monoxide which are present in the welding flames are particularly dissolved by copper. On cooling, the metal is riddled with blowholes.

DIFFICULTIES ENCOUNTERED IN THE AUTOGENOUS WELDING OF COPPER.

If the autogenous welding of copper is obtained by melting of the edges to be joined with the addition of a metal which is simply pure copper, there is necessarily considerable oxidation of the molten mass, and incorporation of this oxide in the metal by dissolution.

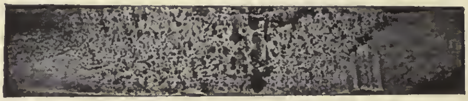

Fig. 213.—Blowholes in a copper weld obtained without using the special welding rod.

The metal is burnt, that is, oxidised, and loses all the properties which are required where copper is used.

No manipulation or regulation of the flame can overcome this oxidation. It is therefore necessary to use a *deoxidiser* capable of reducing the oxide as it is formed. Since the oxide is dissolved in the metal itself, the use of a *flux* does not give the results expected. It is therefore indispensable that the reducing agent should be incorporated in the welding rod and should diffuse in the molten mass according to the fusion of the latter.

All welds made on red copper without a deoxidising welding rod properly prepared are therefore strongly oxidised and cannot possess the required qualities.

Also, as we have seen, molten copper dissolves gases which, on cooling, produce blowholes. One can test this by taking a section of a test piece welded without a special welding rod, and submit it to the corrosion test, as explained in Chapter XII., "Tests for Welds."

It is found that the welding rod containing phosphorus, which we will mention later, prevents the absorption of gases and at the same time acts as a deoxidiser. In fact, the reduction of the oxide brings about the formation of phosphoric acid which rises to the surface of the weld and acts as a protecting varnish.

Lastly, the lowering of the tenacity of copper, almost 60 per cent., when the temperature is raised to 500° C. produces great difficulty for the welder, because the contraction of the metal after melting tends to produce cracks in the line of welding.

To summarise, it is impossible to weld copper properly without taking the necessary precautions to avoid oxidation of the metal, absorption of gases, and fractures on cooling. These difficulties are easily overcome by following, in the preparation of the parts and the execution of the work, an accurate technique.

WELDING ROD AND CLEANING FLUX.

The welding rod used for the autogenous welding of copper is of *phosphor copper* containing traces of aluminium.

The phosphorus is incorporated in a very small quantity, so that none remains in the weld after its execution.

A metal rod which contains too much phosphorus lacks fluidity and melts at a temperature much lower than that of the copper to be welded, which facilitates adhesion. Moreover, the welds in which the phosphorus remains lack elongation, and therefore do not possess the same mechanical properties as pure copper.

It is necessary, in the manufacture of the phosphoretted welding rod, to use an extremely pure copper, because the simultaneous presence of phosphorus and other impurities of copper produces a metal of bad quality.

The manufacture of a uniform welding rod can only be obtained after a large number of tests.

To avoid all misunderstanding, a welding rod in which the purity and the quantity of phosphorus are controlled and guaranteed should be selected.

The phosphoretted welding rod is made in the form of wire varying from $\frac{1}{16}$ to $\frac{5}{16}$ inch diameter. Welding rods called "special" should be rejected; they usually consist of bronzes which melt at a much lower temperature than the copper, and consequently cannot form a true alloy with the edges to be welded. Bad brazings are obtained but not autogenous welds. The same applies to half-red copper.

The cleaning flux used consists of a powder of chloride of sodium, sodium borate, and boracic acid. This cleaning agent is not absolutely indispensable if the edges of the weld and the welding rod are perfectly clean. It is sufficient to use it in very small quantities by plunging the welding rod into the tin or bottle containing it.

The use of all other fluxes or powders is useless and often dangerous, especially if they contain elements which can be incorporated by the copper and constitute impurities in it.

EXECUTION OF WELDS.

Preparation of pieces.—The edges to be welded should be bevelled as soon as the thickness exceeds $\frac{1}{8}$ inch; the joints are prepared in exactly the same way as that given for iron and mild steel, and according to the methods we have indicated in Chapter XI., "General Notions on the Preparation of Welds." Double bevelling need not be done unless the thickness exceeds $\frac{3}{4}$ inch.

Particular care should be taken in cleaning the edges to be united and the neighbouring surface, because the scale makes the welding more difficult and tends to introduce impurities in the metal.

Power of the blowpipe.—The power of the blowpipe should be practically the same as that used for welding the same thickness in iron or steel, or slightly greater. The approximate value for articles preheated is:—

For $\frac{5}{64}$ inch	150 to 200 lits.	(5½ to 7	cub. ft.)	of acetylene	per hour.
,, $\frac{1}{8}$,,	300 to 350 ,,	(10½ to 12½	,,	,,	,,
,, $\frac{13}{64}$,,	450 to 500 ,,	(16 to 7½	,,	,,	,,
,, $\frac{9}{32}$,,	550 to 600 ,,	(19½ to 21	,,	,,	,,

etc. etc.

A blowpipe which is too strong produces too rapid melting; this should be as carefully avoided as that of melting too slowly.

Preheating.—*It is absolutely necessary before commencing the actual operation of welding to raise the edges of the weld and their vicinity to a very high temperature.* The high conductivity of copper necessitates this, as any supply of molten welding rod before the edges are in a molten state inevitably produces adhesion.

The conductivity of copper is such that the heat given to the edges to be welded rapidly spreads throughout the metal and the article is often raised to a red heat by the simple preheating application of the blowpipe.

For this preheating, if a more economical source of heat can be used do not hesitate to use it, the oxy-acetylene flame only coming in to produce the final rise of temperature necessary for melting the edges and the welding rod.

Diameter of the welding rod.—The section of the welding rod, at least for small thicknesses, should always be greater than in the case of welds on iron and steels. Even in the case of very thin pieces, the wire should not be less than $\frac{1}{16}$ inch diameter; thinner wires are burnt under the action of the blowpipe. On the contrary, welding rods that are too large in diameter for the thickness of the metal welded produce the same disadvantages as using a metal containing too much phosphorus.

Cleaning flux.—As we have previously indicated, a cleaning flux is not absolutely indispensable if the edges to be welded and the welding rod have been cleaned. It should be sparingly applied by previously heating the welding rod and covering very thinly the extremity.

Regulation of the flame.—The flame of the blowpipe should be perfectly regulated and maintained without excess of either gas. Excess of acetylene as well as of oxygen produces intense oxidation in the metal. Excess of acetylene, in addition, produces blowholes.

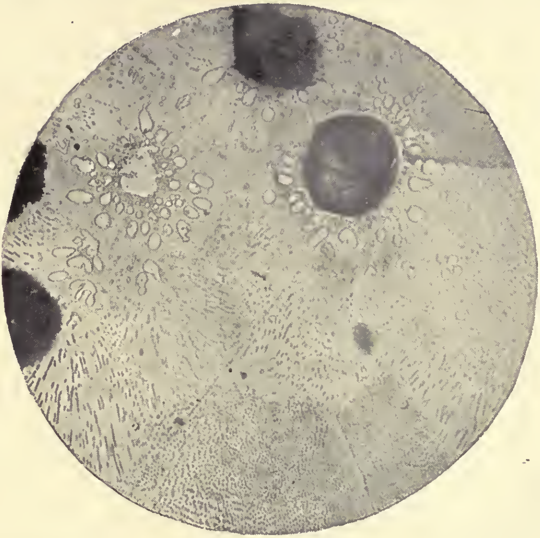

Fig. 214.—Copper melted by a blowpipe with excess acetylene; blowholes, and oxidation (magnified 100 diameters).

Position of the blowpipe.—The blowpipe should be held *nearly perpendicular* to the surface of the weld. Inclining the flame sweeps the molten metal more forward in the line of welding and this tends to produce adhesion.

As when welding cast iron, the white jet should never be in contact with the molten metal. This point is very important. It should be kept at a distance of $\frac{3}{16}$ to $\frac{5}{16}$ inch. If this distance is increased the gases resulting from the second phase of combustion, carbonic acid and water vapour, influence the weld.

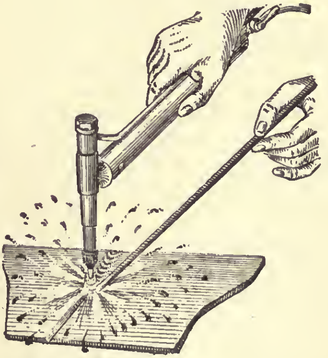

Fig. 215.—The flame is held perpendicular to the line of welding, with the white jet out of contact.

Method of welding.—We repeat, that the fusion of the metal should not be undertaken until the edges of the weld and their vicinity have been raised to a high temperature. At this moment one commences to weld by simultaneously melting the phosphoretted welding rod and the parts to be joined. In all cases it is necessary that the welding rod, which contains the reducing element, should be regularly incorporated in the line of welding. *Never let it melt and fall in drops, and be careful to avoid contact with the white jet.*

The moment melting commences the operation should be conducted rapidly; avoid delaying it by keeping the white jet too far from the line of welding. The operation must be continuous, taking care to attack regularly the two edges and to obtain perfect joining; also to add excess metal for hammering afterwards, etc.

Effects of contraction.—We have said that copper lacks tenacity when heated; hence the contraction of the metal, whose coefficient of expansion is fairly high, can produce fractures, especially in the welded part, whose tenacity is always less than that of cast copper.

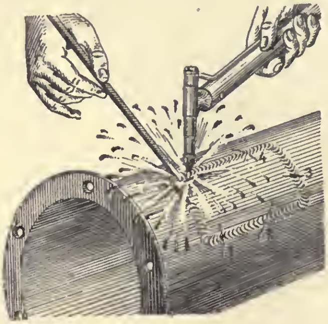

Fig. 216.—Cracks are common in the patching of plates and tubes, due to lack of tenacity at the high temperature. One avoids these by taking precautions to overcome the effects of contraction.

Breaks are very frequent if one does not take every precaution to avoid them. They often show as cracks scarcely visible but which, nevertheless, exist more or less throughout the thickness of the metal.

These cracks are produced at the high temperature at the moment when the tenacity of the metal is almost *nil*, and under the effect of an almost insignificant contraction.

They are particularly common in circular welds; in the patching of plates or tubes, for example, when they are produced at the moment of joining or in the cooling which follows immediately after welding.

These cracks are avoided by taking precautions that the contraction does not produce a strain in the line of welding. This is obtained by preheating the whole body to be welded or, at least, the vicinity of the weld. In default of this, a local heating intelligently applied, or if need be, in some cases, a sprinkling of cold water.

True, for the welding of certain articles, the welder must exercise great reflection to appreciate the effects of contraction, and much ingenuity to overcome its effects.

However, preheating of the article to a high temperature, maintaining this heating after the operation of welding, and slow cooling enables one in the majority of cases to avoid cracks due to contraction. We cannot too strongly advise welders to operate in this manner.

Treatment after welding.—The line of welding always consists of coarse cast metal, and the metal in the immediate neighbourhood consists of rather large crystals, which are formed on account of the high temperature to which it has been raised during the operation.

The coarse cast copper has a resistance which does not exceed 19,000 to 21,000 lbs. per square inch, and its elongation is very low. *It is useful to hammer vigorously the line of welding and its vicinity.* This gives a metal with a much greater tenacity; it can attain a resistance of 33,000 lbs. per square inch, and its elongation increased to about 25 to 30 per cent.

This hammering can be done hot for bars or very thick copper, but care should be taken that the temperature is not too high.

After hammering it is good to reheat the copper, raising it to redness (500° to 600° C.), then plunge into cold water, or cool as rapidly as possible.

Failures.—Failures are very frequent if the welder does not rigorously follow the methods we have indicated.

They can be produced by (1) a welding rod of bad quality; (2) absence of a flux when the edges of the weld are not absolutely clean; (3) execution of the weld before the edges have been raised to a high temperature; (4) by the bad joining of the metal and the irregular addition of the welding rod; (5) effects of contraction badly opposed during or after welding.

Welders should not confuse the true autogenous welding of copper with the brazing obtained by using a blowpipe and a welding rod more or less heterogeneous, and which always produces adhesion in the line of joining. Those who have hitherto used these methods should take special care to avoid the bad habits which are contracted, and especially the common defect of applying the molten welding rod before the edges of the weld are ready for it.

RESULTS OF TESTS.

Tensile tests on test pieces of red copper of $\frac{5}{8}$ to $\frac{13}{16}$ inch thickness, hammered and annealed.

No. of Test.	Thickness in Inches.	Ultimate Tensile Strength in Lbs. per Sq. Inch.	Per cent. Elongation.	Remarks.
1	$\frac{5}{8}$	29,900	22·0	Welded with phosphoretted copper (U.S.A.)
2	$\frac{5}{8}$	31,500	19·5	,, ,, ,,
3	$\frac{5}{8}$	28,400	19·0	,, ,, ,,
4	$\frac{5}{8}$	32,900	20·0	,, ,, ,,
5	$\frac{5}{8}$	33,000	22·0	,, ,, ,,
6	$\frac{13}{16}$	32,700	20·0	,, ,, ,,
7	$\frac{11}{16}$	29,900	25·0	,, ,, ,,
8	$\frac{13}{16}$	27,200	21·0	,, ,, ,,
9	$\frac{13}{16}$	32,800	23·0	,, ,, ,,
10	$\frac{13}{16}$	27,000	17·0	,, ,, ,,

When autogenous welds of red copper have been realised, hammered and annealed, the mechanical properties of the welds approach those of the original metal.

The welded parts can be submitted to machining or stamping without any disadvantage.

Practically, a copper weld hammered and annealed will possess a tensile strength of 33,000 lbs. per square inch and an elongation of 22 to 25 per cent.

When one considers that the French railway companies, in purchasing copper, specify that the minimum tensile strength should be 28,500 lbs. per square inch and the elongation 35 per cent., it is obvious that the results now obtained on red copper are sufficient to allow of its application to a large number of articles which at present are riveted or brazed.

Fig. 217.—Red copper tubes entirely constructed by autogenous welding.

APPLICATIONS.

Applications of the autogenous welding of copper are extremely varied, and could be extended to the majority of articles produced in this metal.

Coppersmiths could make great use of it if they knew how to apply it properly, and according to the principles which we have explained.

Coppersmiths, much more than iron brazers, seek to replace brazing and riveting; and autogenous welding would, in almost all cases, advantageously replace these methods of joining.

We should be liable to make many omissions in enumerating examples of work which are of particular interest, and we prefer not to attempt this.

We will just give one example—that of making pipes and tubes of all forms and sizes from plates. The manufacture of these pipes and their joining in any required manner by autogenous welding allows one to obtain considerable economy over purchasing them commercially.

There are even large numbers of articles which can be manufactured by similar methods of working, without mentioning the numerous cases in which autogenous welding can be applied to the repairing and restoring of deteriorated articles, broken, worn, etc.

BRASSES.

GENERAL PROPERTIES OF BRASSES CONSIDERED FROM THE AUTOGENOUS WELDING POINT OF VIEW.

Brasses are alloys of copper and zinc. The metal called "half red copper" is a brass with a low percentage of zinc (about 10 per cent.).

Industrial brasses can be classified into two distinct classes, possessing different properties, and each having their particular applications.

(1) Plate brass or brass of first quality, which cannot be forged at red heat, containing 65 to 70 per cent. of copper.

(2) Forgeable brass or brass of second quality, containing 58 to 60 per cent. of copper, principally worked in lathes.

Here are the compositions of the principal brasses used industrially as compiled by M. Guillet:—

Alloys for the manufacture of plates		Copper,	66 to 70	per cent.
French cartridge brass		Copper,	67	,,
		Zinc,	33	,,
Plates of first quality		Copper,	67	,,
		Zinc,	33	,,
Plates of ordinary quality		Copper,	65	,,
		Zinc,	35	,,
Bars of second quality for capstan lathe work, viz. cocks, nuts, screws, etc.		Copper,	58 to 60	,,
		Zinc,	42 to 40	,,
Brass for stamping (ordinary quality)		Copper,	65	,,
		Zinc,	35	,,
Yellow foundry brass		Copper,	66·5 to 67·0	,,
		Zinc,	33·5 to 33·0	,,
Brass for castings (French marine)		Copper,	67	,,
		Zinc,	32	,,
		Lead,	1	,,
		Copper,	66·5	,,
		Zinc,	33·0	,,
		Lead,	0·5	,,
Ordinary cast brass		Copper,	60·0	,,
		Zinc,	37·0	,,
		Lead,	2·5	,,
		Tin,	0·5	,,
Brass for tubes	First Quality	Copper,	70·0	,,
		Zinc,	30·0	,,
	Ordinary quality	Copper,	65·0	,,
		Zinc,	35·0	,,

The brasses do not conduct heat so well as red copper, but are equally fluid in the molten state. Their tenacity when hot is much higher than copper.

The colour of brasses does not change from red to white as the percentage of zinc increases; thus the first quality brass is whiter than the second quality, although it contains less zinc.

The first quality melts at about 930° C. and the second quality at about 880° C.

The melting of brass under the action of the blowpipe flame is accompanied by three distinct phenomena: (1) *Absorption of gases*; (2) *volatilisation of zinc*; (3) *oxidation.*

AUTOGENOUS WELDING OF BRASSES REALISED WITHOUT SPECIAL PRECAUTIONS.

The welder who tries to join brass autogenously, without understanding the technique for the treatment of this metal by the blowpipe, is confronted with difficulties which are apparently insurmountable.

First of all, the operation is made very difficult by the volatilisation of a portion of the zinc, which comes off in abundant white fumes. Welds obtained thus are no longer homogeneous, since the percentage of zinc is lowered; in addition, it is easy to verify that they are full of blowholes, and their strength and elongation is obviously insufficient as a result of the considerable oxidation of the copper in the alloy.

All these difficulties disappear by using a special welding rod.

WELDING ROD—CLEANING FLUX.

The welding rod destined for the autogenous welding of brasses should simply consist of very pure metal, manufactured from *new metals*, in which is incorporated a *very small quantity* of aluminium, necessary to deoxidise the welds.

It is important that the aluminium should be uniformly incorporated in the metal, and that the quantity be added after casting.

The manufacture of such a welding rod is extremely delicate, because an excess of the deoxidiser is just as bad as its complete absence; it requires constant control and supervision.

This special welding rod is sold in wires of all diameters from $\frac{1}{16}$ to $\frac{5}{16}$ inch, suitable for welding all thicknesses.

It is understood that it is made in first and second qualities corresponding to welding all kinds of brasses, and the one should not be used in place of the other; a proper labelling is very necessary in workshops using the two qualities.

A cleaning flux is necessary, especially for the proper working of the welding rod, because it is necessary to dissolve the alumina produced by deoxidation of the welds.

Borax does not give satisfactory results. The powder to use is the same as the one we have given for cleaning the edges of red copper: sodium chloride, borax, and boracic acid; but for the autogenous welding of brasses *it is indispensable.* This powder cleans the metal perfectly, dissolves the alumina, and protects the molten surface from oxidation and the gases of combustion, thus avoiding blowholes.

EXECUTION OF WELDS.

Preparation of pieces.—The preparation of pieces is the same as for red copper. The cleaning of the edges to be welded is much more necessary. The welder bevels and prepares according to the methods we have given in Chapter XI., "General Notions on the Preparation of Welds."

Power of the blowpipe.—This should be chosen slightly higher than for red copper, that is to say, much higher than for iron of the same thickness.

Preheating.—The conductivity for heat of brasses is less than that of copper, and the tenacity is higher when heated; this generally dispenses with the necessity for a special addition of heat either for raising the article to a high temperature before welding or for avoiding the effects of contraction.

The operation of welding, however, should be preceded by heating the edges to be welded. This is rapidly done by means of the blowpipe.

Use of welding rod and cleaning flux.—These are used as we have indicated for copper, but taking care to use less of the powder; hence the rod should be sprinkled with the powder.

Position of the blowpipe.—The flame should be perpendicular, or nearly so, to the line of welding, because of the fluidity of the metal, which must not be driven forward. *The white jet should be at a distance of* $\frac{3}{16}$ *to* $\frac{5}{16}$ *inch from the molten metal.*

Method of welding.—As in the case of copper, the melting of the metal should not take place until the edges to be welded and their vicinity are raised to a high temperature. The welder melts the metal of the piece and the welding rod *together*, so that the reducing action takes place throughout the whole molten mass.

The welds should be executed rapidly and without stopping. *The welding rod containing the aluminium almost completely prevents the volatilisation of the zinc, so that the work is not obnoxious to the welder.*

One avoids going back; in case of a second melting the addition of a new quantity of the deoxidising welding rod is indispensable.

If the effects of contraction are to be feared, the precautions we have already indicated should be taken.

Treatment after welding.—Hammering considerably improves the mechanical properties of brasses. It should be done *cold* for the *first quality* and *hot* for the *second quality*, and in the latter case always above 500° C., because a lower temperature causes the metal to crack or break under the shock of the hammer.

After hammering cold the first quality should be heated to about 650° C., but in no case should it attain 800° C., that is to say, too near the melting-point. The operation of annealing is indispensable for the first quality brasses. With second quality brasses annealing is not necessary, and is only used for removing the hammer marks.

The welds are finished off as usual if a clean surface is required.

Failures.—Failures only occur when a welding rod of bad quality is used, that is to say, inferior to the metal of the article to be welded, or by not observing the methods which we have indicated. Apart from this, a certain dexterity of the hand is required in order to avoid holes which are formed on account of the excessive supply of heat and *adhesion* which results from trying to avoid holes. The autogenous welding of brasses is extremely easy to acquire.

. . . .

The strength of brass welds is quite sufficient to justify its application to the manufacture of articles made up to the present by stamping.

A weld on brass of first quality, hammered and annealed, can withstand energetic forging and complex stamping without showing cracks. We have hammered a weld on plates of ⅛ inch thickness down to a thickness of $\frac{1}{100}$ inch without observing any cracks in the weld or in its immediate neighbourhood.

A weld on brass, even when very thick, for example 1 inch to 1¼ inches, can always be compressed without showing cracks.

BRONZES.

GENERAL PROPERTIES OF BRONZES CONSIDERED FROM THE AUTOGENOUS WELDING POINT OF VIEW.

Bronzes are alloys of copper and tin.

The colour of bronzes varies from that of red copper to white, depending upon their composition. With 90 per cent. copper and 10 per cent. tin, this colour tends to yellowish gold. At 85 per cent. the colour is distinctly gold, and at 50 per cent. the alloy completely loses its coppery colour and becomes white.

These alloys of copper and tin generally possess little malleability. With 20 per cent. tin the elongation is practically *nil.*

The hardness of the metal increases with the proportion of tin.

The breaking stress of bronzes, which at first increases with the increase of tin, diminishes when the proportion of this element exceeds 16 per cent.

The conductivity for heat of bronzes is very low compared to that of red copper. These alloys when heated totally lack strength, and the simple weight of the parts can produce fracture.

Here is the composition of the different industrial bronzes according to M. Guillet:—

Very hard bronze for bearings	Copper,	81
	Tin,	17
	Zinc,	2
Hard bronze for bearings	Copper,	84
	Tin,	14
	Zinc,	2
Bronze for cocks, valves, etc.	Copper,	88
	Tin,	10
	Zinc,	2
Bronze for stuffing boxes	Copper,	86
	Tin,	11
	Zinc,	3
Bronze for steam whistles	Copper,	80 to 81
	Tin,	18 to 17
	Zinc,	2
Bronzes for capstan lathe work	Copper,	92 to 96
	Tin,	8 to 4

It is easy to choose from amongst the three types of welding rod sold commercially, viz. *machine bronze*, *bronze for bearings*, *bronze for bells*, that which most closely approaches the alloy to be welded.

Bell bronze is a very hard bronze containing from 20 to 24 per cent. of tin.

The melting of bronzes under the blowpipe is accompanied by a violent ebullition following oxidation of the metal; the tin in the alloys plays the *rôle* of a reducing agent, and, as a consequence, the percentage of this element is lowered.

Molten bronze absorbs the gases contained in the flame of the blowpipe, and on cooling they form large and numerous blowholes.

Treated without special precautions the autogenous welding of bronze produces the following defects:—(1) *loss of tin especially at the surface of the welds, which tends to completely degrade the metal*; (2) *blowholes throughout the melted mass, which greatly reduces the resistance of the joint.*

These disadvantages disappear if a special welding rod is used and the welds executed in a proper manner.

WELDING ROD—CLEANING FLUX.

The welding rod destined for the autogenous welding of bronze should contain a certain quantity of phosphorus, this element acting as a reducing agent before the tin in the alloy plays this *rôle*.

As in the case of the welding of red copper, these metals should, where possible, contain traces of aluminium. Their manufacture should be very carefully carried out, especially for the alloys containing a high percentage of tin. A homogeneous metal is difficult to obtain when casting in rods. The temperature of casting is also very important for obtaining a uniform product.

The welding metal sold in the form of drawn wire is not bronze; *it is generally brass, and cannot possibly give a good result.* In fact, bronze cannot be wire-drawn unless the percentage of tin is less than 8 per cent., a percentage which is not used industrially.

The welding rods for the autogenous welding of bronzes are of three different qualities, viz. *machine bronze* (90–10), *bearing bronze* (84–16), and *bell bronze* (22 to 24 per cent. tin). The quality is chosen according to the approximate composition of the parts to be welded.

The cleaning flux used is of the same composition as that given for the welding of copper and brasses. It is added to the line of welding by dipping the rod, previously heated, into the tin or box containing the powder.

EXECUTION OF WELDS.

Preparation of pieces.—The welding of bronze is analogous to autogenous welds on cast iron, in the preparation of the parts and applications.

Articles are prepared for welding as explained for the case of cast iron.

The metal is cleaned bright. It is very important to support the lines of welding and their vicinity, where this is possible, to prevent the collapsing of the metal when near the melting-point.

Preheating.—To avoid breaks on contraction, due to complete lack of tenacity, complicated articles should be heated before welding, avoiding too great a heating. On the other hand, articles which have been heated should be moved from the fire with great care, because breaks or collapse can be produced under their own weight. Many articles do not require preheating.

Power of the blowpipe.—The power of the blowpipe should be the same as that chosen for identical thicknesses in brass, that is to say, of distinctly higher power than for iron and steels.

Regulation of the flame.—It is important that the flame should be perfectly regulated, without excess of acetylene or oxygen. Excess of acetylene is always detrimental, producing bubbling of the metal by absorption of gas and the formation of blowholes.

Method of welding.—In welding articles which have not been preheated, the lines of welding and their immediate neighbourhood should be heated with the blowpipe, *taking care not to bring the white jet near the surface of the metal.* A localisation of the heat produces the segregation of the tin, that is to say, the separation of the constituents of the alloy.

The edges of the weld and their neighbourhood being at a red heat, warm the welding rod and dip it into the powder, then approach the edges of the weld with the flame and the welding rod, so as to melt them both.

During the execution of the weld the white jet of the blowpipe must not come into contact with the molten metal.

The welding rod should be applied very regularly, so that the reducing agents which it contains diffuse throughout the line of welding.

The welds should not be remelted, at least not without adding a new quantity of the welding rod. As in the case of copper and brasses, they should be rapidly executed and without stopping.

The effects of contraction are not to be feared, especially when the articles have been preheated.

Treatment after welding.—It is indispensable to anneal after welding followed or not by tempering, according as one desires to increase the hardness of the piece, or, on the contrary, to soften it. One smooths the welds in the same manner as for cast iron.

RESULTS OF TESTS—APPLICATIONS.

Autogenous welding of bronzes well executed and realised with the special welding rod give excellent results. The lines of welding and its properties are absolutely close to that of the metal, and traces of the weld completely disappear on working.

The process deserves to be better known. It will find very large application, especially for the repair of bronze parts of all kinds, relining of bearings, repair of bells, etc. etc.

Let us give, as an example, the method of operating in repairing a bell:—

The cracked part is first of all bevelled. The extension of the crack is prevented by drilling a hole in its theoretical extension. The bell is then heated on a low fire, carefully watching that the temperature is not raised too high. Next proceed to weld with the special welding rod of bell bronze, conducting the operation as we have just previously indicated; the line of welding is slightly overcharged.

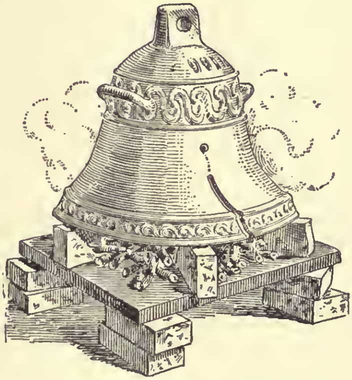

Fig. 218.—Repairing a bronze bell by autogenous welding.

After execution it is left to cool; then, in order to obtain the original tone, proceed to a moderate reheating, followed by tempering in cold water. It only remains to clean it up, that is, to remove the excess metal on the weld. The bell can then be considered as good as new.

CHAPTER XVII.

AUTOGENOUS WELDING OF ALUMINIUM.

THE autogenous welding of aluminium, which generally discourages beginners because it requires a short apprenticeship, can be classed amongst the most easy to realise. If there is true welding the joint cannot have defects, at least for the usual applications of this metal. In fact, the actual process of autogenous welding of aluminium enables one to avoid all incorporation of oxide, and the metal melted under the action of the blowpipe is absolutely clean, that is to say, free from impurities.

The autogenous welding of aluminium is not sufficiently known industrially, or it would replace advantageously the numerous heterogeneous methods of joining the metal which always give bad results. There is no doubt that it will develop considerably.

We shall deal first with pure aluminium. The study of its welding logically precedes that of the alloys of the metal with zinc, which are used in the foundry for the manufacture of a large variety of castings.

GENERAL PROPERTIES OF ALUMINIUM CONSIDERED FROM THE AUTOGENOUS WELDING POINT OF VIEW.

Aluminium is a metal of a beautiful white colour, with a slight blue tint; it is easily polished; its powder is grey, odourless and tasteless. The structure is fibrous; the malleability and ductility are very great; its hardness can be compared to that of silver if the metal is cast, and to that of soft iron when it is hammered.

The tenacity varies greatly according to the physical state. The tensile strength is about 15,600 lbs. per square inch in the cast state, 24,000 lbs. per square inch in the rolled and annealed state, and attains 28,000 to 43,000 lbs. per square inch in the cold-hammered state.

Rolled and annealed, its elongation is 16 to 20 per cent. Being extremely malleable, it can be easily forged.

The commercial metal is generally 99 to 99·5 per cent. pure aluminium. It can contain, as impurities, traces of iron, silicon, and sodium.

It melts at 650° C., and becomes very fragile just previous to melting. The fluidity of melted aluminium is very great.

A characteristic property of aluminium is its lightness; its density is 2·6 (iron 7·7, copper 8·8, lead 11·3).

Its conductivity for heat is very great; it is classed from this point of view immediately after silver, copper, and gold.

Its specific heat is considerable; that is to say, to raise the temperature of a given quantity of aluminium requires a larger quantity of heat than for the same weight of other metals, independent of all loss by conduction, radiation, etc.

Aluminium oxidises very superficially in free air. If it is impure, water or simply humidity corrodes it; it produces a veritable electrolysis of the water; the oxygen combines with the metal and forms alumina.

It remains in its original state up to high temperatures, right up to bright red, but a little before the melting-point is reached it commences to rapidly oxidise.

The melting-point of the oxide of aluminium (alumina) is very much higher than that of the metal. Its density is also much higher.

Aluminium in a molten state can absorb gases by occlusion, and can retain them distributed in the mass.

DIFFICULTIES ENCOUNTERED IN THE AUTOGENOUS WELDING OF ALUMINIUM.

The properties of aluminium, which have just been given, show the difficulties that the welder has to overcome in autogenously joining by melting articles of aluminium.

It is first of all necessary that the edges to be welded should be very clean and the welding rod very pure, so as to avoid the incorporation of impurities which can bring about rapid disintegration in the line of welding.

The relatively low melting-point requires a certain amount of skill in the application of a blowpipe which furnishes a high temperature. A very hot flame is necessary to compensate for the great dispersion of heat by conductivity. This conductivity requires certain precautions being taken during the execution of the welds.

The alumina formed in the course of melting being in an earthy state, and not always rising to the surface, especially with great thicknesses (its density being higher than that of the metal), it is necessary to eliminate it by chemical means, using an appropriate *flux. Without this precaution it is impossible to obtain a good weld.*

The occlusion of gases can make the metal porous, lacking in cohesion, and susceptible to the action of acids.

The mechanical properties of the line of welding are those of the cast metal. Cold hammering and annealing improves them, when these treatments are easily applied.

WELDING ROD—CLEANING FLUX.

The welding rod used for the autogenous welding of aluminium is of aluminium wire as pure as possible. It is specially important to see that the surface has no trace of copper from the wire-drawing benches, *because traces of this metal can render the welds susceptible to action by water or simply moist air.*

The reducing flux, for melting the alumina, is used in the form of a very fine powder which is incorporated in the molten metal by the aid of the welding rod.

This powder has the following composition (*Union de la Soudure Autogène* formula):—

Lithium chloride . . .	15	per cent.
Potassium ,, . . .	45	,,
Sodium ,, . . .	30	,,
Potassium fluoride . . .	7	,,
Bisulphate of potassium . .	3	,,
Total .	100	,,

The manufacture of powders destined for the welding of aluminium is a delicate process, because it is necessary to take precautions to completely dry the salts and thus avoid their combination with each other. It is best to leave their preparation to specialists, and even these do not always make it perfectly. With reference to this, let us say that all powders which *shrivel* up under the action of the blowpipe are of defective manufacture.

EXECUTION OF WELDS.

As a general rule, the pieces to be welded are prepared the same as for the welds on iron, copper, or brass, *i.e.* edges polished, bevelled when the thickness exceeds $\frac{1}{8}$ inch, etc.

The power of the blowpipe to be used increases rapidly with the thickness to be welded. For thin plates up to $\frac{1}{16}$ inch a blowpipe of very low delivery is used: 50 or 60 litres of acetylene per hour; in fact, the edges are molten before the conductivity has had sufficient time to disperse the heat. As the thickness increases the conductivity of the metal absorbs a great part of the heat, and it is necessary to use a blowpipe of much larger power. For $\frac{3}{32}$ inch a blowpipe delivering 120 litres of acetylene per hour is used. For $\frac{1}{8}$ inch the blowpipe most suitable is 225 to 250 litres, and for $\frac{3}{16}$ inch one of 500 litres.

It is understood that if the parts to be welded were preheated it would not be necessary to use such a powerful blowpipe, since the melting-point of aluminium is about 650° C.

The deformations from expansion are in theory great, but, in practice, much less to be feared than for similar welds on iron or steel, because the great conductivity of heat of aluminium tends to distribute the heat in the whole mass.

Nevertheless, if it is a case of welding plates, the separation of the edges to be welded in the form of a "V," when one proceeds in this manner, should be at least the same as for plates of steel.

The movements due to expansion can be avoided by heating the piece before welding, either with a blowpipe, or any kind of fire, an operation which is facilitated by the great conductivity of the metal. It is always necessary to avoid exceeding a temperature of 400° to 500° C., above which aluminium becomes fragile and sinks, or is deformed under its own weight.

The welding rod, as we have seen, should be as pure as possible. After $\frac{1}{16}$ inch its diameter should be about equal to the thickness of the weld.

The cleaning flux is applied by dipping the end of the welding rod into the vessel containing the flux. At the commencement of welding this extremity is warmed in order that the powder shall adhere. Avoid using too much, and consequently the powder should not be distributed by the hand over the line of welding.

The rate of advancement is not regular. The first fusion takes longer to obtain because of the loss of heat by conductivity; the execution of the weld should become more and more rapid as the edges to be welded become heated by conductivity. At this moment the heat should be localised as much as possible to the line of welding, so as to avoid the fusion or sinking of neighbouring parts.

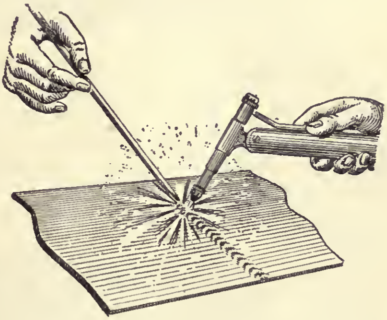

Fig. 219.—Position of welding rod for welding thin pieces of aluminium.

In executing the weld avoid contact of the white jet with the metal just about to be melted or molten, because the high temperature of this part of the flame tends to produce holes which are difficult to mend.

The distance of the white jet should vary, according to the power of the blowpipe, from $\frac{3}{16}$ to $\frac{3}{4}$ inch.

For thin welds, up to $\frac{1}{16}$ or $\frac{1}{8}$ inch thickness, it is preferable to hold the welding rod in front of the blowpipe in the direction of the edges to be welded; as soon as the latter begins to melt, it is heated rapidly and lowered to form one molten bath with the metal of the piece. The welding is thus done very rapidly.

For great thicknesses it is, on the contrary, preferable to obtain fusion of the welding rod, previously heated and powdered, in the molten bath of the bevel, as we have indicated for cast iron (fig. 198).

More detailed methods cannot be indicated, because the method of melting depends mainly on the thickness of the metal, shape of parts, etc. In all cases welds on aluminium should be very rapidly executed from the moment the first fusion is obtained.

We repeat that a short apprenticeship is necessary to obtain autogenous welds on aluminium, especially for perfectly joining the welding metal, that is to say, avoiding the interposition of alumina, holes, and sinking, and lastly, for obtaining a regular and good-looking line of welding.

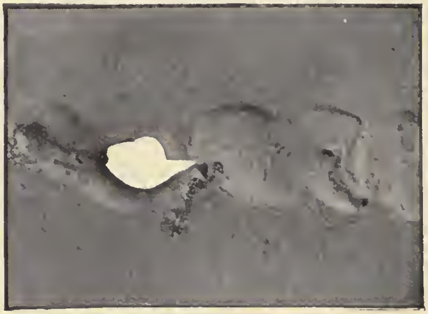

Fig. 220.—Aluminium welded by a beginner.

Beginners on the welding of this metal should not be discouraged, because they will rapidly improve by reflecting on the phenomena which they have to overcome.

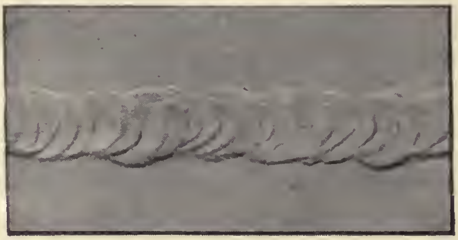

Fig. 221.—Aluminium weld executed by an experienced workman.

For very thin plates, up to a maximum of $\frac{1}{32}$ inch, the welding is facilitated by grooving the edges or flanging them, as we have mentioned under "Thin Pieces," in Chapter XI., "Preparation of Welds."

TREATMENT AFTER WELDING.

The phenomenon of contraction does not generally produce cracks in the welds on pure aluminium, at least for short lengths, on account of the great conductivity of the metal, which tends to distribute the heat throughout the mass.

Nevertheless, we have said that it is fragile at temperatures near the melting-point, and which, of course, it will have to pass on cooling after welding. Thus for welding thick pieces whose shape tends to localise the effects of contraction, precautions of a kind which we have indicated in the chapter on "Preparation of Welds" can be taken.

After cooling, the lines of welding and their immediate vicinity should be brushed in running water so as to remove completely the effects of the cleaning flux, which would slowly corrode the metal.

Where possible, the lines of welding should be *cold*-hammered, so as to give the melted metal the same physical texture and the mechanical properties of the rolled metal. To make the marks of the cold-hammering disappear it is necessary to anneal.

APPLICATIONS.

Autogenous welding of aluminium can be applied for all permanent joints on articles in this metal. One can even say that it is the only process capable of giving good results.

If well executed, the welds possess no defects, and consist of pure aluminium free from oxide. After a suitable thermic and mechanical treatment it has the same properties as that of the metal, from the point of view of mechanical strength, elongation, etc. The only thing against it is that it is much more sensitive to corrosive agents than the metal, and this is no doubt due to very slight impurities and a different physical state which the thermic and mechanical treatment have not completely removed. However, in the majority of applications of aluminium this defect of welding is of no consequence.

Fig. 222.—Aluminium water-bottle (military pattern) constructed by welding two stamped pieces.

Here are chosen at random a few applications of the autogenous welding of aluminium:—Welding of vats and tanks; making of bottles and light cans; various joints for aeroplanes and dirigible balloons; welding of receivers of all kinds; joining end to end of bars, wires, and electric cables, etc. etc.

AUTOGENOUS WELDING OF ALLOYS OF ALUMINIUM.

Aluminium has been alloyed with other metals with the aim of obtaining alloys with special properties. We give a few notes in the next chapter on the welding of aluminium bronzes, which generally contain 90 per cent. of copper and 10 per cent. of aluminium.

We leave aside the complex alloys of aluminium, cadmium, magnesium, and tin, which are more or less used in the manufacture of white metals, and whose composition is so extremely variable that it is not possible to define their treatment by autogenous welding.

We will only deal with the *aluminium-zinc* alloy used for the manufacture of light and strong castings, such as gear-cases for automobiles, parts of machines, etc. The composition of this alloy, as met with industrially, is very variable; it can contain from 10 to 30 per cent. of zinc, the best qualities being those with the lowest percentage of zinc. The best compositions of aluminium-zinc alloys for castings also contain from 1 to 3 per cent. of copper. Their density is about 3·5, and the breaking strength varies from 28,000 to 36,000 lbs. per square inch.

Autogenous welding is principally applied for repairing articles made from these alloys, which are not very ductile, especially when subjected to repeated shocks or vibrations, the metal then becoming crystalline and brittle.

Owing to the varying proportions of aluminium and zinc which enter into these alloys, it is necessary to find a welding rod of average percentage for the purposes of autogenous welding. The question is rather complex, because the melting-point of alloys of aluminium-zinc vary according to their composition, and it is necessary that the melting-point of the welding rod should be near that of the metal to be welded.

The following composition (*Union de la Soudure Autogène* formula) is the one which up to the present has given the best results:—

Aluminium	88 per cent.
Zinc	10 ,,
Copper	2 ,,

This alloy is made homogeneous and cast in rods of sizes appropriate to the repairs to be executed.

Castings which are of no further use could evidently be used for the making of welding rods, but since their exact composition is not known, there is a danger of introducing into the alloy dirt, foreign bodies, or various impurities.

The use of pure aluminium for the welding of articles of aluminium-zinc does not give a true autogenous weld; the welded zone is more flexible, but much softer than the rest of the piece, and this lack of strength is a defect which must be avoided.

It is necessary to guard against using compositions called "brazings for castings of aluminium," sold in great numbers and which generally consists of an alloy containing a high percentage of zinc whose melting-point does not exceed 400° C. The mechanical properties of such a joint are totally different to that of the metal, and the joint does not possess any cohesion.

From the point of view of the formation of alumina during the execution of the work, the autogenous welding of alloys of aluminium and zinc present the same difficulties as in the case of pure aluminium, that is to say, one must use the same flux destined to destroy the alumina which is formed when the metal is melted; the quantity, however, is less, because the fusion of the welding rod takes place in the bath of metal, that is to say, free from the air. *In spite of all the precautions that may be taken, a weld executed without a cleaning flux never presents perfect homogeneity.*

We have seen that these alloys of aluminium-zinc, excellent for castings, do not possess great ductility. As a result, the phenomena of expansion and contraction become of very great importance, as the articles often contain ribs, angular recesses, or parts which prevent the expansion or the contraction having free play.

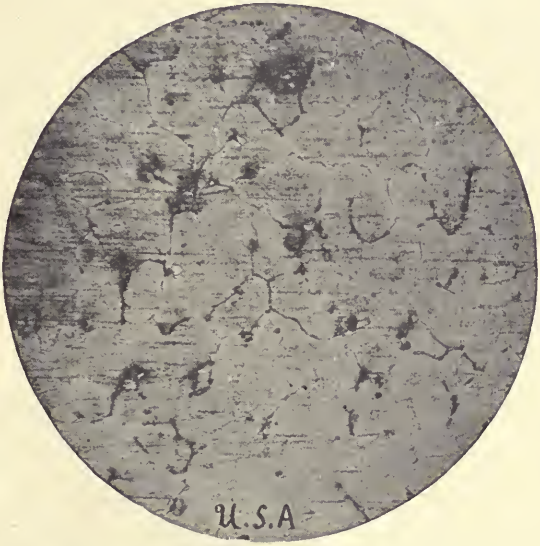

Fig. 223.—Microphotograph of an aluminium-zinc weld (gear-case metal) executed without cleaning flux; numerous layers of alumina in the metallic mass.

It is therefore necessary in the majority of cases, and especially in gear-cases of automobiles, to preheat the whole piece up to the neighbourhood of 450° to 500° C.

This preheating should be done with many precautions to avoid melting of the metal and its collapse on account of the lack of cohesion above 550° C.

The preheating should be done in the absence of air, and where possible in a furnace made for the purpose (figs. 78 and 79).

The article must be constantly watched so as to stop the heating before the critical temperature is attained: this can be recognised by rubbing the metal with an iron rod or a rasp; as soon as it becomes easily impressed and gives a dull sound, it is time to stop heating and effect the repair.

The furnace is then opened and a blowpipe of appropriate power is used, according to the thickness of the casting. The delivery of acetylene is from 400 to 800 litres (14 to 28 cubic feet) per hour, because the fusion should be done rapidly. For repairing gear-cases of the usual pattern a blowpipe of 700 to 750 litres (25 to 27 cubic feet) per hour is advisable.

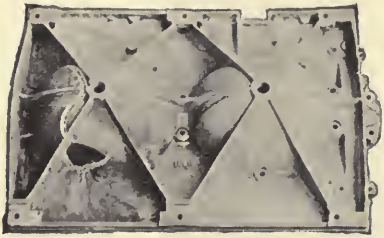

Fig. 224.—Gear-case bevelled previous to welding.

As soon as the repair is completed the article is replaced in the furnace still warm, then covered as hermetically as possible in order to avoid currents of air and to bring about excessively slow cooling. It must not be taken from the furnace until the cooling is complete. It only remains to work it, that is, to remove the roughness, by the aid of a chisel, grindstone, or file. *Sand-blast* can profitably be used, so as to give the article a new appearance. The welded part then becomes invisible.

The operations of preheating and excessively slow cooling are absolutely indispensable for obtaining welds on castings of aluminium-zinc.

Fig. 225.—The same, after welding and use.

We have omitted to mention that, before welding, the edges to be joined should be bevelled and made bright. Extension of the cracks on preheating can be avoided by drilling holes at their extremities.

As in the case of welding pure aluminium, avoid bringing the white jet too near the molten metal. It should be at a distance of $\frac{3}{8}$ to $\frac{3}{4}$ inch, if it is only to avoid the volatilisation of the zinc at the very high temperature.

Certain articles have ribs which tend to produce cracks during cooling, in spite of all precautions. It is useful, in these cases, to cut the ribs so as to allow the necessary expansion and contraction to take place. Afterwards proceed to weld these artificial cracks, an operation which does not present any difficulty.

When the castings are thin, which is the case in certain types of aluminium gear-cases, it is necessary to avoid the collapse of the metal by supporting the fragile parts. This preparation is done with the aid of thin iron plates supported and wedged by crossbars.

The repair of aluminium castings is a very simple operation for the regular welder of these jobs. Beginners should not be discouraged by their first failures.

Fig. 226.—Gear-case, badly damaged.

Fig. 227.—The same, after welding and use.

We again recommend them to guard against using the fusible mixtures sold commercially, and which apparently make the operation easier, but only result in deplorable work.

CHAPTER XVIII.

AUTOGENOUS WELDING OF VARIOUS METALS AND ALLOYS.

In theory autogenous welding can be applied to all metals and alloys used industrially. Nevertheless the technique of the process is not yet established for certain of them, but the difficulties which confront the first experimenters are not without doubt insurmountable. In other cases autogenous welding will probably never attain the desired end, and it will be well to give the reasons.

We have just studied the application of autogenous welding to the materials most generally used in metallic construction, *i.e.* iron, steel, cast iron, copper, brasses, bronzes, and aluminium. We will now devote a few lines to other metals or alloys, explaining briefly with reference to each the difficulties the welder meets and the methods of welding which appear to be the most rational.

MALLEABLE CAST IRON.

We have mentioned in Chapter XV., on the "Autogenous Welding of Cast Iron," that we would give here a few notes on the joining of malleable cast iron.

Malleable cast iron is obtained by decarbonising more or less completely ordinary cast iron. The castings are placed in cast-iron boxes in contact with oxide of iron and raised to a high temperature in a special furnace.

By an excessively slow reaction the oxide of iron gives up its oxygen to the carbon of the metal, whilst the cast iron changes to iron.

It will be understood that the reaction commences at the surface of the casting and spreads little by little to the interior of the mass.

In theory, if the parts of castings are all of the same thickness, the decarbonisation can take place completely; in practice, the articles of malleable cast iron consist of a core of cast iron surrounded by a more or less thick layer of iron. Of course it is understood that between the surface, which is practically free from carbon, and the centre of the core, which is cast iron, there exists a more or less carbonised intermediate zone according to its distance from the surface or the core.

In those articles of malleable cast iron which have varying thicknesses, the thin parts are sometimes totally decarbonised, and in these cases their repair by autogenous welding can be done just the same as in the case of mild steel, using the same soft iron welding rod.

On the contrary, in the thick parts the core of cast iron is present, and the repair becomes difficult on account of the entirely different nature of the metal between the surface and the core, *i.e.* different melting-points, oxide fusible or not, as the case may be, etc.

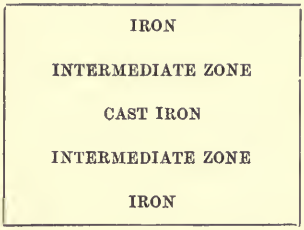

Fig. 228.—Diagram to indicate the composition of a piece of malleable cast iron.

Of course, if the exact value of the decarbonisation of a part of a malleable casting was known, the welder could operate and repair almost rationally by autogenous welding, save in the intermediate zone, between the surface and the core. But these considerations are outside the sphere of practice and, as a general rule, all welds executed on thick parts of malleable cast iron cannot be rationally executed. A line of welding of steely cast iron is obtained, containing blowholes and impossible to work. It is better to make use of brazing, which usually gives better results, and the welder should abstain, except in the case of repairs to thin articles, from trying to obtain joints by the fusion of a metal which is not homogeneous.

WELDING IRON TO CAST IRON.

All that we have said with regard to malleable cast iron can be applied to the case of joining pieces of iron and cast iron.

Certainly, the skill of the welder enables him to obtain suitable joints, but such welds, needless to say, are not autogenous. For their execution a wire of mild steel is used, which forms with the cast iron a steely cast iron, hard, brittle, and unworkable. This intermediate zone is unavoidable.

Evidently there are cases where such welds can be executed without disadvantage, but it is logical to say that brazing is always preferable.

CHROME AND MANGANESE STEELS.

Chrome steels are weldable if the percentage of carbon does not bring them in the category of hard steels, which is more generally the case. The joints obtained by welding then possess all the defects of which we have spoken when dealing with the welds obtained with hard steels.

The same remarks apply to manganese steels, which are used more generally in the form of mild steels. In these cases they are perfectly weldable, the manganese being favourable to the execution of the welds, on account of it playing the *rôle* of deoxidiser.

The welding rod to be used should, where possible, have the same percentage of chrome or manganese, but in case of necessity iron or mild steel can be used.

NICKEL.

For the moment nickel should be considered as *unweldable.* The well-known phenomenon of the absorption of gases is particularly intense in the case of nickel melted under the action of the blowpipe, and on cooling the melted portion becomes spongy and possesses practically no strength.

Attempts have been made to overcome this absorption of gases by using very fusible materials floating on the line of fusion and destined to prevent all contact between the metal and the gases of the blowpipe. Of course this is an improvement, but the absorption is not completely avoided, and up to the present no method of welding nickel has given good results. It is probable that a much deeper study of the question, followed by numerous tests, will enable the welder to avoid this absorption of gases, but until then welders should completely abstain from trying to weld it.

FERRO-NICKEL AND NICKEL STEEL.

The use of these two alloys is very common, and the welding of them is therefore of interest.

If the percentage of nickel does not exceed 20 per cent., it is easy to prevent the absorption of gases, and consequently to avoid the *rochage* or *spitting* of the molten mass. It is only necessary to interpose between the flame and the metal a protecting varnish consisting of a *thick solution of silicate of soda* or *crushed glass.* The supply should be very abundant, so that the layer opposes the absorption of gases. The welding rod, consisting of ferro-nickel of the same composition, should be equally protected. The welds are executed in the same manner as that given for mild steel.

Above 20 per cent. of nickel the absorption of gases is difficult to avoid. At 30 per cent. the lines of welding always possess numerous blowholes.

COPPER-NICKEL ALLOYS.

If the alloys do not contain more than 30 per cent. of nickel their autogenous welding can be obtained under the same conditions as for welds of ferro-nickel, that is to say, by interposing between the metal and the flame a protecting varnish destined to prevent the absorption of gases, *i.e.* a very thick solution of silicate of soda or ground glass.

The welding rod should be of the same composition as the parts to be welded.

ALUMINIUM BRONZES.

In practice two principal qualities of aluminium bronzes are used, *i.e.* the metal with 10 per cent. aluminium, and the light bronze which, on the contrary, has a high percentage of aluminium and a low percentage of copper—95 per cent. aluminium and 5 per cent. copper.

The bronze containing 10 per cent. aluminium is perfectly weldable. Those who have failed have not used a flux sufficiently energetic for destroying the alumina in proportion to its formation.

The flux to be used is of the same nature as for the welding of aluminium, but much more energetic. A research for a definite formula is actually being carried out by the *Union de la Soudure Autogène.*

The light bronze is treated in the same manner as for aluminium and alloys of aluminium and zinc, that is to say, with the flux which we have given for the autogenous welding of these metals.

In both cases it is necessary to use a welding rod of the same composition as the parts to be welded.

GERMAN SILVER.

German silvers are complex alloys of copper, zinc, and nickel, the respective percentages varying greatly according to their manufacture.

In view of the difficulties which are met in the welding of each of these constituents and which require different treatments, it is better for the moment to consider that the autogenous welding of these alloys are unrealisable. Brazing is preferable.

BI-METAL.

Metallic articles made by intimately joining two pieces of different metals— iron-copper, copper-nickel, etc.—cannot be welded by fusion with the blowpipe so as to produce autogenous welds. The welder is confronted with the simultaneous melting of two entirely different metals always opposing the good joining of each other. Here, again, brazing is much more preferable.

LEAD.

The autogenous welding of lead is obtained in a perfect manner and very economically by the oxy-acetylene blowpipe.

At first sight it would appear that the use of a very hot flame is not only useless but unfavourable. Experience proves, however, that the use of the oxy-acetylene flame offers many advantages, *i.e.* a close line of welding, perfect homogeneity, and rapid execution. In the autogenous welding of lead the rapidity of the execution is, moreover, a guarantee of non-oxidation in the line of fusion.

A cleaning flux is not necessary, *but the edges to be welded should be scraped bright and have no kind of slag on the surface.*

The welding rod should be of lead free from tin, antimony, etc., and perfectly cleaned, so that in fusion it is equally exempt from any layer of oxide, grease, powder, slag, etc.

Fig. 229.—Oxy-acetylene weld on lead.

For the obtaining of welds on lead a blowpipe of very feeble delivery is used, consuming 25 to 60 litres (1 to 2 cubic feet) of acetylene per hour for thicknesses varying from $\frac{1}{16}$ to $\frac{3}{16}$ inches. With very little practice an experienced welder succeeds in welding sheets of lead in a very perfect manner.

The process deserves to be developed, as it has considerable advantages over all other methods of autogenous welding, *i.e.* hydrogen and air, hydrogen and oxygen, etc. Note that the quantity of gas used is absolutely insignificant, as is seen from the figures quoted above.

ZINC.

Although in industrial practice the autogenous welding of zinc does not often occur, it should be known that the metal is perfectly weldable by the oxy-acetylene blowpipe.

It might be thought, on considering the welding of brass and other alloys containing zinc, that there would be a great volatilisation during execution. This is quite otherwise because, if the metal melts at a low temperature, its volatilisation point is much higher.

For a flux, simply use sal-ammoniac as for soft soldering. The welding rod should be of zinc as pure as possible, but in case of necessity pieces cut from plates of zinc of very best quality can be used.

PRECIOUS METALS.

The autogenous welding of precious metals by the oxy-acetylene blowpipe offers no particular difficulty. Silver, platinum, and gold are weldable without any special precautions, the joining of the molten metal taking place very easily.

CHAPTER XIX.

WELDING MACHINES.

The art of the welder depends upon reflection and skill. True, we place the first of these qualities above the second, but it is none the less true that skill in the management of the blowpipe is the indispensable complement which should be acquired by every practitioner of autogenous welding, so as to accurately apply the principles which he has acquired.

Here skill is not only the result of practice, because the jobs differ too much amongst themselves for mechanical movement to come in. If it were otherwise, welding machines, working better and more rapidly than the most skilful welder, would quickly replace them. This has been done for certain work in which the operation does not require any effort of the intelligence and particular skill.

Welding machines do not replace welders; they only supplement them in the sense that they take possession of the work at the moment when it becomes mechanical; they keep the true practitioner to his art, where reflection and non-mechanical skill have constantly to be exercised, and they prevent him from getting into a groove where his best faculties become blunt. Thus there are really two distinct classes of workers: the reflective welder, skilful and conscientious, and the mechanical. It is preferable that the latter should not consist of human welders.

HISTORICAL.

The idea of automatic welding machines dates from the commencement of the use of welding blowpipes; certain manufacturers having to weld a series of identical articles, designed mechanical arrangements which could be well described as welding machines. It is sufficient to move the edges to be welded underneath a fixed blowpipe, or the blowpipe above the edges to be welded, for such an arrangement to be realised. The other parts of the machine consisted of arrangements necessary for holding the edges, keeping the article in position, etc. etc.

In a pamphlet published in 1907 by the *Société l'Oxhydrique Française*, we find a description of a machine for welding tanks and parts of boilers.

In an article published in the same year, by M. R. Thomas, the manufacture of tubes by the use of automatic welding machines is fully explained, and at that time many applications of the process had already been realised.

Machines for welding have since been perfected, especially for the manufacture of tubes. Those for the manufacture of tanks, repetition articles, etc., have also been designed, and to-day a number of designs can be obtained which work excellently.

It is the German constructors who have obtained, in this respect, the most important improvements, notably in machines for manufacturing tubes.

PRINCIPLES OF WELDING MACHINES.

The principle of welding machines differs with the work which is demanded of them.

Those destined for the manufacture of tubes are, for example, very simple, at least as far as the actual realisation of the weld is concerned. In fact the edges to be welded can easily be maintained one against the other by rollers, which hold them in such a manner that it is only necessary to give the tubes a regular advancing movement under the flame of the blowpipe to obtain perfect joints.

In machines for welding tanks or objects of large diameters and various shapes, the maintaining of the edges to be welded against each other and at the same level is more difficult to obtain, and special arrangements have to be made. Moreover, if the edges to be joined are not perfectly adjusted, the fixed position of the flame with regard to the line of welding, or the line of welding with regard to the flame, welding is impossible; in fact, if the flame once gets between the edges to be joined it melts the parts to be united and drives the molten metal away, bringing about the formation of a hole, which becomes larger as the blowpipe advances.

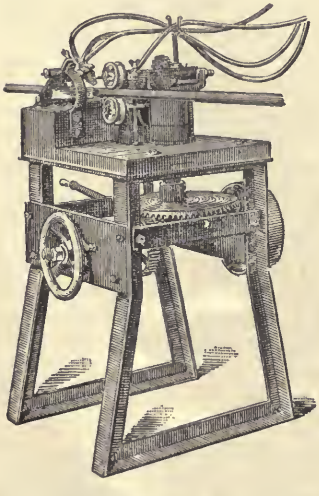
Fig. 230. — Machine for welding tubes, simple pattern, without preheating (Hager and Weidmann).

The ingenuity of designers is always exercised in creating mechanical arrangements for exactly maintaining the edges one against the other.

Other constructors have thought it good to give to the blowpipe the same oscillatory or gyratory movement which the welders give, or to keep the blowpipe fixed and give the article being welded a movement.

The first solution is preferable, and is, in fact, the one that has been adopted. Meanwhile, a mixed solution consists of giving a gyratory or oscillatory movement to the blowpipe, whilst the movement of the weld is obtained by the progressive displacement of the piece.

. . . .

We will not undertake the description of welding machines, especially the numerous patterns which have been designed for welding steel tubes; such a study is outside the scope of this work. We will just mention a few of the machines from amongst the best known, including those intended for welding coppersmiths' articles, other than tubes.

The machines for welding tubes are generally built for two tubes so as to reduce the cost of labour.

Once the machine is regulated, one workman can supervise the two blowpipes placed side by side, welding simultaneously two similar tubes.

The simple machines consist of mechanical arrangements for regulating the rollers. The unwelded tube is gripped between two rollers, the blowpipe being placed behind at any desired angle.

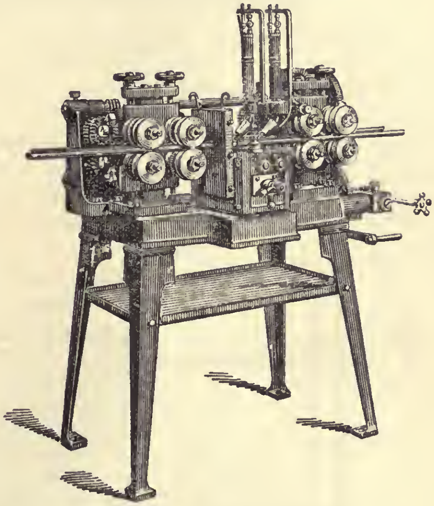

Fig. 231.—Machine for welding two tubes, preheating by waste heat of the flame.

The blowpipes used for this work are specially constructed so as to be easily adapted to the machines. They are also provided with water circulation to avoid too much heating.

An edged wheel which engages in the slit of the unwelded tube serves to keep the line of welding exactly under the flame of the blowpipe. It is only necessary to regularly advance the tube by rotation of the rollers to obtain a perfectly regular weld.

For manufacture on a large scale the machines for two tubes are to be preferred, and preheating of the tubes is practised either by the waste heat of the blowpipe or by a charcoal furnace, or again by flames, using benzol or petrol.

This preheating avoids the effects of expansion, increases the rate of execution, and produces considerable economy.

Thus, after preheating by benzol, nearly 330 feet of tube 2 inches diameter and $\frac{3}{32}$ inch thick can be welded in two hours, whereas it requires twice as long for machines without preheating. The cost of gas and labour, which is about 13s. in the latter case, are reduced to 3s. 6d. in the first.

Fig. 232.—Photograph of a machine weld on a tube of mild steel.

The manufacture of the tubes previous to welding should be perfect. The making of the strips into tubes can either be done in special rolling machines, or by pulling the strips through a die. It is essential that the edges meet exactly.

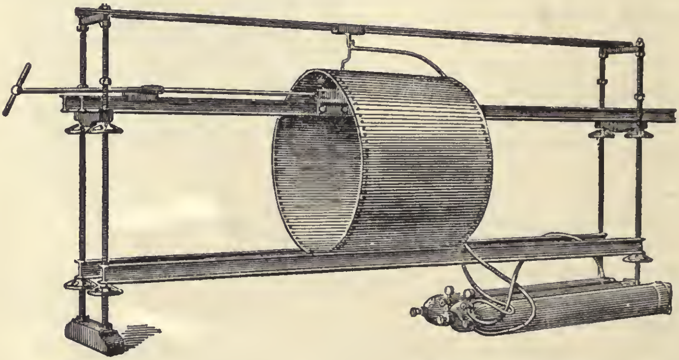

Fig. 233.—Machine for welding cylindrical tanks, etc., made by the *Société l'Oxhydrique.*

After welding, the tubes are generally stretched; this operation completely removes the line of welding and considerably improves the resistance of the joint. It is understood that to commence with the tubes are slightly thicker in order to obtain the required thickness after stretching.

This manufacture by autogenous welding is generally practised at present on tubes of $\frac{5}{8}$ to 2 inches diameter, but much larger tubes can be welded, say, up to 4 inches diameter and $\frac{1}{8}$ to $\frac{3}{32}$ inch thick.

. . . .

We have said that the *Société l'Oxhydrique* were the first to design a machine for the welding of cylindrical bodies of large diameter. This machine, which is very simple, can easily be applied in workshops. It is necessary to prepare the articles so as to overcome the effects of expansion in the same manner as for welding by hand.

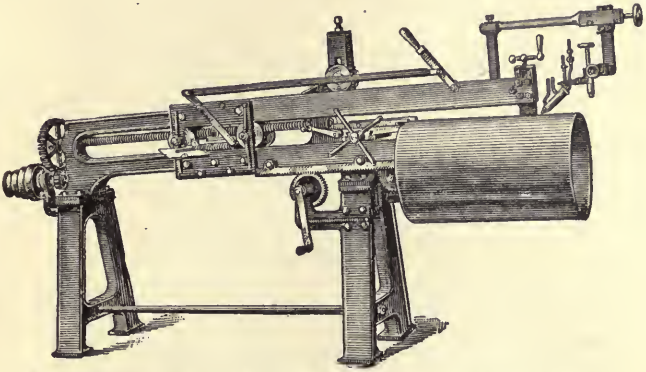

Fig. 234.—Machine for welding cylindrical bodies (Bastian type).

The *Bastian* machines, also designed for the welding of cylindrical bodies of all kinds, are employed in a large number of workshops, and give good results.

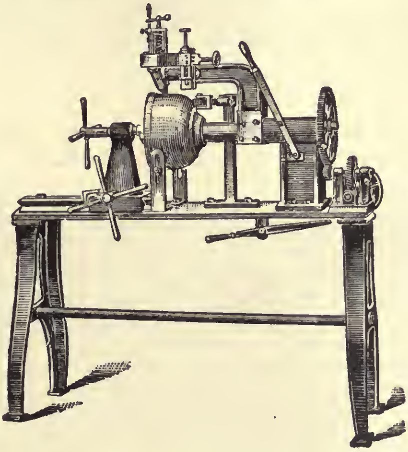

Fig. 235.—Machine for welding repetition articles (Bastian type).

The same firm have designed machines for the autogenous welding of repetition articles of all kinds, especially household utensils.

In all these machines the blowpipe is fixed, and the pieces to be welded movable.

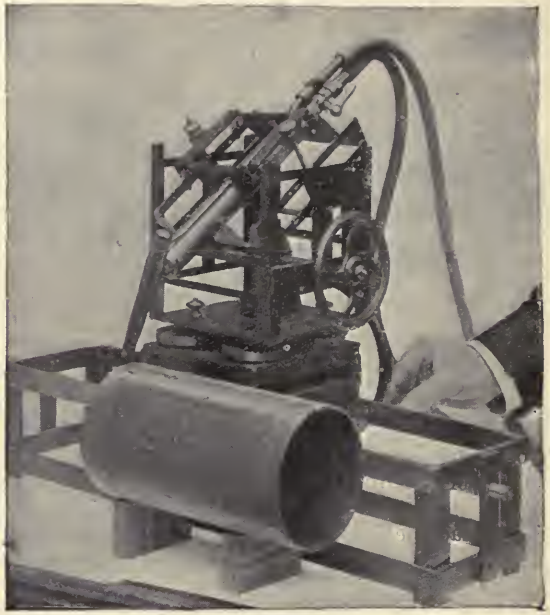

Fig. 236.—The first Trambouze machine (demonstration model).

The opposite principle is employed in the Trambouze welding machine. The blowpipe is mechanically worked in such a way that it reproduces much more regularly the movements which are ordinarily given by the hand of the welder, and at the same time

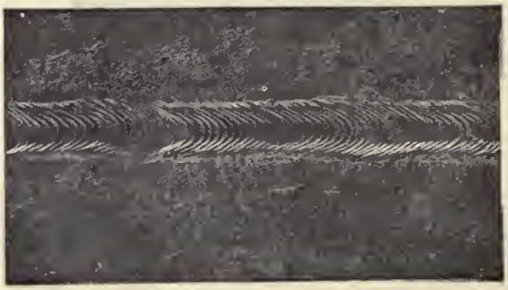

Fig. 237.—Photograph of weld obtained on a Trambouze machine, actual size (plates $\frac{3}{32}$ in. thick).

advances regularly. This machine consists of a frame carrying rails on which slides a carriage, to which the blowpipe is attached in such a manner that a gyratory or oscillatory movement can be given to it.

It is only necessary to give a certain velocity to one wheel in order to obtain the same movements which experienced welders give to the flame.

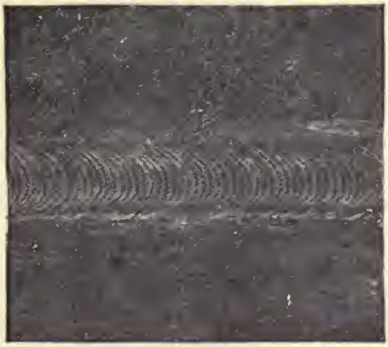

Fig. 238.—Photograph of weld obtained on a Trambouze machine, actual size (plates $\frac{3}{16}$ in. thick).

Such machines can be applied to all kinds of welds, without the pieces being prepared in any other way than that required for executing the weld by hand.

This machine is constructed in all sizes and for all applications.

CHAPTER XX.

CUTTING OF IRON AND STEEL WITH THE BLOWPIPE AND A JET OF OXYGEN.

The process of rapidly cutting iron and steel with the blowpipe and a jet of oxygen has been considerably developed, especially in workshops using autogenous welding, since the necessary material, save the blowpipe, is the same in the two cases. The addition of one or more cutting blowpipes to the welding installation is, in many cases, of great value.[1]

It is from this point of view that we will devote the last chapter of this work. We will also mention in passing certain interesting applications in metallurgy and in large constructional work.

HISTORY OF THE PROCESS.

The application to iron and steel of rapid cutting by oxidation of the metal has only been known industrially for a few years. Its development dates from the time when oxygen could be sold at a price sufficiently low for the process to become of interest.

The rapid combustion of iron in oxygen has been known for more than a century since it was mentioned by Lavoisier. The chemical treatises mention in this respect that the oxide formed being more fusible than the iron, is detached as the combustion proceeds.

M. H. Sainte-Claire Deville, who was one of the first to study the fusion of metals by the aid of the oxy-hydrogen blowpipe, states that "if one continues to heat and increase the quantity of oxygen, the iron burns and throws on all sides sparks of fire."

Nevertheless, the design of blowpipes specially intended for cutting iron and steel, consisting of a heating flame and a special ejector of oxygen under pressure, is only a few years old. The *Société l'Oxhydrique* appear to have established and exploited the first industrial apparatus of this kind, and they have claimed the monopoly by taking out patents in all the principal countries. The value of these patents was first of all neglected, then contested, discussed, and judged. In Germany the Patent Comptroller, then the Imperial

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[1] The *Union de la Soudure Autogène* has recently published a pamphlet on the cutting of iron and steels based on the recent work of their research engineer, M. Amédéo.

Tribunal, recognised them as valid, but lawsuits to annul them have again been commenced. In France they were annulled by a judgment of the Tribunal of the Seine (20th July 1909), but the *Société l'Oxhydrique*, having appealed to the Cour de Paris, decided to submit the case to a commission of experts (14th December 1911).

The question will not be definitely settled until this year (1913), and it will be necessary to be very reserved as to the issue and consequences of this case. Let us complete this information by adding that the *Société l'Oxhydrique Français* have given licences for exploitation to certain constructors of oxy-acetylene blowpipe cutters who were competitors outside the lawsuit before the first judgment.

COMBUSTION OF IRON IN OXYGEN.

The majority of metals oxidise under the action of the oxygen of the air. It is, as we have said, a slow combustion which continues until the layer of oxide is dense enough to protect the rest of the metal from the action of the air, as in the case of iron, for example.

On the other hand, we know that the oxidation is much more intense and rapid as the temperature of the metal is raised, and we have seen that this phenomenon has constantly to be overcome in obtaining autogenous welds.

From the point of view of cutting by a jet of oxygen, one seeks, on the other hand, to produce the oxidation and to render it as intense as possible so as to burn in the shortest time, by contact with the oxygen, the narrowest cut possible.

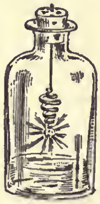
Fig. 239.

If a thin strip of iron or steel is taken, for example a watch-spring, and plunged into a jar of oxygen after first raising the extremity to a red heat, the iron rapidly burns in contact with the gas. The oxide of iron which is formed is detached from the metal, and projected on all sides in a molten state (fig. 239).

What is the "mechanism," so to speak, of this rapid combustion of iron in oxygen? The oxidation commences at the part which has previously been heated to redness, because at this temperature the reaction takes place readily. The combustion of this portion of iron disengages heat, a portion of which is absorbed by the neighbouring part; this is sufficient to raise it to red heat, so that it in turn burns, and this reaction is progressively propagated throughout the metal. The oxide formed has a much lower melting-point than that of the metal, and is detached, leaving the iron continually bare.

The case is not the same for other metals which, in contact with oxygen, have a less degree of oxidation, and whose oxide has a melting-point equal or higher than that of the metal, and so prevents it being detached. Indeed, copper, brasses, bronzes, and aluminium do not burn in oxygen in the manner which we have described in the experiment on iron or steel.

Highly carbonised steels whose melting-point is appreciably lower than that of iron, and in the neighbourhood of the oxide of the metal do not lend themselves well to cutting, because the oxidation does not propagate itself, nor in the case of cast iron, on account of the impossibility of eliminating the oxide mixed with the molten metal.

Therefore, iron and steel are alone amongst the ordinary metals which can be burnt in a continuous manner by contact with oxygen, because the oxide of iron produced by the combustion is eliminated, in proportion as it is formed, in the molten state.

It would therefore be useless to attempt to apply the process to other metals or alloys which do not possess this property.

GENERAL IDEAS ON THE CUTTING OF IRON AND STEELS BY A JET OF OXYGEN.

It is therefore well understood that only iron and steels are capable of being cut by rapid combustion of the metal under the action of oxygen. The operation consists of projecting, on the metal previously heated to redness, a jet of oxygen escaping under a sufficiently high pressure. The oxide is driven away as it is produced, and the combustion extends throughout the thickness to be cut. It is only necessary to displace progressively and regularly the nozzle of the oxygen jet to obtain any desired line of cutting.

We have seen above, that in the experiment on the thin strip of iron or steel plunged into the jar of oxygen the heat of the reaction is sufficient to maintain the temperature necessary for the oxidation of the adjoining portion, and so on. In the process of cutting it is slightly different. In reality, the conductivity of the metal to be cut absorbs a considerable part of the heat given to the metal, and the temperature is not maintained in the part to be cut to the degree necessary for oxidation. For the reaction to proceed it is therefore necessary to constantly add the amount of heat necessary to maintain at a red heat the part of the metal to be cut. This result is obtained by means of a flame, which immediately precedes, in the course of the work, the oxygen jet. It is natural that this flame should be oxy-acetylene in installations that are using oxygen and acetylene for obtaining autogenous welds.

We shall see, elsewhere, that oxy-hydrogen, oxy-gas, and oxy-benzol flames can be used with equal success, because here it is a question of heating the metal and not melting it, so that they do not have the same disadvantages as in the case of autogenous welding. One might even say that the oxy-hydrogen flame, perhaps because of the large proportion of hydrogen which it contains, lends itself more than the others to the preparation for cutting of iron and steels by a jet of oxygen.

TECHNIQUE OF CUTTING BY OXYGEN.

We have said that certain recent improvements in cutting blowpipes not only tend to produce better work, but also to reduce the expenditure on oxygen. It is true that the technique of the process has, until recently, been altogether neglected, and one has scarcely commenced at present to fix the methods to be used from the scientific facts that have been obtained through experiment.

Thus, until now, it was always thought that the oxide of iron detached by the cutting blowpipe was the magnetic oxide corresponding to the formula Fe_3O_4. The engineer of the *Union de la Soudure Autogène*, M. Amédéo, was curious enough to analyse various samples of oxide gathered in workshops using cutting blowpipes of different types. It was thus discovered that the oxide obtained from cuts on iron and steel with a jet of oxygen was very often far from that corresponding to the formula Fe_3O_4, and sometimes corresponded to the lowest oxide, FeO.

Note the importance of this fact: the less oxygen the oxide contains, the lower the consumption of this gas, without speaking of other considerations the scientist must not neglect. Now it is not impossible to regulate the operation of cutting in such a manner as to obtain this result, inasmuch as in the majority of cases it is obtained without seeking it.

Other experimenters have been struck by the fact that one plays on iron raised to a red heat a jet of oxygen which is cold, the more so as the expansion of the gas as it leaves the cylinders considerably lowers the temperature, sometimes 5° C. to 10° C. below zero.

The *Union de la Soudure Autogène* called attention to the possibilities in the preheating of the oxygen used in cutting, by the simple passage of the gas through a spiral tube surrounding the heating flame. From the very decisive experiments which have since been made, they certainly point to the application of this process, the economy realised being much more important in that it results from the suppression of cooling, which, for the same delivery of oxygen, enables one to obtain a much greater velocity of cutting (15 to 25 per cent.), the oxidation of the metal being considerably facilitated.

The pressure to be given to the cutting oxygen for different thicknesses is again very indeterminate; it depends, moreover, on the construction of the blowpipe, especially as regards the exit nozzle for the oxygen and the tube that immediately precedes it. It will be understood that it is a question of obtaining the thinnest possible jet with the greatest length, capable of detaching the oxide and blowing it away if necessary, and using the minimum pressure. The problem is the same, or nearly the same, as that of obtaining a jet of water of the greatest length for the same pressure, or given a fixed length to find the lowest possible pressure.

The results vary according to whether the iron or steels are more or less carbonised, or, again, whether the steels are special, viz. chrome, nickel, etc.

The intensity of the heating flame, its length, the distribution of the heat, its nature, can likewise influence the results; also the distance and direction of the oxygen jet with reference to the line of cutting.

Lastly, the purity of the oxygen is an important factor which counts, more or less, in the perfection of the work of cutting and, above all, for the fixing of the cost. The oxygen should be as pure as possible, at least 97 to 98 per cent. With oxygen of 95 per cent. purity, which is very satisfactory for welding, the inferiority is evident for cutting; with 90 per cent. and less the cutting blowpipes no longer work normally.

It is seen, then, that the technique of the process is much more complex than would appear at first sight. We have simply called attention to it; we cannot go further into it because the results are not complete.

CUTTING BLOWPIPES.

We will just explain the constitution of cutting blowpipes as they are actually constructed and used, without taking into account the improvements which are about to be obtained as a result of the researches of which we have just spoken.

Fig. 240.—Outline diagram of cutting blowpipe.

Cutting blowpipes consist of an arrangement for giving a heating flame, generally that which is adopted in welding blowpipes and to which is joined in a permanent manner a second arrangement for bringing the cutting oxygen, its regulation and its projection on the metal. The chief characteristic of a good cutting blowpipe being that these arrangements should be so combined that it is hardly possible for them to get out of order, and of easy management.

However, the construction and regulation of cutting blowpipes are not so simple as this definition might lead one to believe; the form and arrangement of the various details have considerable influence not only on the good working of the blowpipe during the operation, but also on the cleanness of the cut and, above all, on the consumption of oxygen.

In other words, it is not sufficient to project an oxygen jet escaping from an orifice on to iron or steel heated to redness in order to obtain the results which are given by the best blowpipes; and those who make a cutting instrument by adding an outlet sprayer in the vicinity of the exit nozzle of a welding blowpipe with the object of saving, produce a false economy. The value of the heating flame, the direction of the jet of oxygen in reference to the heated zone, the section of the exit nozzle, and the shape and size of the tube which supplies it, have an importance which has not escaped the specialists, and which even the amateur constructors recognise. This is so true that improvements tending to produce clean and rapid cutting with considerable economy of oxygen have been added to blowpipes within the last year or two without modifying their general arrangements.

. . . .

The *Phœnix* blowpipe of the *Société l'Oxhydrique* is of very simple construction. It consists of two tubes bringing the gases, which can be separated at will. The lower tube serves to convey the mixture of hydrogen and oxygen previously mixed and destined for the heating flame. The cutting oxygen arrives by the upper tube, and is played on the metal at the correct moment by means of a valve manipulated by a lever. A guiding arrangement on rollers completes the blowpipe.

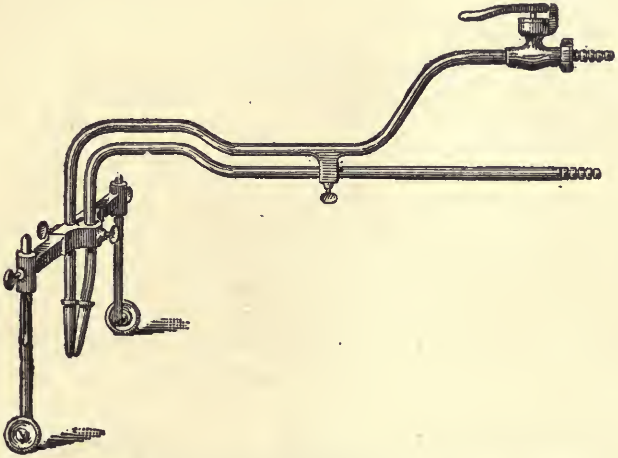

Fig. 241.—Phœnix cutting blowpipe of the *Société l'Oxhydrique.*

As with the majority of cutting blowpipes using separate jets, the operation is performed by drawing the blowpipe and not by pushing it. The heating flame which should precede the cutting jet would, in the case of pushing the blowpipe, follow it.

The arrangement of the nozzles is of interest. The heating flame is held much higher from the metal than that of the oxygen jet. On the other hand, the first is slightly inclined to the second.

These nozzles are made for all deliveries and are interchangeable.

The *Société l'Oxhydrique* have also designed a cutting blowpipe with a central jet of oxygen (see fig. 242).

In the *Pyrocopt* blowpipe, where the heating flame is oxy-acetylene, the oxygen necessary for the latter and for the cutting jet arrive by the same tube; two conical valves placed side by side on the blowpipe distribute the gas. The heating flame consists of a nozzle, in the centre of which is fixed another nozzle for the escape of the jet of oxygen, with the result that the oxy-acetylene mixture destined for heating escapes in an annular ring. This arrangement enables one to cut in all directions, since the oxygen jet is in the centre of the flame. For repairs and the work of demolition this advantage is valuable. For straight cuts, this arrangement has no advantage.

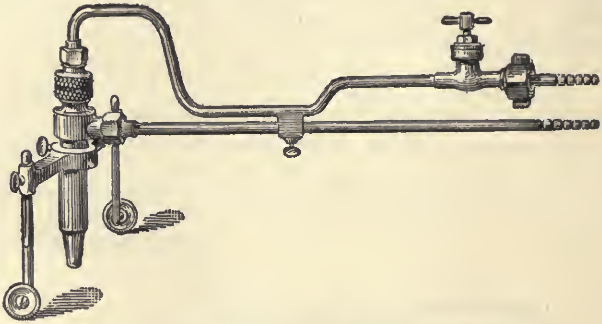

Fig. 242.—Phœnix cutting blowpipe with central jet.

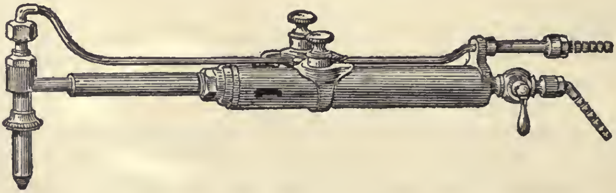

Fig. 243.—Pyrocopt oxy-acetylene cutting blowpipe (central jet).

A blowpipe of the same pattern is made for cutting thin work. The valves for regulating the oxygen are placed one on top and the other on the side.

The blowpipe of the *Société l'Air Liquide* is constructed on the same lines as the *Pyrocopt*, but the heating flame is not annular. It escapes by three or four orifices which surround the cutting jet, which is central.

In the *Columbia* blowpipe there is only one nozzle, but the heating flame escapes by a single orifice placed by the side of the cutting jet, which is central.

The control of the cutting oxygen is by a very easily controlled lever.

The *Simplex* cutting blowpipe has separate jets. The heating flame consists of a mixture of oxygen and acetylene. It is, to a certain extent, the Simplex welding blowpipe, on which has been fixed a cutting arrangement.

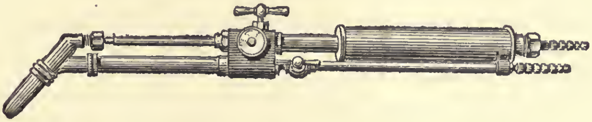

Fig. 244.—Oxy-acetylene cutting blowpipe of the *Société l'Air Liquide* (central jet).

The *Helios* cutting blowpipe has separate jets. On the cutting oxygen tube a gauge is fixed, to give the pressure of the gas in this part.

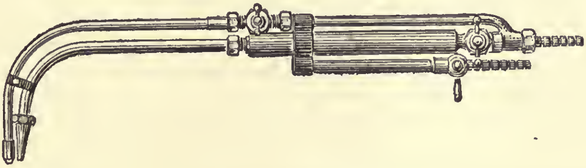

Fig. 245.—Simplex oxy-acetylene cutting blowpipe (cutting jet separate).

We could mention a large number of other types of hand-cutting blowpipes which have been designed on nearly the same principles. They only vary a little in shape and details.

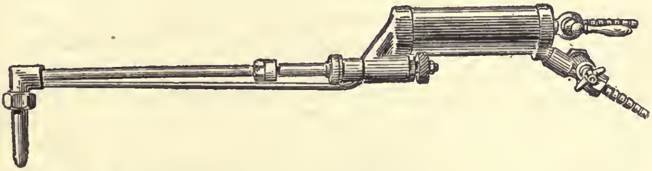

Fig. 246.—Pyrocopt blowpipe (type Champy Frères) (oxy-acetylene, central jet, and oxygen regulator).

Let us recall, however, that a certain number of considerations, relative to the making of these details, their mounting, and regulation are often of very great importance, and often makes one pattern much superior in use to another of the same appearance.

USE OF CUTTING BLOWPIPES. EXECUTION OF CUTS.

We repeat that the cutting by a jet of oxygen can only be applied to iron and steels, and it is absolutely useless to experiment on other metals and alloys, including cast iron.

All thicknesses met with industrially can be cut, from thin plates to armour plate or runners on steel castings attaining 12, 16, and even 20 inches. At the same time, after a certain thickness, the use of a machine holding the blowpipe perfectly rigid and giving it a regular advancing movement is absolutely indispensable, especially for obtaining clean cuts, if, for example, it is a case of new work and not demolition.

In all cases where the execution is by hand, and the line of the cut must be clean and regular, the use of a blowpipe on rollers or at least on a guiding support is necessary.

The intensity of the heating flame and the delivery of oxygen to the cutter should be proportional to the thickness cut. Nevertheless, there seems to be a great amount of latitude allowed if one knows how to control these factors in the regulation of the speed of execution.

For the ordinary cases of using a cutting blowpipe in autogenous welding installations, the apparatus is simply mounted in place of the welding blowpipe at the extremity of the flexible tubes, one carrying the oxygen and the other the acetylene.

We will not occupy ourselves with the more complete installations, which generally include blowpipes for triple tubing, the cutting oxygen coming from a special cylinder, or at least by a second reducing valve fixed at the side of that which feeds the heating flame.

The pressure is therefore regulated by a special reducing valve which only controls that necessary for cutting. If this pressure is too high for the heating flame, it can be reduced by means of a cock placed for the purpose on the blowpipe.

In the majority of workshops it has become a habit to use the oxygen, destined for cutting, under a pressure much too high. The workman seems to think that the higher the pressure the better and more rapid is the cut. This is a grave error. Pressures from 14 to 45 lbs. are sufficient for almost all ordinary work, giving better results and requiring less expenditure of oxygen than when the valve is regulated, as is often seen, from 70 to 140 lbs. or even more.

The principal requirement for cutting great thicknesses is not that the reducing valve should be graduated for high pressures, but that it should be able to supply the necessary *quantity* of oxygen. Special reducing valves have been made for the requirements of cutting; it matters little that their graduation is up to 300 or 350 lbs., which is not necessary, and seems to invite the operator to use high pressures. The principal point is that on the opening of the cutting jet the pressure should not appreciably fall on account of the very rapid flowing of the gas. Moreover, the preliminary regulation of the blowpipe draws the attention of the operator to this point. Here is how to proceed:

Open fully the valve on the oxygen tube, close the oxygen cutting valve on the blowpipe, and send the oxygen and acetylene as for a welding blowpipe. Light and regulate the heating flame as near as possible in proportion to the thickness to be cut. Then open the valve for the cutting oxygen and regulate at the same time the pressure by the reducing valve. This generally brings about irregular working of the flame; the opening of the cutting jet, in effect, lowers the pressure of the oxygen, and the flame contains an excess of acetylene. It is therefore expedient to obtain the final regulation of the flame with *the valve controlling the cutting oxygen open.* This done, close the valve, and it only remains to begin the work.

If the heating flame which has been normally regulated with the cutting jet open becomes too oxidising when it is closed, it is either because the reducing valve is too weak for the total delivery of oxygen, the cylinder is not sufficiently open, or that the oxygen pressure is not high enough.

The cutting is commenced on one of the edges of the piece; the direct attack away from the edges can only be done with thin plates or, if one cannot do otherwise, by directing the jet of oxygen in such a manner that the oxide is blown along the cutting line.

The metal is heated by playing the blowpipe on the corner of the piece, and when it is raised to redness, cutting is commenced by opening wide the oxygen valve. The oxide of iron is thrown on the side at the beginning and underneath as soon as the cut has gone through the thickness of metal. The blowpipe is then advanced very regularly so as to follow up the operation.

If the operator moves too quickly the cut does not go through, and the oxide is blown on the sides or all round the blowpipe; if he goes too slowly the oxygen is wasted, since the edges of the metal are more or less melted by the heating flame. According to the thickness to be cut and the power of the blowpipe, the speed of advancement must be regulated so that the operation is followed up normally.

Excess speed or irregular advancement often produces stoppage of the cutting; the jet of oxygen meets a part which is too cold, and the oxidation ceases. At this moment the oxygen jet should be turned off, as it is being wasted, and is also cooling the metal; then go back a little and heat the part required and take up the operation again.

Blowholes in steel castings and interposition of slag sometimes make the work difficult, because the least discontinuity or the lack of homogeneity will prevent the oxidation from normally propagating itself. Let us notice in passing, with reference to this, that articles whose surface is painted, greasy, or scaly, etc., should be cleaned along the whole line of passage of the blowpipe, as without this the attack of the surface, in proportion to the advancement of the cutting, would be difficult and irregular.

In addition to the fault of raising the oxygen to too high a pressure, we should mention the tendency which some makers have of giving their blowpipes a too powerful heating flame. True, the cutting operation proper is commenced more rapidly since the heating is more rapid; but a flame which is too intense has the disadvantage of overheating the line of cutting, that is, to raise the metal to its melting-point, and then to produce an alloy of the oxide and of the molten iron which plugs the cutting section and stops the operation, or at least always makes the cut less clean.

It is therefore necessary that the operator should not use too powerful a heating flame, especially for thin cuts. It is much better to wait a little longer time before commencing the operation, and then obtain better work.

In the course of cutting it frequently happens that the nozzle of the heating flame is more or less obstructed by the projection of oxide, whence a possibility of a return of the oxygen in the acetylene tube, and a burning right up to the hydraulic valve—which further emphasises the usefulness of this arrangement.

Apart from the usual care which it is necessary to give to cutting blowpipes, the same as for welding blowpipes, it is frequently necessary to clean the nozzles which, during the course of the work, get projections of oxide in them. Care should be taken not to enlarge or deform them, or even to scratch the surface of the exit orifice for the oxygen.

The tightness of the valves, joints, and unions should be particularly secure and tested.

COST OF CUTTING.

In a general way one might say that the cutting of iron and steel by oxygen is much more economical than the mechanical processes. It is, however, necessary to guard against applying it to all jobs, and especially those for which special tools have been designed or are easily adaptable.

Experimenters do not absolutely agree as to the cost of cutting with the blowpipe. This is not surprising, considering the absence, until now, of the fundamental technique, and the variety of apparatus used. Here are some figures by M. Guillet obtained on plates of mild steel with the cutting blowpipe of the *Société l'Oxhydrique.*

Thickness of Plates in Inches.	Total Consumption of Gases per Foot of Cut.				Time per Foot in Seconds.
	Hydrogen		Oxygen		
	in Litres.	in Cub. Ft.	in Litres.	in Cub. Ft.	
$\frac{3}{16}$	41	1·45	41	1·45	49
$\frac{3}{8}$	57	2·01	57	2·01	68
$\frac{9}{16}$	70	2·48	70	2·48	84
$\frac{3}{4}$	85	3·00	85	3·00	102
$1\frac{3}{16}$	100	3·54	113	4·00	77
$1\frac{9}{16}$	105	3·72	126	4·45	81
2	113	4·0	168	5·95	87
$2\frac{15}{16}$	140	4·95	266	9·4	107
4	210	7·43	440	15·5	161
$5\frac{1}{8}$	290	10·2	655	23·2	196

According to the same experimenter, the width of the cut would not exceed $\frac{1}{16}$ inch up to $\frac{13}{16}$ inch in thickness, $\frac{3}{32}$ inch up to $1\frac{5}{8}$ inch, and $\frac{3}{16}$ inch for much greater thicknesses.

The blowpipes have been improved since the tests of M. Guillet, and the consumption of oxygen notably reduced. It depends, moreover, on the shape and thickness of the pieces to be cut.

The Arsenal at Lorient, which uses a Pyrocopt blowpipe for the cutting of plates varying in thickness from $\frac{3}{8}$ to $1\frac{3}{8}$ inches, only use 5·8 litres or 0·21 cubic foot of oxygen per square inch of cut.

Here are the results of some tests made at the beginning of 1911 by the P.L.M. Railway Company, using a Pyrocopt blowpipe:—

Cutting an elliptical manhole in a boiler.

Perimeter or length of ellipse	$31\frac{1}{2}$ inches.
Thickness	$\frac{9}{16}$ inches.
Area of section cut	$17\frac{1}{2}$ square inches.
Consumption of oxygen	150 litres or 5·3 cubic feet. (0·3 cubic foot per square inch.)
Consumption of acetylene	40 litres or 1·4 cubic feet.

Cutting a locomotive frame of $1\frac{3}{16}$ inches thickness.

Length of cut	55 inches.
Thickness	$1\frac{3}{16}$ inches.
Area of section cut	65 square inches.
Consumption of oxygen	500 litres or 17·7 cubic feet. (0·27 cubic feet per square inch.)
Consumption of acetylene	100 litres or 3·5 cubic feet.

According to the tests made on cutting by the Company of Fives-Lille, on steel plates of 1 inch thickness with various systems of cutting blowpipes, the consumption of oxygen per foot-run was:—

140 litres or 4·9 cubic feet for the oxy-benz blowpipe.
98 ,, 3·5 ,, ,, oxy-hydrogen ,,
100 ,, 3·5 ,, ,, oxy-acetylene ,,

The *Société l'Air Liquide* has carried out cutting on the runners of castings 14 by 14 inches (cradles for 12-inch canons); each runner was cut in eleven minutes, and the average consumption of oxygen did not exceed 106 cubic feet.

CUTTING MACHINES.

In construction work the line of cut should be as clean as possible. The use of a machine holding the blowpipe absolutely rigid, always at the same distance, and allowing a very regular advancement according to the cutting, is indispensable, especially for great thicknesses.

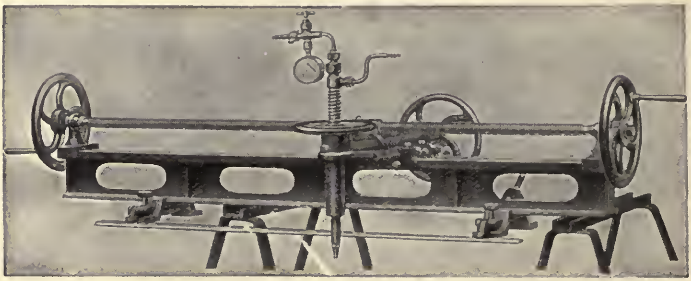

Fig. 247.—Cutting machine of the *Société l'Oxhydrique.*

Certain forms, curves, and accurate angles cannot be obtained satisfactorily with the blowpipe held by the hand.

Machines have therefore been designed to obtain accurate cutting for these conditions, especially from the point of view of cleanness of cutting and facility in carrying out the operation.

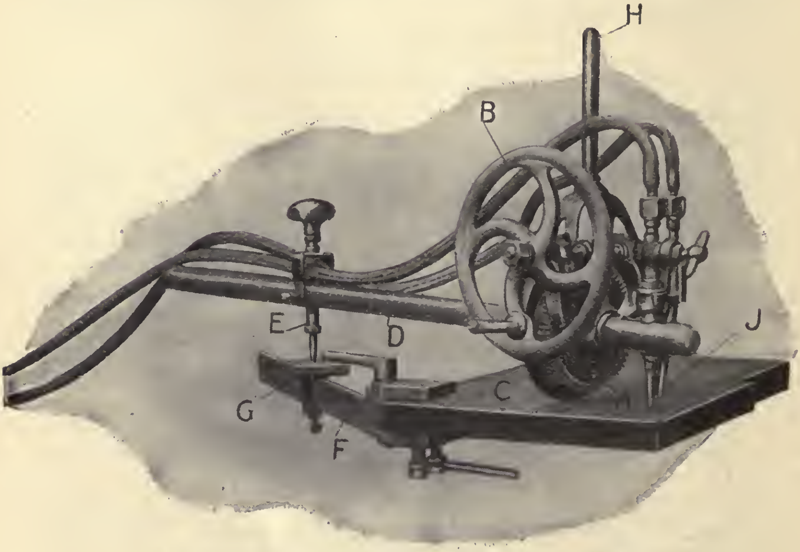

Fig. 248.—Circular cutter of the *Société l'Oxhydrique.*

The *Société l'Oxhydrique* has particularly studied the mechanical arrangements of such cutting machines; they are generally constructed in a special manner, but contain, none the less, the heating flame and the oxygen jet under pressure.

We reproduce several of these machines designed for cutting iron and steel for constructional work.

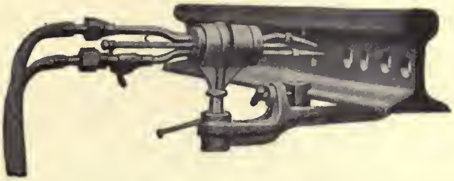

Fig. 249.—Piercing machine of the *Société l'Oxhydrique.*

APPLICATIONS OF CUTTING BLOWPIPES.

One might divide the applications of cutting blowpipes into three main classes, viz. new work, repairs, demolitions.

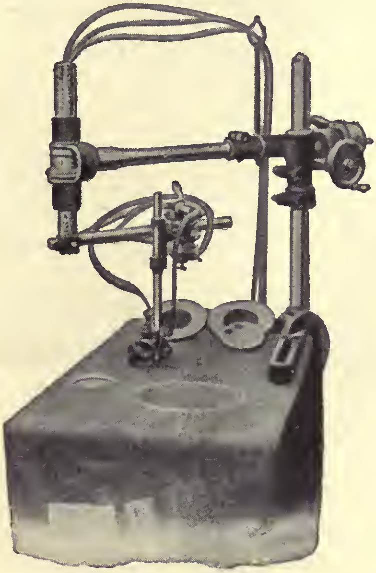

Fig. 250.—Cutting machine.

Cutting with a jet of oxygen has not yet been applied on a large scale to new work, but with the improvements in the process and the lowering of the price of oxygen, it will probably become of considerable importance in the near future.

One cannot attempt to name all the kinds of constructional work in which it may be used, so numerous and varied are they. We will just mention a few from among those where it has been tried. Let us say, first of all, that the cutting blowpipe may be used for a host of current work requiring the division of iron and steel—plates profiles, bars, tubes, etc.

Its application is particularly interesting for the construction of articles of complicated shape which previously could only be obtained at the forge but can now be cut from the solid. This is the case in the manufacture of crank-shafts, for example.

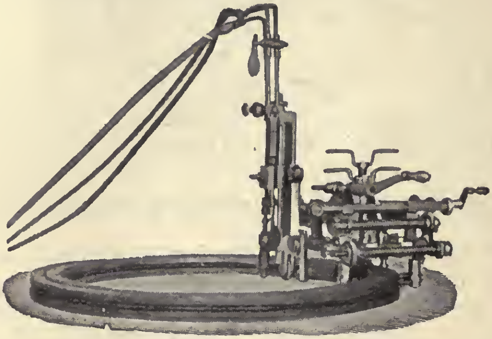

Fig. 251.—Cutting machine (system Eiman) rolling on a lead rail previously bent to the shape of cut required.

A host of articles, of small, medium, and large dimensions, can be obtained by this method. Thus, by simple cutting in a plate of suitable length and thickness, very complicated pieces, such as locomotive frames, can be obtained.

Fig. 252.—Crank-shaft cut by the cutting blowpipe from a plate.

Let us mention, in passing, that the metal in the neighbourhood of the cut is practically unaffected; all the tests have been conclusive from this point of view.

Cutting enables one to obtain important economies in the large iron trade industries when it is a question of cutting articles which are bulky, difficult to manipulate and work by mechanical tools.

In steel foundries it has found numerous applications for the cutting of runners. In naval workshops it is employed at the present time for cutting armour plates and other pieces of steel of great thickness.

Fig. 253.—Piece completely executed by cutting blowpipe.

In ordinary smithing the cutting blowpipe advantageously replaces pneumatic tools.

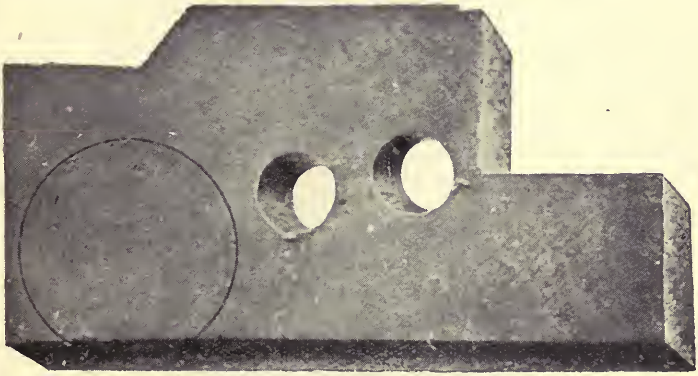

Fig. 254.—Work executed by cutting blowpipe.

The photographs which we reproduce give a clear idea of its application to new work.

In repair work the cutter renders great service. In fact, in a large number of cases it is necessary first of all to demolish the joints before submitting them to the necessary repair, and very often this work has to be done in position, that is to say, inaccessible to machine

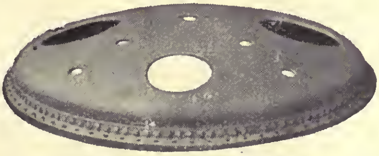

Fig. 255.—Holes obtained with the cutting blowpipe.

tools. The cutting by a jet of oxygen in such cases is always indicated. Many repair jobs could not be executed without this process.

Let us also mention the process of removing rivets by the jet of oxygen and a special blowpipe. This removal is done by experienced workmen without altering in any way the riveted plates; the driving out of the rivet after the head is burnt away is a simple operation. Two workmen operating together, one manipulating the blowpipe, the other driving out the rivets with a punch, can remove 30 to 60 rivets ($\frac{7}{8}$ inch diameter) per hour.

Fig. 256.—Rapid demolition with the cutting blowpipe of a bridge which had collapsed and was obstructing the harbour at Havre.

In the case of demolition, the cutting blowpipe offers a very particular interest; it is, in a way, the only process which enables one to cut up on the spot, rapidly and with little cost, old steel constructions, no matter how thick the sections may be—ships, boilers, structural iron work, metal constructions of all kinds, etc., etc.

It is incontestable that in this way oxygen finds an enormous market.

True, the development and use of cutting blowpipes will be considerably accelerated with the lowering of the price of oxygen, since the economy of its application depends entirely upon the latter. It is hoped that the manufacturers of oxygen will consider this, and will deliver to the industry, for the special use of cutting, oxygen at a price which might not immediately prove remunerative, but which will create for them an exceedingly important market, and favour greatly the exploitation of their industry.

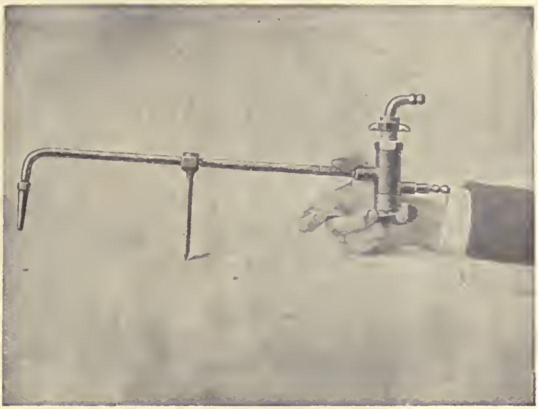

Fig. 257.—Blowpipe for removing rivets (*Société l'Oxhydrique*).


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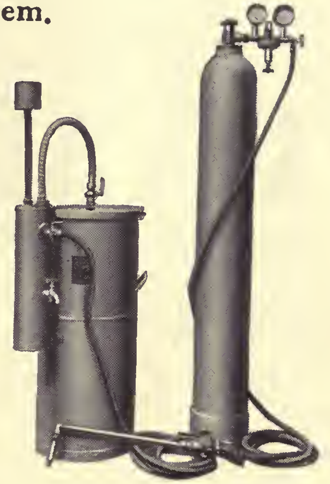

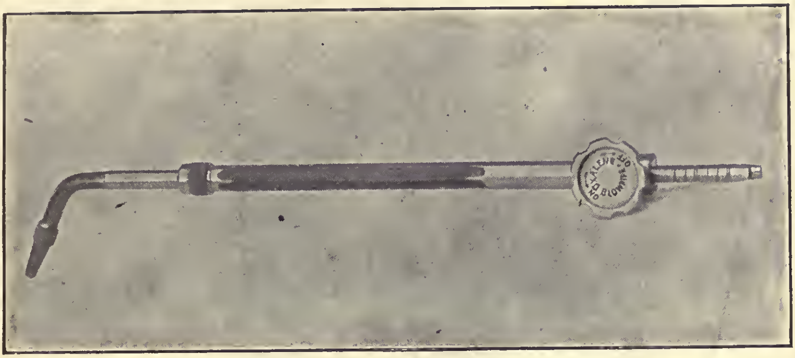

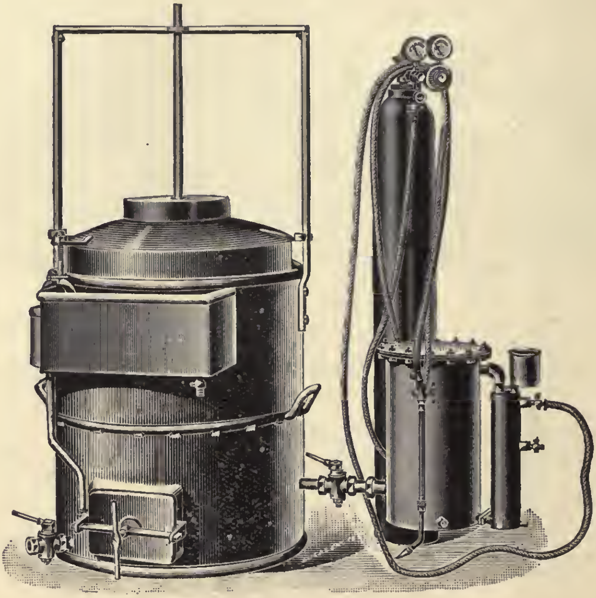

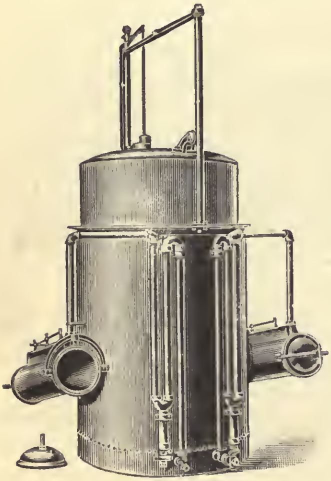

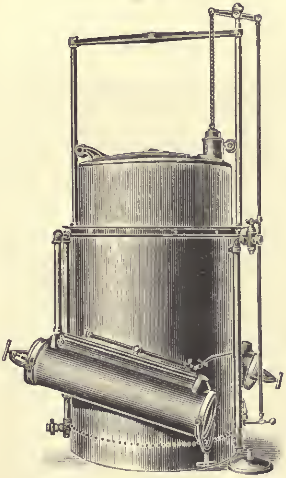

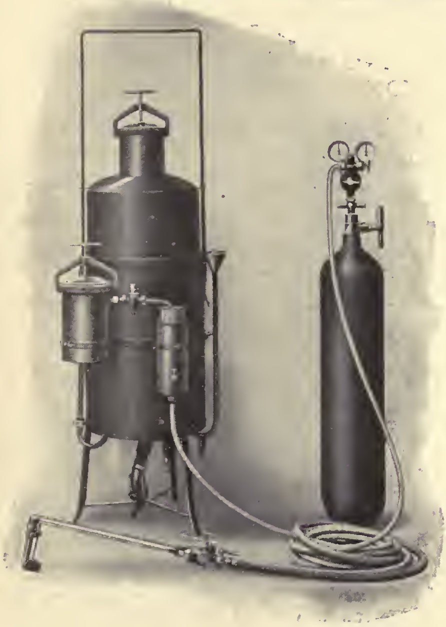

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