SHAW

Methods of Welding Metals

Mechanical Engineering

B. S.

1908

METHODS OF WELDING METALS

BY

James William Shaw

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE
IN MECHANICAL ENGINEERING

IN THE
COLLEGE OF ENGINEERING
OF THE
UNIVERSITY OF ILLINOIS
PRESENTED JUNE, 1908

UNIVERSITY OF ILLINOIS

June 1, 1908

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

JAMES WILLIAM SHAW

ENTITLED METHODS OF WELDING METALS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Mechanical Engineering

J. H. Gill
Instructor in Charge.

APPROVED: L. P. Breckenridge

HEAD OF DEPARTMENT OF Mechanical Engineering

CONTENTS.

METHODS OF WELDING METALS.

Introduction.

1. Historical.- The art of welding is doubtless as old as the use of iron in the arts, and its development from the manipulation of pieces within the limits of human strength at the blacksmith's forge, to the massive productions of the steam hammer and hydraulic forging press makes its operations well known. Welding is one of the most important and at the same time one of the most difficult operations in the manufacture and use of metal.

2. Definition of Welding.- Welding is the operation of uniting two or more pieces of metal by heating the surfaces required to be joined, and forcing them together either by hammering or other pressure, while the metal surfaces are in the plastic state. A perfect weld might be defined as a molecular combination of two pieces of weldable material, in which the metal at or near the weld remains equal in strength and ductility to those parts of the metal which have not been heated.

3. Methods of Welding.- In the ordinary process of welding two pieces of metal, the smith heats the ends in a fire, until, so far as he is able to judge, the temperature has become somewhat higher than the correct welding point. The ends are placed together, sometimes treated with a flux such as borax which melts quickly and covers the heated surface, thus preventing the further access of air, and, at the same time, reduces the oxide scale already formed to a liquid state. The smith then hammers

the two ends together, his aim being to force out from the surfaces in contact all the burnt iron, and all the flux, and to produce a smooth surface. The strength of the weld depends almost entirely upon the skill which has been exercised in bringing the metal to just the right temperature and in hammering out all the burnt metal and flux.

The welding of brass, copper, and some other metals, is impracticable by the old hand method since copper would need to be raised to a very high temperature as compared with iron, and it is then highly oxidizable and liable to form a scale difficult to treat by any flux. It also passes quickly from the solid state to the molten state and is brittle near the welding temperature. With brass, it is difficult to avoid volatilization of the zinc before the copper constituent has been raised to the necessary temperature, and, furthermore, the alloy becomes very brittle near the welding temperature. Because of these facts such metals and alloys have been united by brazing or soldering, operations requiring considerable skill, and are expensive in the matter of solder, fluxes, heating appliances and labor charges.

4. New Methods of Welding. - Within the last ten years there have been developed several new methods of joining metals which are far more simple, require less skill on the part of the operator, and produce a more substantial joint. Three of these methods now find an important place in the manufactories of today. These are, The Electric Welding Process, The Autogeneous Welding Process, and The Thermit Cast Welding Process. Two others not so much used and comparatively little known are The Oxy-hydrogen Blowpipe Process- a form of Autogeneous Welding-, and The Weldit

Process, the latter being of very late origin. These methods will be treated in detail under separate heading.

GENERAL PURPOSE.

The general purpose of this thesis is to investigate the various methods of welding, apply them in so far as apparatus could be had or constructed to do the work, and to test the pieces welded, the main object being to find the efficiency of the weld, and that as compared to different kinds of welded joints, the secondary object being to note the effect of annealing after welding.

WELDING WITH HAMMER OR PRESSURE.

1. Review of these Methods.- The oldest form of welding was confined to the blacksmith shop only,but the advances made in the use of the steam hammer and forging press gradually extended the field of operations. These together with the drop forging press and the rolling and seaming machines, facilitated the work so much and produced a much more uniform joint, that, today they have clearly replaced the old hand methods entirely where large or duplicate pieces are required to be joined.

2. Classification of Welds.- Welds as made by hand or machine are classified according to the manner in which the contact between the pieces is made. There are many ways in which this may be done, and the selection of the kind of weld to use is made with reference to the use of the finished object, the strains it has to resist, and the equipment for making the weld. The following are some of the principal kinds of welds:- lap weld, scarf weld, butt weld and cleft or V weld. They are used according to the judgement and skill of the smith with reference to the work in hand.

3. Heat Treatment of Steel Welds.- When steel is first cast and allowed to cool, its temperature does not fall uniformly as many suppose. It solidifies at 2600 degrees Fahr. and from this point the temperature falls uniformly to that of dull redness, about 1200 to 1300 degrees Fahr. At this point the temperature ceases falling for a time, and either increases or remains stationary, afterwards, it again falls regularly until the steel is cold. That critical point at which the temperature remains constant or increases slightly is called the recalescent point and the internal structure of the steel undergoes important changes.

When the steel begins to solidify in the mold it also begins to crystallize until the point of recalescence is reached when this ceases. If the steel is heated again to any temperature less than that of the recalescent point the crystallization will not be affected, but if this point is passed the steel becomes amorphous in structure, the crystalline structure being destroyed by the heating.

In welding and forging the temperature of the steel must be above the recalescent point, ~~and~~ the working makes it amorphous or plastic and the crystalline structure is very close grained if present at all. If heated too hot the recalescent point is passed to far, and to bring the steel back to its normal condition it has to be properly annealed. In the process of annealing the steel is reheated up to the recalescent point and cooled very slowly.

The most difficult operation in welding is to heat the metal to the correct welding temperature so that the metal is plastic.

This is left entirely to the judgment of the smith. If, in welding steel the temperature corresponding to the recalescent point is exceeded very much, after the weld is made and has cooled, upon being broken the crystalline structure will be found to be very coarse. In this state the steel is very brittle and will stand but little abuse. If the steel is reheated up to the recalescent point, and allowed to cool slowly its proper structure is regained.

4. Effect of Proper Sized Hammer.- In welding, as well as in forging, with either hand or power hammers, the weight of the hammer must be taken into consideration. The penetration of the blows depend much on the weight of the hammers, and the welded or forged pieces show the effects very noticably. Fig. 1. illustrates the effect of using too light a hammer for a certain piece of work.

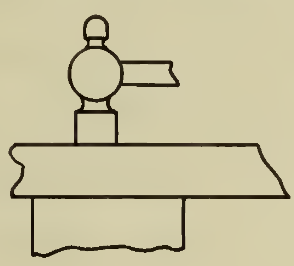


Fig.1.

The blows are not heavy enough to penetrate to the center of the piece. As a result, only the outside fibers are welded, the center remaining unchanged in position and retaining the slag, since the blows are not heavy enough to cause a flow of metal at the center. The light blows on the outside fibers cause them to expand longitudinally, force out the slag and unite, while the mass at the center is not affected and the flux is not driven out.

By using the proper weight of hammer, the result is as shown in Fig. 2.

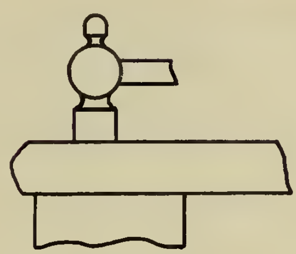


Fig. 2.

The hammer blows have penetrated to the center fibers causing them to expand, consequently forcing the flux from the center outward, thus assuring a perfect weld and a uniform structure of metal thruout.

5. <u>Power Hammers and Presses</u>.- When the pieces to be welded are so large, complicated or unwieldy, that they cannot be handled quickly by the blacksmith, one of the many forms of power hammers is used. Among these may be mentioned the belt driven rubber cushioned hammer or helve hammer, the belt driven forging hammer, the friction board drop hammer and the steam hammer, all of which are used in welding to a great extent.

Another class of machines which force welds by steady pressure are called presses. Among these may be mentioned the bulldozer and the hydraulic forging press. In the same class may be mentioned the flue rolling machines and tube lap and butt welding machines.

6. <u>Furnaces and Fuels</u>.- In making successful welds of all kinds, a large element in the success is the furnace and fuel used to heat the metal. There are many types of furnaces and forges in use using one kind of fuel or another. For small work a bituminous coal and coke is used, while in the large furnaces

serving power hammers and presses, oil or gas is used almost exclusively. Figures 5 to 8 inclusive, show types of oil burning furnaces made by the W.N.Best American Calorific Co. N.Y.

7. <u>Description of the Work Done</u>.- In order to obtain information as to the strength of the different kinds of welds, several were made of each of the lap, clef and butt welds using 5/8 and 3/4 inch round mild steel. Some of these welds the author made, the rest by Messrs Lanham and Cook. No flux was used, the object being to obtain a good weld without using a flux.

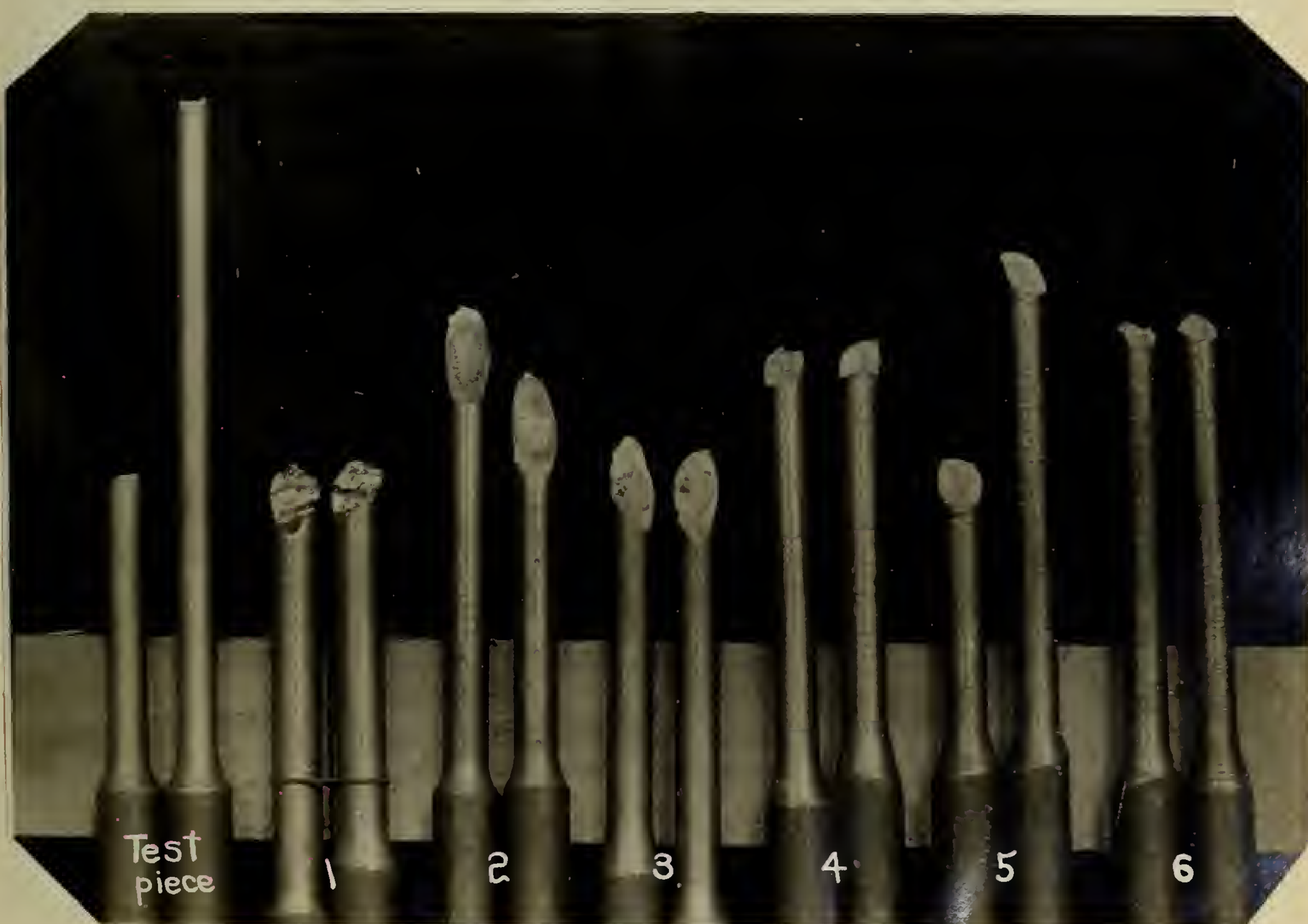
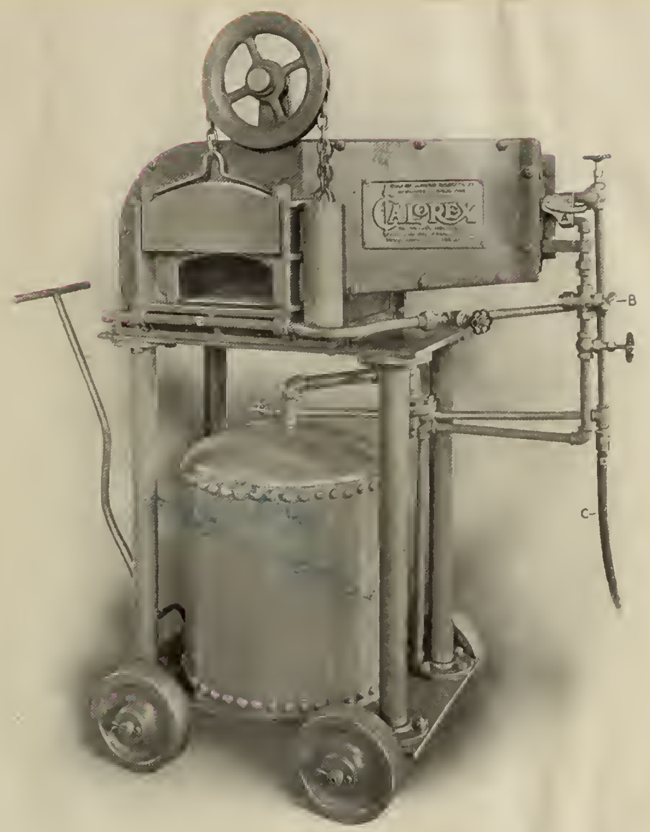


Fig.3.

Welds Made Using 3/4 inch Stock.Afterward Turned to 1/2 inch and Tested.

Fig.4.

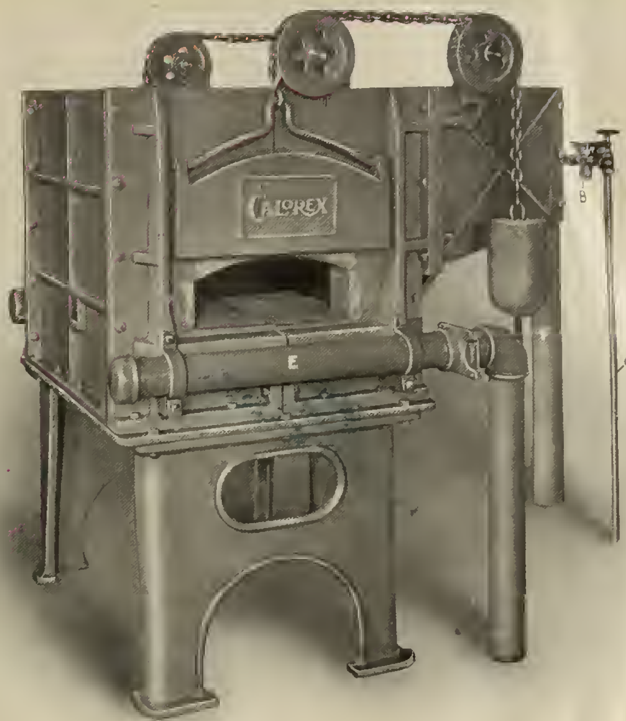
Welds Made Using 3/4 inch Stock, and Tested.



A—Oil burner B—Oil regulating cock C—Compressed air connection
D—Air reducing valve E—Deflection blast

Class "C" "Calorex" Forge Furnace

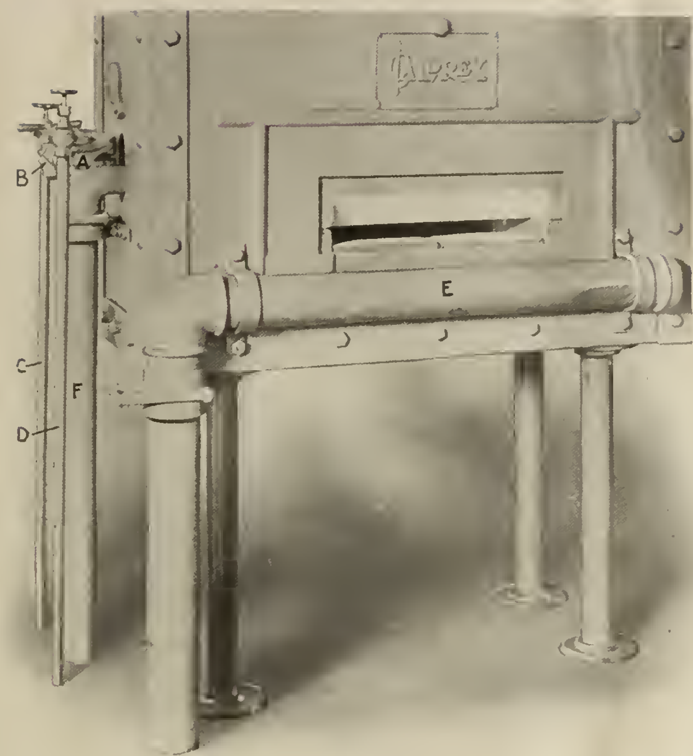
Fig.5.



B—Oil Regulating Cock   C—Air Pipe   E—Deflection Blast   F—Auxiliary Blast

Class "D" "Calorex" Forge Furnace

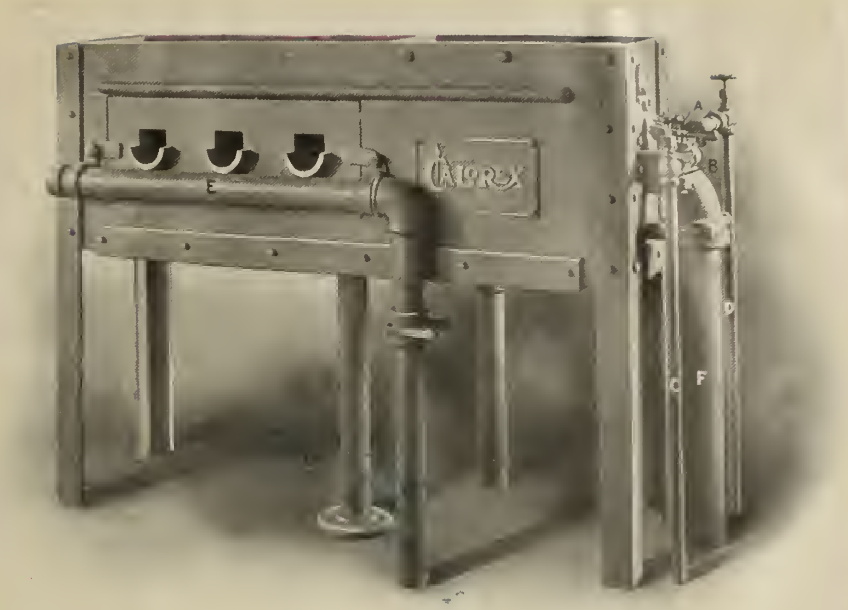
Fig.6.



A—Oil burner B—Oil regulating cock C—Air pipe D—Oil pipe
E—Deflection blast pipe F—Auxiliary blast

Class "G 8" "Calorex" Bolt Heading Furnace

Fig.7.



A—Oil burner B--Oil regulating cock C--Air pipe D—Oil pipe
E--Deflection blast F--Auxiliary blast

Class "B/5" "Calorex" Flue Welding Furnace

Fig.8.

TABLE No1.

Results of Tests on Hand Welded Pieces.

Number	Size of Test Piece	Kind of Weld	Made By	Condition of Piece	Length between marks	Original diameter	Final diameter	Area of cross section	Area of fracture	Reduction in area	% Reduction in area	Elongation in 8 inches	% Elongation in 8 inches	Maximum Load	Breaking Load	Ultimate Strength	Breaking Strength	Efficiency of weld.	Remarks
	5/8"			Not turned	8"	.62"	.37"	.301□"	.107□"	.194□"	64.5	2.27"	28.4	19970	18780	66345	62350		Fracture cup shaped, silky.
1	"	L	S	" "	8"	.58		.264				.20	2.5	11950	11950	45350	45350	72.8	Broke in weld. Fracture shows much scale Scarf too long. Crystalline.
2	"	L	S	Not turned Annealed	8	.62		.301				.55	6.87	16600	16600	55350	55350	88.8	Broke in weld. Fracture ragged Crystalline structure but fine.
3	"	L	L+C	Not turned Annealed	8	.62		.301				.70	8.75	17350	17350	57600	57600	92.5	Broke at edge of weld. Very fine crystalline structure.
4	"	V	L+C	Not turned	8	.62		.301				1.00	12.5	17680	17680	58850	58850	94.5	Broke at edge of weld. some scale fracture ragged.
5	"	B	L+C	" "	8	.62	.32	.301				1.10	13.75	19820	18690	66100	62290	99.9	Broke 8" from weld.
	3/4"			" "	8	.752	.452	.444				2.65	33.1	25500	22190	57500	49900		Fracture cup shaped, silky.
1	"	L	L+C	" "	8	.75		.442				.20	2.5	19070	19070	43290	43290	87.	Broke in weld. scarf too long some scale.
2	"	L	L+C	" "	8	.749		.440				.50	6.25	22120	22120	50600	50600	100+	Broke at edge of weld. some scale present.
3	"	L	L+C	Not Turned Annealed	8	.75		.442				.65	8.12	25200	25200	57100	57100	100+	Broke at edge of weld. Fracture square across rod.
	1/2"			Turned down from 3/4" rod	8	.50	.315	.196				2.30	28.7	12090	11450	61600	58500		Fracture cup shaped, silky.
1	"	L	S	"	8	.555		.242						2960	2960	12230	12230	20.9	Not wholly welded. some scale. Fracture ragged.
2	"	L	S	"	8	.502		.198						2502	2502	12650	12650	21.6	Broke in weld. scarf too long not wholly welded, much scale.
3	"	L	S	"	8	.505		.200						2900	2900	14500	14500	24.8	Broke in weld. scarf too long not welded, some scale.
4	"	L	S	Turned Annealed	8	.49		.188				.50	6.25	11100	11100	59200	59200	100+	Broke at edge of weld, ragged fracture, fine crystalline structure.
5	"	L	L+C	Turned	8	.493		.191				.25	3.12	8150	8150	42650	42650	73.	Broke in weld, not wholly welded. some scale.
6	"	L	L+C	"	8	.502		.198				.30	3.5	10900	10900	55100	55100	94.	Broke in weld. much scale in center. edges welded only.
7	"	L	L+C	Turned Annealed	8	.492		.182				1.20	15	12053	12053	65900	65900	100+	Broke in weld. fracture ragged. some scale.

8. Conclusions.- By referring to the data and results of the tension tests of these welded pieces given in Table 1. and Figures 3 and 4 which show the shape of the fracture, it will be seen that the butt weld is the most efficient joint, the short scarf lap weld next, the cleft or V weld third and the long scarf lap weld last. The data also shows the importance of the heat treatment of the steel after welding. The best results were obtained from those pieces which had been annealed after welding.

ELECTRIC WELDING.

1. Application of Electricity to Welding.- The next important step in the art of uniting metals was by the use of the electric current. The apparatus most generally consists of an A.C. generator furnishing comparatively high potential current to the primary coil of a step down transformer, the secondary of which is made so large in section and so short in length, as to supply to the work currents not exceeding two or three volts pressure at a very large rate of flow. To the ends of the secondary terminals, connection is made to suitable welding clamps.

2. Methods of Electric Welding.- There are two methods of electric welding in use, first, by the resistance method, second, by the arc method, the former being most generally adapted as the best because it is not so injurious to the abutting pieces or the eyes of the operator. The high current producing a very high heat at the ends of the pieces to be welded, where the resistance is the greatest, quickly brings them to a welding temperature and the area of metal heated is just sufficient to make the weld, in other words, the heat is concentrated just where it is needed.

Welding by electricity is capable of producing astonishing results, that is, it has revolutionized many manufacturing operations, doing away with highly skilled labor, increasing enormously the rate of production, while the final result is that more reliable work can be turned out at a fraction of the cost of hand welding. The system adapted and the machines employed must, how-

ever, be suited for the particular class of work to be done.

3. Description of the Prescott Welder.- The system adapted in the construction and operation of the Prescott Welder shown in Fig.9 is as follows.

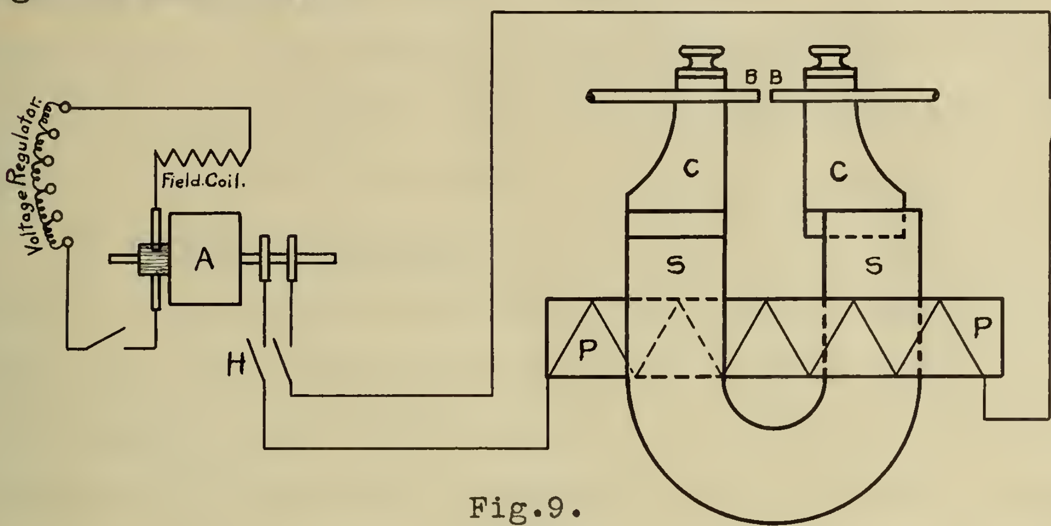


Fig.9.

A is an A.C. generator which is connected by switches H and D to the primary coil P of the transformer, the secondary of which consists of a massive single copper convolution SS terminating externally in two large clamps CC which grip the two rods required to be welded together.

When the switches are closed, the generator supplies current of moderate strength at a pressure of about 110 volts to the primary coil P. This current is transformed into a current of very low voltage but very great ampereage in the secondary coil S, and the heavy current flows across the junction of the two pieces to be welded BB, their ends being kept in contact under moderate pressure.

The electrical resistance in the secondary circuit being practically located at the abutting end surfaces thus kept in contact, all the heat is developed at those surfaces, ie, just where the weld is made, and the resulting increase in temperature by

the higher resistance at this point adds to the desired effect. A device is provided for regulating the pressure between the ends of the rods, since this pressure must be adjusted to the size of the rods and the plasticity of the metal at the welding temperature. After a few seconds the metal begins to flow and the rods become perfectly united, the metal bulging out around the joint, and at this stage the current is shut off at switch D.

4. General Discussion.- The condition for successful welding varies with different materials. With iron or steel it is necessary to keep the temperature below the melting point, to avoid injuring the mechanical properties of the metal, and consequently considerable pressure is required to make the weld. In the case of copper and brass the pressure must be lighter, the metal is allowed to fuse at the junction, and the pressure is only just sufficient to force out the burnt metal, the current being cut off at the moment the ends of the pieces are forced together at the proper welding temperature. It is this forcing out of the burnt metal which enables such good results to be obtained with drawn brass rods. Not only can copper, brass, aluminum and other metals and alloys which are unweldable by any other process be welded, but in case of iron and steel, an unskilled man or boy after a little practice can produce welds far superior to those turned out by a highly skilled smith.

Thoroughly sound welds can be made with the utmost ease, and it is an important fact that brass can be welded without destroying the structure given to it by drawing or rolling, and the welds will stand all the rolling and drawing processes necessary to work the material down to smaller sizes.

Among the metals and alloys which have been successfully welded by electricity are the following:-

Steel:- every variety seems to be weldable.

Iron:- cast, wrought,malleable,case hardened, ferro-aluminum.

Copper:- cast, rolled, drawn.

Brass:- cast, rolled, drawn.

Delta metal, Muntz metal, Babbitt metal.

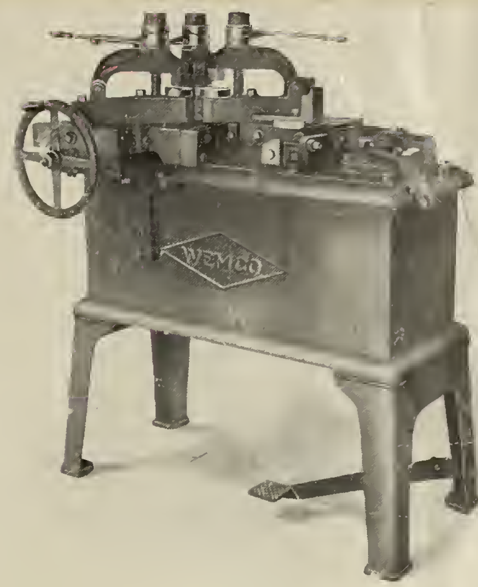
Aluminum, silver, gold, platinum, tin, lead, zinc, nickel, cobalt, manganese, bismuth, iridium, bronze, aluminium phosphor bronze, silicon, gun metal.

Gold to platinum, iron to steel, brass to iron, copper to iron, bronze to iron, German silver to iron, German silver to brass, copper to brass.

Figures 10 & 11 show cuts of the Wemco Welder manufactured by the Warren Electric Manufacturing Co. of Sandusky,Ohio. These are made in several sizes, to do all kinds of welding with unskilled operators. The following table taken from literature sent out by this company shows the power, time and energy required for welding different sizes of iron and steel rods.

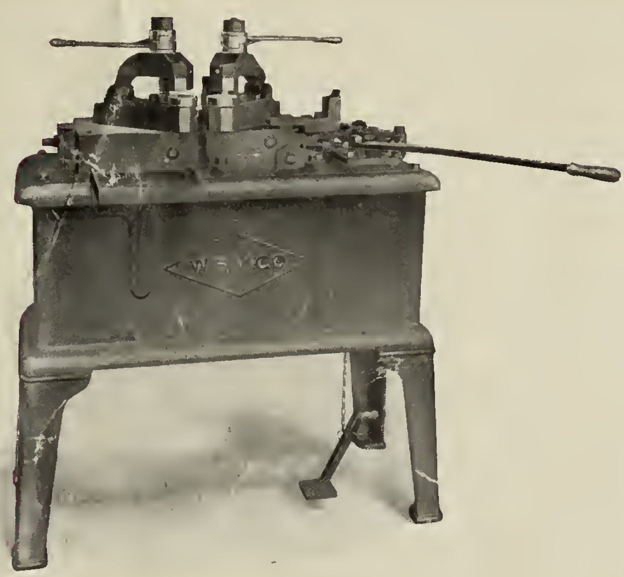
Dia. inches.	Power. H.P.	Time.sec.	Energy.H.P.sec.
.25	2.0	10	20.0
.50	6.50	21	136.5
.75	13.0	31	403.0
1.00	22.0	40	880.0
1.25	33.0	50	1650.0
1.50	45.0	60	2700.0
2.00	68.0	81	5508.0

The power stated above is the value at the generator, while the



Wemco Double Electric Welding Machine

Fig.10.



Wemco Single Electric Welding Machine

Fig.11.

time is that required solely for the use of the electrical energy.

A square piece requires from 25 to 50 percent more power and from 12 to 50 percent more time than does a round piece equal in diameter to the side of the square. Copper pieces require from two to three times as much power and only 50 to 70 percent as much time as does a piece of iron the same size.

Besides being used for welding, the electric arc is used to patch up defective iron and steel castings at a very low cost of operation. The heat being concentrated at the junction of the carbon conductor and the metal to be fused. Steel scraps are placed over or in the fracture, and the carbon applied. These are melted, and the casting in the vacinity of the carbon is brought to a fusing heat, the metal then flows together without the use of a flux.

5. Advantages of Electric Welding.- Among the advantages of electric welding may be mentioned the following:-

(a) Absolute control of the heat by the operator thru mechanical means of increasing, decreasing, or holding the heat for any desired length of time.

(b) The weld is made in the open and can be constantly watched at all times.

(c) The operation is almost instantaneous, the speed depending upon the amount of power used.

(d) Perfect welds are assured, as, being hottest in the interior of the joint, all possibility of defects are confined to the exterior in plain sight of the operator.

(e) Accuracy in location of parts is assured, as they are held rigidly while undergoing the welding process.

(f) The heat is confined entirely to the immediate vacinity of the weld, no other parts being effected; and, as there is very little blistering or scaling, finished pieces can be welded without effecting the finish except right at the joint.

(g) Parts heretofore impossible or very difficult to weld are successfully united by this process.

(h) The economy is high as the energy spent is all used in the weld. None is wasted, as there is no expenditure at all when the welding is not in progress.

(i) Although the quantity of current employed is enormous, the potential is so low as to be quite incapable of giving any shock to the operator, and the power is not exorbitant considering the work done.

(j) The machine and process is adapted to all classes of wagon and carriage work, bicycle frames, tool work, wire products, hoop and tire work, pipe and flue welding and uniting small rods or pieces of any shape.

6. Apparatus used for Making Test Welds.- Figure 12 shows an electric welding machine designed and constructed for this work by the author. It consists of two suitable cast iron jaws mounted on a lathe bed. The stationary jaw S is in two parts as shown, being separated and insulated by fiber board. The movable jaw M is also in two parts, the upper piece working in a dovetail slide and moved by the lever H and toggle joint T so a high pressure can be secured at the abutting ends of the rods R R when welding. The rods are clamped tightly to the brass contact pieces C by the clamps B B held by nuts.

Fig. 12.

The transformer O is immersed in transformer oil in the case to prevent overheating. The primary leads P P come from the switch Z to which the wires from the generator are connected. The transformer secondary leads X X are fastened to the contact pieces C C of each jaw.

The transformer is of the shell type, the primary winding consisting of 168 turns of No.14 D.C.C. magnet wire, and the secondary of 3 turns of No.0000 cable, the ratio of transformation being 1 to 56. For welding iron and steel a 220 volt A.C. current was used, the diagram of connections being shown below.

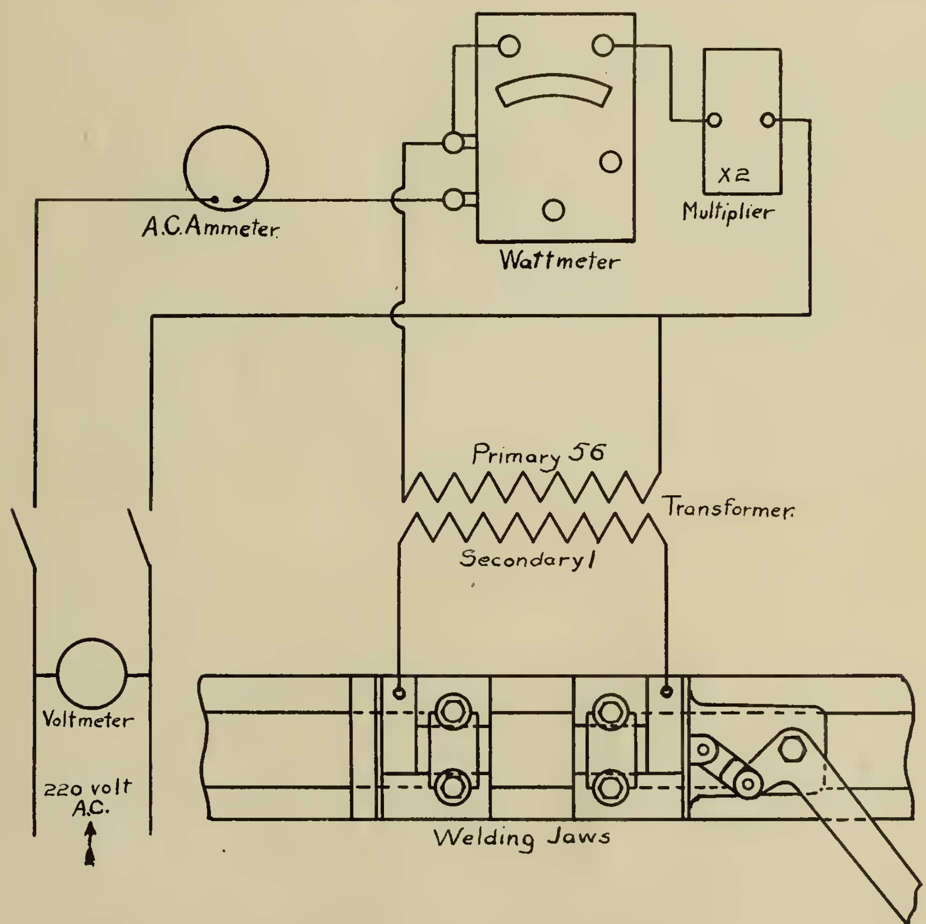


Fig.13.

TABLE No. 2.

Results of Tests on Electric Welded Pieces.

Number	Length between marks	Original diameter	Final diameter	Area of cross section	Area at fracture	Reduction in area	% Reduction in area.	Elongation in 8 inches	% Elongation in 8 inches	Maximum Load	Breaking Load	Ultimate Strength	Breaking Strength	Efficiency of Weld.	Remarks
Test Piece	8"	.375"	.21"	.1104	.034	.076	20.2	1.82	22.8	6680	4570	60500	41400	100	Fracture cup shaped, silky.
1	8	.375	.36	.1104	.1017	.0087	7.	.60	7.5	6170	6170	55800	55800	100+	Broke 1/4" from weld. ragged fracture
2	8	.375		.1104				.31	3.8	5200	5200	47000	47000	100+	Broke at edge of weld. annealed. silky.
3	8	.375		.1104				.50	6.25	5580	5580	50500	50500	100+	" " " " " overheated slightly
4	8	.375	.36	.1104	.1017	.0087	7.	.35	4.37	5070	5070	46000	46000	76.	" " " " " coarse crystals
5	8	.375	.35	.1104	.0962	.0142	12	1.20	15.	6440	6440	52800	52800	100+	Broke 1/2" from weld. annealed, silky
6	8	.375	.36	.1104	.1017	.0087	7	.90	11.25	6160	6160	55700	55700	100+	Broke 3/8" from weld. annealed. silky.
7	8	.375		.1104				.15	1.87	4150	4150	37500	37500	62	Broke in weld, fracture ragged, overheated
Test Piece	8	.50	.30	.196	.076	.120	61.	2.25	28.	11170	7730	57000	35700	100	Fracture cup shaped, silky
1	8	.50		.196				.30	3.7	10480	10480	53400	53400	93.7	Broke in weld, not annealed, coarse grain
2	8	.50		.196				.55	6.8	12030	12030	61500	61500	100+	" " " " " welded in center.
3	8	.50		.196				.12	1.5	8770	8770	44750	44750	786	" " " " " coarse crystals
4	8	.50		.196				.20	2.5	9270	9270	47300	47300	83	" " " " " " "
5	8	.50	.32	.196	.080	.116	.59.	1.60	20	13000	10210	66500	52000	100+	Broke 3" from weld, annealed. silky
6	8	.50	.31	.196	.075	.121	61.8	1.55	19.4	11170	7560	57000	38600	100+	" 3 1/4" " " " "
7	8	.50	.28	.196	.061	.135	69	1.52	19	11210	7880	57260	40500	100+	" 4 1/2" " " " "
8	8	.50	.275	.196	.052	.144	73.5	1.20	15	11230	7690	57400	39200	100+	" 4 1/4" " " " "
9	8	.50	.29	.196	.066	.130	66.4	1.30	16.3	11280	7240	57500	36900	100+	" 4 1/8" " " " "

TABLE No.3.

Power Consumed in Electric Welding.

No.	Diam. inches.	Volts.	Amps.	Power. K.W.	Time. sec.
1	3/8	220	29	5.6	15
2	"	"	29	5.8	18
3	"	"	29.5	5.7	14
4	"	"	29	5.7	18
5	"	"	28	5.76	18
Average:-		220	28.9	5.71	16.6
1	1/2	220	31.5	6.	45
2	"	"	31.	6.2	40
3	"	230	32	6.2	40
4	"	240	32	6.4	42
5	"	235	32	6.5	45
Average:-		229	31.7	6.26	43
1	1/4" sq.	220	31	5.2	10
2	" "	230	31.5	5.25	8
3	" "	230	30	5.1	8
4	" "	220	31	5.2	9
Average:-		225	30.7	5.18	8.7
1	3/4" X 3/16"	220	31.5	6	30
2	" " "	"	30	6	40
3	" " "	"	32	6.2	37
Average		220	31.2	6.03	35.6

9. Conclusions.- From an inspection of the table of results of the tests, it will be seen that electric welds can be made to hold even though the swelled part around the weld is ground off as was done with all these test pieces. In cases where the metal was overheated at the weld, the pieces broke either in the weld or very close to it. The effect of annealing is here more noticable than in any other series of tests conducted. In nearly every case where the welds had been properly annealed, the rods gave way at a considerable distance from the weld.

Previous to welding these test pieces, welds were made with the ends of the rods flat as shown in the sketch below.

Upon testing these in transverse bending and in tension the weld gave way every time, and all joints showed the presence of slag and scale and were not thoroughly welded. When the ends were made slightly cone shaped as shown in the sketch below, the joining

started at the center, and, as the pressure increased, the weld was made from the center outward, thus driving all the scale and slag before it. In no case did one of the joints treated in this way fail, and upon filing into the joint, perfect amalgamation of the metal was found to have occurred. All joints tested were made this way, and the pressure brought to bear was about the same as nearly as could be judged.

AUTOGENEOUS WELDING.

1. General Discussion.- The demand for a method of welding in which the great waste of energy and heat is obviated, and a high temperature produced upon a very limited area, being under such control as to permit special forms of welding to be practically accomplished, gave rise to the use of the blow pipe flame for welding.

This method is such that the metal itself is structurally united in such a manner that the finished product pieces are homogeneous and of uniform quality and proportions thruout. The metal is heated to a temperature high enough to cause it to be its own joining material without the use of a flux, and has been given the name of "autogeneous welding", meaning that the parts are fused together by their own substance.

2. Use of The Oxy-hydrogen Flame for Welding.- The first step in this direction was the oxy-hydrogen blow pipe flame perfected by a Belgian engineer, Felix Juttrend of Uccle, Belgium. In his process he used oxygen and hydrogen gasses under moderate pressures, combined them in a suitable blowpipe, and applied the flame to the metal to be welded. The iron was first reduced to an oxide by this flame, and the oxide then melted, the success of the method depending on the fact that the oxide melts at a lower temperature than the pure metal.

3. Heating Value of Hydrogen.- The combustion of two parts of hydrogen and one part of oxygen should generate theoretically a temperature of 6700 degrees C. but by the dissociation of the vapor of water, this temperature falls to 2400 degrees C. By an

examination of the temperature of a piece of magnesite exposed to the action of the oxy-hydrogen blowpipe flame, using the Wanner optical pyrometer, Herr Wiss found that a temperature of 2100 degrees C. is actually attained. The difference is accounted for partly by the inability of the pyrometer to perceive the maximum temperature, and partly to the losses by radiation.

4. Production of Oxygen.- The next advance in this direction was the use of oxygen and acetylene gasses in a blowpipe, and the process is adapted by many manufacturing concerns.

The great factor in bringing about the use of the oxy-acetylene flame has been the introduction of the so called "Epurite". This substance under this trade name, has sodium peroxide Na_2O_2 as one of its fundamental constituents, for sodium peroxide when placed in water liberates oxygen, according to the reaction, $Na_2O_2 + H_2O = 2NaOH + O$. Therefore, "Epurite" when brought into contact with water liberates oxygen, the action being analogous in every respect with that caused by water on the calcium carbide in producing acetylene gas. The oxygen thus obtained is chemically pure, and the cost of producing much less than the present price of the gas in tubes. It can be generated anywhere, and in any desired volume. One Kilogram (2.2#) of "Epurite", yields about 55 Litres (2 cu.ft.) of oxygen at a temperature of from 59 to 68 degrees Fahr.

5. Acetylene- Its Production, Heating Value and Combustion.- Acetylene C_2H_2 is a hydrocarbon colorless gas, of an ethereal odor when pure, but as ordinarily obtained is distinctly offensive to the smell. It is also an endothermic or heat absorbing gas and nearly as heavy as air, its densitity being .92 as com-

pared with air.

When calcium carbide CaC_2 is brought into contact with water, there is produced acetylene gas according to the reaction, $CaC_2 + 2H_2O = C_2H_2 + Ca(OH)_2$.

Since the heating value of acetylene is higher than that of hydrogen, a higher temperature may be produced with this flame than with the oxy-hydrogen flame. It has been computed that the temperature in the oxy-acetylene burner approximates 3600 degrees C. but Herr Wiss states that an examination with the Wanner pyrometer shows the highest temperature attained in practice to be about 2340 degrees C. as compared with 2100 degrees C, for the oxy-hydrogen flame. Since 1900degrees C. is ample for the welding of wrought iron and steel plate, the higher temperature appears unnecessary and possibly injurious, so that there seems to be no necessity for using acetylene instead of hydrogen except for the cost of producing the latter gas.

As acetylene is rich in carbon, containing 92.3%C, it is possible when mixed with air in a Bunsen burner, to obtain a temperature of nearly 3100 degrees C. and when mixed with pure oxygen this temperature is raised.

Theoretically two and one half volumes of oxygen are required for the complete combustion of one volume of acetylene. Practically, with the oxy-acetylene blowpipe, the best results in welding are obtained with one and seven tenths volumes of oxygen, to one volume of acetylene. The latter is not completely burned according to the reaction, $2C_2H_2 + 5O_2 = 4CO_2 + H_2O$, but is incompletely burned according to the reaction, $C_2H_2 + O_2 = 2CO + H_2$

The flame therefore, consists largely of CO which is being converted at its extremity into CO_2. This with the hydrogen in reality forms a cool jacket which protects both the molten metal and the inner cone of the flame from loss of heat.

At the moment of initial combustion, when the acetylene is decomposed into elements of C and H, about 300 B.T.U. per cu. ft. of the gas are generated. The total heat, however, generated per cu.ft. of acetylene is about 1500 B.T.U. which aside from the initial decomposition, is furnished mainly by the combustion in the O of the CO_2, and in a lesser degree by the combustion of H into water vapor.

6. Facts about the Safety of Acetylene.- Pure acetylene at a pressure of less than 30 pounds per sq. in. even when passed through pipes at a white heat is perfectly safe, but when mixed with oxygen or air is dangerous. An explosive gas mixture enclosed in a pipe does not inflame at once thruout the entire pipe, but from one end of the pipe ignition travels at a certain speed which increases as the square of the pipe section, therefore, to render safe the use of oxygen and acetylene in a blowpipe flame, the gas mixture is given a speed by pressure greater than the rate of projection of the flame.

7. Fluxes for Welding Metals not Required.- No flux or moulds are required to weld metals such as iron, steel, or copper, but for alloys like brass and bronze, a little borax or boracic acid moistened with water is used, simply to prevent the volatilized zinc from being deposited on the parts and destroying the weld.

8. Commercial Applications of the Oxy-acetylene Blowpipe Flame.- The oxy-acetylene blowpipe flame for welding and joining metals, is used by over eight hundred firms in France alone. In the United States, however, only one large concern makes any great use of it, the Worcester Pressed Steel Co. at Worcester, Mass. While they do not use the "Epurite" for the generation of the oxygen, they do use the same apparatus in general for the generation of the acetylene gas.

Their oxygen generating plant is operated as follows. They employ a combination of a calcium compound, with copper sulphate and iron sulphate. The oxygen generating apparatus consists of a lead lined chamber, arranged with a scrubber and settling chamber between. In generating the gas, one generator is filled with the required amount of luke warm water to which a chemical charge is added. While the solution is being stirred with an agitator provided for the purpose, a solution of iron sulphate and water is added which acts as a catalyzer. The chemical reaction taking place is shown as follows, $6FeSo_4 + 7CaOCl_2Ag + CuSO_4Ag = 2Fe_2(SO_4)_3Ag + CuSO_4Ag + Fe_2Cl_6 + 7CaCl_2 + 3CaSO_4 + 7O$.

The liberated oxygen passes from the generator thru the scrubber and a water sealed trap into a gasometer. From the latter the oxygen is compressed by an ordinary air compressor to a pressure of ten atmospheres, or 147 pounds per sq. in. into a pressure storage tank, from which a system of copper piping enables the gas under pressure to be delivered to any part of the works. The main pipe is 3/8" double strength copper, and the leads 1/4" copper.

The acetylene generator is of the water feed type, composed

of a cylindrical tank which serves as a gasometer and regulator, connected by three water supply pipes to three carbide receptacles, or trays, semi-cylindrical in shape, each containing six compartments, ~~each~~ holding about twelve pounds of lump carbide. The acetylene is maintained under a pressure ranging from 2.2 to 3 pounds per sq. in.

The pressure is obtained, and maintained, by two water levels in the gasometer, employing as a means the well known water column which automatically governs the supply and pressure of the gas. Any pressure in excess of three pounds is relieved thru a blow off pipe, outside the generator building.

The blowpipe is of brass, especially designed upon the injector principle, and carefully proportioned for its purpose, being about two feet long and weighing two pounds. It is provided with two inlets which run practically separate the entire length of the instrument, and into a mixing chamber with a common outlet at the point of combustion.

9. Examples of the Commercial Use of the Oxy-acetylene Blowpipe Flame.- Some of the uses that the oxy-acetylene blowpipe flame is put to are mentioned as follows,

(a) Welding iron, steel or copper up to one inch thick. (1) Replacing riveting by welding for thin sheets. (2) Replacing soldering and brazing.(3) Making boilers and reservoirs and repairing such, with plates up to one inch thick. (4) Welding angle and profile iron. (5) Manufacture of tubes of all dimensions, making both the lengthwise and end joints.

(b) Welding flanges, pipe, nozzles of iron, steel, copper

and brass.

(c) Making steel castings, malleable iron, bronze and brass castings.

(d) Repairing cast iron faults in general,and in automobile and bicycle manufacturing, doing away with all rivets, bolts and screws, and making the frames in one piece.

(e) General welding, all sorts of repairs and making endless pipe lines, etc.

(f) In mechanical and electrical construction work, where several pieces are to be joined even if they are of different metals, as for instance, in dynamo and motor armatures, and in making joints in conductors.

(g) Ornamental iron work, the manufacture of burglar proof safes, and sheet iron ware whether enamelled or not.

(h) Welding saw blades, and the manufacture of army materials such as small cannon and side arms.

(i) Making shovels, spades, hoes, plow shares, etc.

(j) Repairing gear wheels of steel, brass, or cast iron.

(k) In locomotive building, rail welding for narrow gauge railroad building, and in ship building.

(l) Construction of iron ships, and motor boats of pressed steel. Repairing boilers and tanks on board.

(m) Manufacture of steel and cast iron heaters.

(n) Manufacture of iron window frames, also in any machine shop or similar establishment where machinery is used, broken parts may be repaired in place.

Another use of the flame is that of cutting iron or steel,

in which case the kerf of the flame is made as small as possible, and the pressure is increased. This flame will cut anything from thin plate up to six inches thick, and in any shape desired by simply directing the flame on one spot and waiting until it is burned through, then moving the flame around in the shape of the hole to be cut.

10. Cost of Welding by the Oxy-acetylene Blowpipe Flame.- The Worcester Pressed Steel Co. give out some figures as to the cost of welding steel plates by an operator of average ability that are interesting. They are given in the table below.

Thickness of sheets.	Inches per hour.	Cost per inch.
.035"	288	.0031¢
.062"	200	.0065¢
.125"	120	.016¢
.377"	60	.075¢
.625"	14	.09¢

11. Scope of Oxy-acetylene Welding and Conclusions.- By far the largest field opened for the use of this method of welding is that of tanks, cylinders, exhaust heads, smoke boxes, etc, made of thin plate, while but few instances are recorded of successful use in welding large masses of iron or steel. It has been used successfully in mending broken crank shafts up to three inches in diameter, and in welding small broken steel parts of machinery. Because of the comparatively high first cost of apparatus for gas generation and welding, together with the element of danger in handling the gasses, it was not thought advisable to get apparatus to make sample welds by this process, so the efficiency of welds

made by this method could not be arrived at experimentally.

THE THERMIT CAST WELDING PROCESS.

1. General Discussion.- The demand for a welding process to join very large sections of iron and steel, as met with in locomotive and shipbuilding erection and repair work, which would make the welding as simple, effective and as quickly accomplished as the oxy-acetylene blowpipe flame and the electric welding process does for small pieces, is fulfilled in the use of the Thermit cast welding process.

The heating and welding compound "Thermit" introduced into commerce during the last few years, is the result of important researches carried on by Dr. Hans Goldschmidt of Essen-Ruhr, Germany, who gave it the name it bears.

It is a mixture of finely divided aluminum and oxide of iron, and posesses the remarkable property that when ignited in one spot the combustion so started, continues thruout the whole mass, without the addition of heat or power from the outside, producing superheated liquid steel, and superheated liquid slag (aluminum oxide or corundum). The chemical reaction is shown by the following formula, $Fe_2O_3 + 2Al = Al_2O_3 + 2Fe$.

The reaction is made to take place in a cone shaped magnesia lined crucible, and the heat generated is most intense, being estimated at 5400 degrees Fahr. The most remarkable feat of the reaction, however, is the short time required for its completion, less than thirty seconds, no matter how large the amount of "Thermit" in the crucible.

It is evident that if this superheated liquid steel produced,

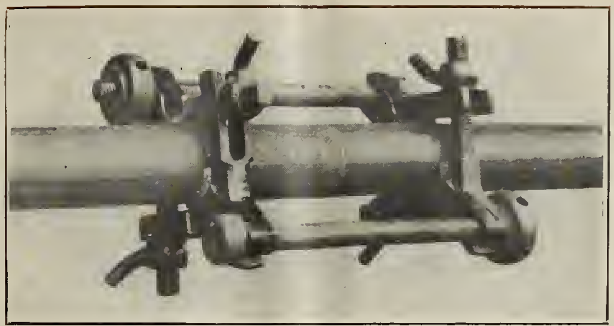


FIG. 1.—CLAMP IN POSITION.

Fig. 14.

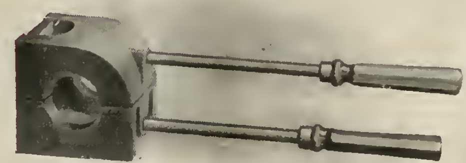


FIG. 2.—CAST IRON MOLD.

Fig. 15.

FIG. 4.—WELDING 1¼-INCH PIPE.

Fig. 16.

which posesses twice the temperature of ordinary steel, be poured into a mould surrounding any two broken steel sections which have previously been heated to a red heat, the result will be the fusing of the Thermit steel with the broken sections, so that when the contents of the mould are cooled, they will be found to be united into one homogeneous mass.

In making a weld using steel from the Thermit reaction, it is very important that the full time be given for the reaction, in order that the slag, which has three times the volume of the steel, may become fully separated. To be sure of this point, a few seconds more time should be given after the reaction has ceased, the steel being the heavier, naturally goes to the bottom of the crucible, and the slag floats on top so preventing the steel from losing heat by radiation. If this slag should by chance get down into the mould, because of its refractory nature it would prevent the Thermit steel from uniting with the sections to be welded.

This property of the slag sometimes serves a useful purpose, and is taken advantage of in the butt welding of iron and steel pipes and rods, (see Figures 14,15, and 16) during which process the slag is poured before the steel and forms a collar around the ends of the pipes, which, while bringing them to a welding heat, does not adhere to the surface and may be knocked off on the completion of the weld. The liquid steel following the slag, assists in the welding by adding its heat to that of the slag, but is prevented by the latter from coming in contact with the metal. In all other welds, however, using the "Thermit" process, the operation

must be conducted in such a way as to prevent the slag from coming in contact with the surfaces to be welded.

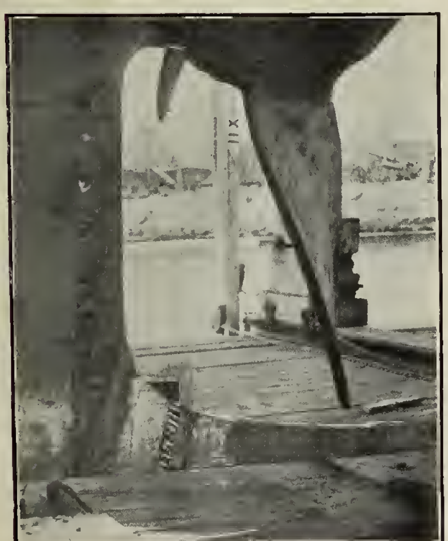
In making repairs or welds using the "Thermit" steel as the welding agent, the pieces to be joined,-if they are rods-, should be held apart about 3/8", and if a fractured, or broken steel or iron section, the fracture should be opened by drilling holes along the line of the break (see Figures 17, 18, and 19), the object being to allow space for the free flow of "Thermit" steel between the parts to be welded. A mould is then constructed around the parts to be welded.

2. Construction of the Mould.- One important principle determining the construction of the mould is that the "Thermit" steel must run through a gate to the lowest point of the mould and rise through,and around, the pieces to be welded, into a large riser. In no case, should the gate allow the "Thermit" steel to impinge directly upon the sections to be welded. The mould must also allow for a band or collar of the steel to be cast around the defective parts. The "Thermit" steel flowing through this space in the mould will actually dissolve the metal with which it comes in contact, and amalgamate with it, forming a reinforcement which adds to the strength of the original pieces. In cases where breaks have occurred through lack of strength at that point of the original piece, it acts as a reinforcement and should not be machined off.

The shape of this band or collar should resemble, in cross section, approximately, the segment of a circle, the thickest part being directly over the fracture and sloping off gradually

Fracture in Gun Cradle, Drilled Out Preliminary to Welding with Thermit Steel.

Fig. 17.



Fracture in Sternpost of U. S. S. "Gen. Nathaniel Greene," Opened Up by Drilling Preliminary to Welding.

Fig. 18.

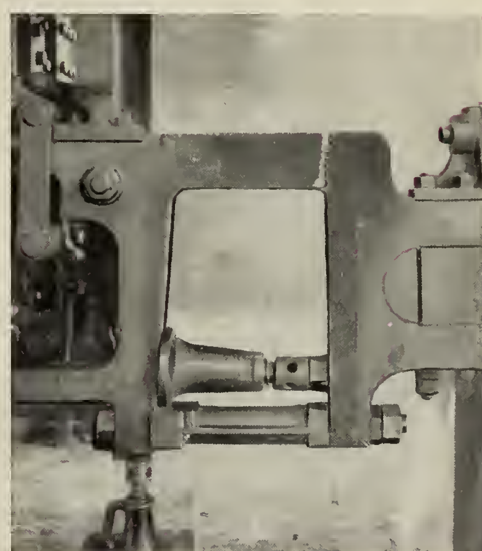


Fig. 2. Fracture on Locomotive Frame, Opened Up by Drilling and Held in Place by Jacks, in Preparation for Thermit Welding.

Fig. 19.

to the edges. It should overlap the edges of the break at least one inch. The thicker and more bulky the metal to be repaired, the thicker must be the band of "Thermit" steel, and the general dimensions of the collar must be in accordance with the nature of the repair.

In constructing the pattern or matrix to do a job of welding, the "Thermit" process allows for a very simple and inexpensive construction. This is the use of wax for the matrix. The parts to be joined are first placed the right distance apart, and a wax pattern of the exact shape desired in the final weld shaped around them. After this is done, the moulding sand which consists of fire clay and sand is tamped about the pattern in the usual manner, except that a small hole is left at the very lowest point of the mould. Particular care should be taken to make the mould strong enough to withstand the weight and scouring action of the superheated "Thermit" steel.

The patterns for the pouring gate and riser are made of wood, and their combined volume should equal that of the reinforcement or collar which is to be cast around the fracture, as the first steel running out of the crucible into the mould, becomes chilled when coming in contact with the pieces to be joined, which, even when preheated, has a considerably lower temperature than the "Thermit" steel. This chilling effect can only be overcome by a sufficient quantity of the steel, so that the chilled portion is driven up into the riser, and is replaced in the reinforcement by metal which has practically the full temperature it received during the reaction.

Fig. 20.

Wax Matrix in Position for Welding a 9" Shaft, at the Atherton Blast Furnaces, Atherton, N.Y.

When the mould is completed the wooden pouring gate and riser are pulled out, then instead of taking off the mould and drying it, a gasoline torch is directed into the riser, directly on the green sand. The heat melts the wax, which runs out of the hole at the bottom. The heating is continued until the mould is thoroughly dried, and the parts to be welded are brought to a bright red heat, the hole in the bottom is then closed by a sand core or loose sand, and the mould is ready for casting.

3. Calculation of the Amount of Thermit to Use.- The calculation of the amount of Thermit to use in making a weld is a simple matter, and is one of the strong points favoring the use of Thermit, since any one who can handle it, can determine the quantity. One cubic inch of steel weighs four and one half ounces. To produce this amount of steel requires nine ounces of Thermit. Then to calculate the amount of Thermit for any weld, it is only necessary to liberally estimate the number of cubic inches in the reinforcement to be cast around the pieces, and double that to allow for metal in the pouring gate and riser, multiply this figure by nine and get the number of ounces of Thermit to use. A method that is still simpler, is to weigh the amount of wax on hand both before and after forming the matrix, this difference, when doubled gives the amount of Thermit in pounds.

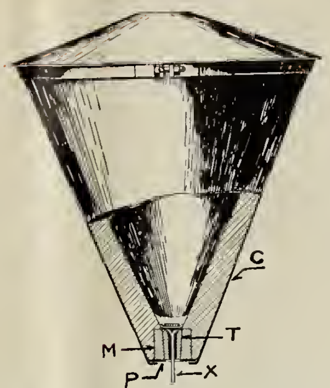
When more than ten pounds of Thermit are to be used, it is necessary to mix steel punchings or chips of steel free from grease into the Thermit powder. This moderates the intensity of the reaction a little, but does not interfere with the efficiency of the weld. In all cases, the steel scrap should be preheated

before being mixed with the Thermit, to be sure all grease is burned off. For more than 10 pounds of Thermit, a proportion of 10% of steel punchings should be added. For quantities over 50 pounds of Thermit, 15% of punchings should be added. With very large pieces to weld, where, through the ignition of several hundred pounds of Thermit, the intensity of the reaction is enormously increased, 20 to 25% of punchings, such as slugs, or rivets, etc. should be used. The reaction will then take more time, and care should be taken not to tap the crucible too soon.

An addition of 2% of manganese is recommended. In fact, it is quite possible, and often advisable, to introduce small quantities of manganese, nickel, chromium, vanadium, or other metals into the Thermit steel in making certain classes of repairs. This is done by introducing the elements into the crucible with the Thermit.

4. <u>Description of the Crucible</u>.- The crucible in which the reaction takes place, is illustrated in Figures 21 and 22.

Fig. 21.



Sectional View of Crucible with Plugging Material in Place.

Fig. 22.

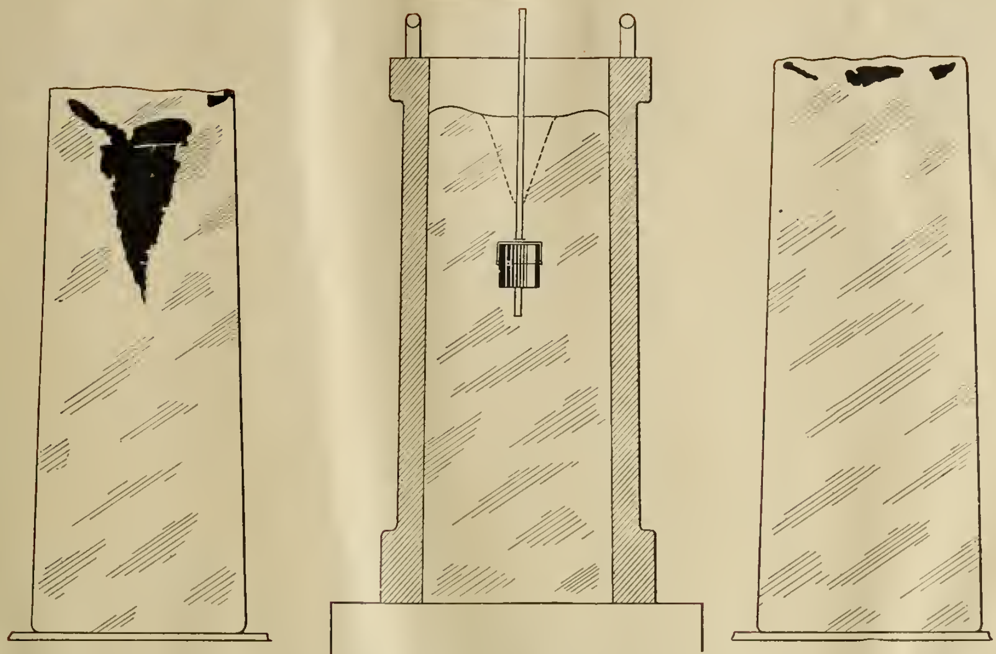
It consists of a sheet steel shell C riveted together, and beaded over a steel plate P with a central hole at the bottom. On top of this plate is a magnesia stone M, which has a taper hole in it into which is fitted the thimble T, also of magnesia. When putting the thimble in it is first wrapped with one thickness of newspaper which carbonizes, and allows the thimble to be removed after several reactions without injuring the stone M. A magnesia tar lining is built up inside the shell C so it is the thickest near the stone M, and will stand from 25 to 35 reactions if it is properly handled after a reaction. A sheet iron cover is provided to stop metal from spattering out and sparks from emanating too freely.

5. <u>Charging the Crucible</u>.- The method of charging the crucible is as follows. A scarfed pin X is first suspended in the opening in the thimble T so that its lower end projects about two inches below the crucible. Over this are placed one or two thin asbestos washers, then a round metal disc. These are rammed firmly into place, after which a layer of refractory sand, i.e.ground up

slag from a previous reaction, is placed on top and rammed down firmly so there is no danger of the reaction boiling it away, and permaturely tapping the crucible.

The predetermined amount of Thermit powder is next poured into the crucible, and, if punchings are to be used, these should be preheated and mixed with the Thermit before it is put in. In the center of the crucible, on top of the Thermit, is placed a pinch of ignition powder, which is a mixture of barium peroxide and aluminum. This may be ignited by applying a storm match, a bundle of parlor matches, or a hot rod. The chemical reaction so started, continues thruout the mass and the resulting superheated liquid steel sinks to the bottom of the crucible, from which it is tapped into the mould by giving the tapping pin a sharp blow upward, and the steel runs directly into the pouring gate of the mould.

6. Uses of Thermit.- Thermit has come to be used in a great many manufacturing concerns, railroad repair shops and in ship yards in the last few years. Among these are the following, (a) Preventing the piping of steel ingots, Fig. 23. as practiced in the Hungarian Government Steel Foundries at Diosgyör, Austria. (b) Reviving dull iron in the foundry ladle or mould. (c) Welding broken locomotive frames, Figures 24 to 32 inclusive. (d) Welding the shoes, skegs, rudder posts, main propeller shafts, propellers, etc, of large steamships, Figures 33 to 35 inclusive. (e) Welding broken shafts either in position or dismantled, Figures 20, 36 and 37. (f) Welding street railway rails, Figures 38 to 41 inclusive. (g) Butt welding pipes, rods, structural steel shapes, etc.

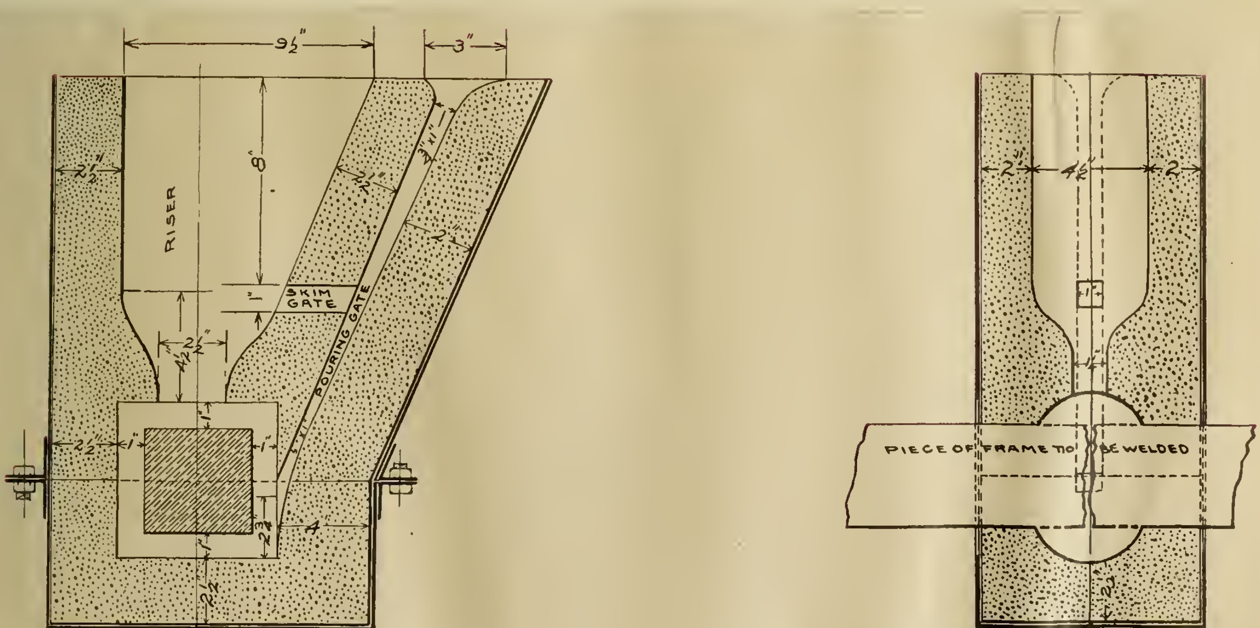


STEEL INGOT SHOWING DEFECTIVE HEAD PIPING WITHOUT ANTI-PIPING THERMIT.

SHOWING INGOT WITH BOX OF ANTI-PIPING THERMIT IN POSITION.

TEN TON STEEL INGOT HAVING BEEN TREATED WITH ANTI-PIPING THERMIT.

Fig. 23.



MOULD FOR
REPAIRING LOCOMOTIVE FRAMES
WITH THERMIT.

Fig. 24.

Fig. 25.

Fig. 26.

Fig. 27.

Fire Brick Mould for Welding Locomotive Frames in Place.

Fig. 28.

Fracture in a Locomotive Frame Opened Up Preliminary to Welding.

CRUCIBLE AND MOLD IN POSITION.

Fig. 29.

WELD COMPLETE.

Fig. 30.

FRAME READY FOR WELDING.

Fig. 31.

READY FOR POURING.
Crucible and sand box surrounding fire brick mold in position.

Fig. 32.

Fig. 33.

Just after pouring. Weld on the stern post of the tug Sachem, made at the New London Marine Iron Works, New London, Connecticut.

Fig. 34.

Finished weld, showing metal in gate and riser, on the stern post of the U.S.S. Gen. Nathaniel Greene. Repair made at the New London Marine Iron Works, New London, Connecticut.

11

Fig. 35.

Finished weld, showing riser and bottom end of the pouring gate, of the S.S. Corunna of the Canadian Lake Navigation Co. Repair made at Montreal, Can.

Fr

terifoer

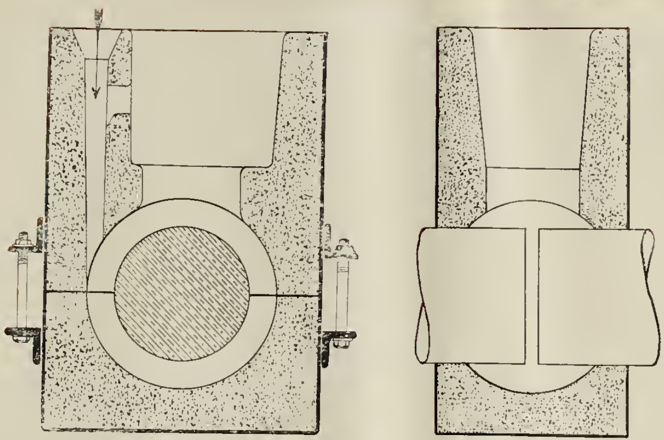


Fig. 3—MOLD FOR REPAIRING BROKEN SHAFTS

Fig. 36.

Finished Weld on Stern Wheel Shaft of S. S. "Betsy Ann" Before Removing Metal Left in Gate and Riser.

Fig. 37.

Welding Trolley Rail at Holyoke, Mass.

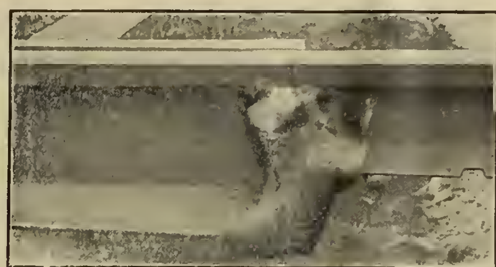
Fig. 38.

Fig. 39.

The cuts show the welding gangs at work.

9 INCH WELDED RAIL.

Fig. 40.



COMPROMISE RAIL JOINT.

Fig. 41.

New Jaw Burned to Frame Casting of Heavy Shear.

Fig. 42.

WELDING SPOKE OF DRIVER.

Fig. 43.

(h) Mending broken bosses on rolls, broken shear and punch frames, connecting rods, fly wheel rims and spokes, locomotive cylinder flanges, motor case castings, locomotive driving wheel spokes, etc. Figs 42 and 43. (i) For filling up holes and defects in castings, making small steel castings, producing metals free from carbon and alloying metals.

7. Object of using Thermit for this Thesis.- To become familiar with the use of Thermit, to determine its effects on steel rods welded with it, and the efficiency of the welds, some Thermit welds were made on 1.25" round soft steel rods. The moulds for this work were made of core sand, and were baked hard and dry. The two halves of a mould are shown in Figure 44. In Figure 45 is shown the mould and crucible in position, with the liquid steel running into the mould a few seconds after tapping. In all these cases, the rods were preheated in a forge to facilitate the work, and save the time of preheating in the mould.

8. Conclusions.- By consulting the following table and Figure 46, it will be seen that in all cases but two the weld was successful, the reason of the two being unsuccessful was because of premature tapping of the crucible which let slag into the mould. The effect of annealing is noticable also, and of turning off the reinforcement. Those welds which were annealed showed better results than those not so treated. Referring to Figure 47 it will be seen that in the latter case the fractures were square across, and had a coarse crystalline structure. Very little elongation of the rods occurred near the welds, all going to show that a proper annealing as recommended by the Goldschmidt Thermit

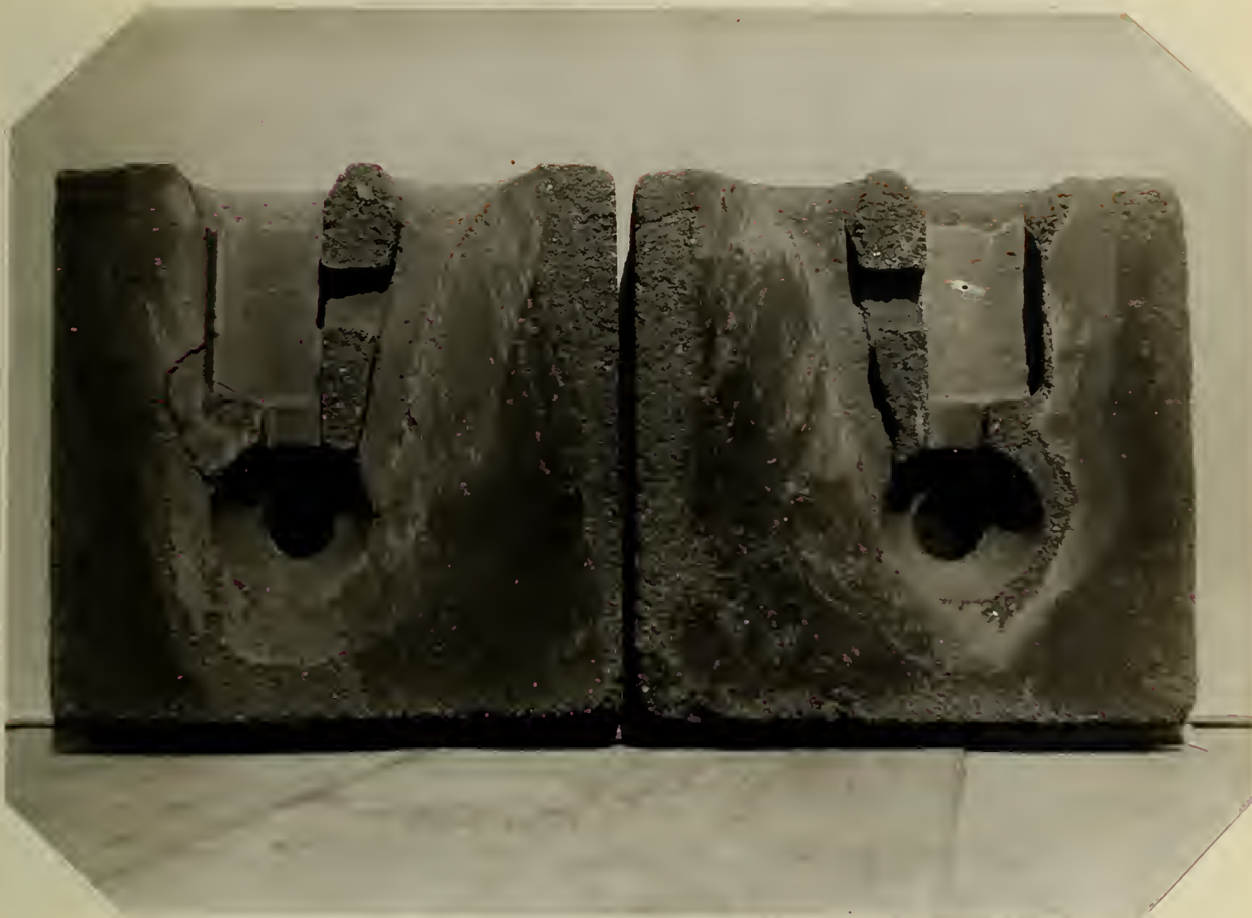


Fig. 44.

Fig. 45.

TABLE No. 4.

Results of Tests of Thermit Welds

Number	Time of Reaction - sec.	Weight of Thermit used.	Weight of Slag left	Percent of Slag left.	Condition of Specimen	Length between marks	Original diameter	Final diameter	Area of cross section	Area at fracture	Reduction in area	% Reduction in area	Elongation in 8 inches	% Elongation in 8 inches	Maximum Load	Breaking Load	Ultimate Strength	Breaking Strength	Efficiency of Weld	Remarks
Test Piece						8"	1.25"	.75	1.22	.441	.78	64	2.7	33.7	67110	58600	55100	48000	100	Fracture cup shaped, silky.
1	18	7#	.5#	7.14	Annealed and Turned	8	1.11	1.095	.967	.933	.034	3.52	.40	5	47180	47180	48750	48750	70	Broke square across at edge of weld. Small blowhole on edge. crystalline
2	20	7#	.5#	7.14	Annealed and Turned	8	1.105	1.065	.950	.882	.068	7.16	.15	1.87	36590	36590	38500	38500	54.5	Broke square across 1/2" from weld. Large crystals on edge, small in center.
3	19	7#	.5#	7.14	Annealed Collar on	8	1.25	.74	1.22	.430	.79	64.75	.65	8.12	70130	49900	57600	41000	100+	Broke 5 1/2" from weld. Fracture square across, silky.
4	22	10#	5.25#	52.5	Not Annealed Collar on	8	1.25		1.22						50090	50090	41000	41000	74.7	Broke in weld. Premature tapping Metal is honeycombed because of slag.
5	21	7#	.5#	7.14	Annealed Collar on	8	1.25	.75	1.22	.442	.78	64	.95	11.87	70030	51350	57500	42100	100+	Broke 7" from weld. Fracture slightly cup shaped. Silky
6	20	7#	.5#	7.14	Not Annealed Collar on	8	1.25	1.16	1.22	1.056	1.64	13.4	1.0	12.5	74470	74470	61000	61000	100+	Broke square across 1 1/2" from weld. Very small crystalline structure.

Note:—

For test piece fracture see Figs. 46, 47.

For No 1. see 1 in Fig 46, 4 in Fig. 47.

For No 2. see 2 in Fig 46, 3 in Fig 47.

For No 6. see 6 in Fig 46, 2 in Fig 47.

Fig. 46.

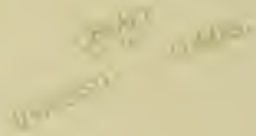


Fig. 47.

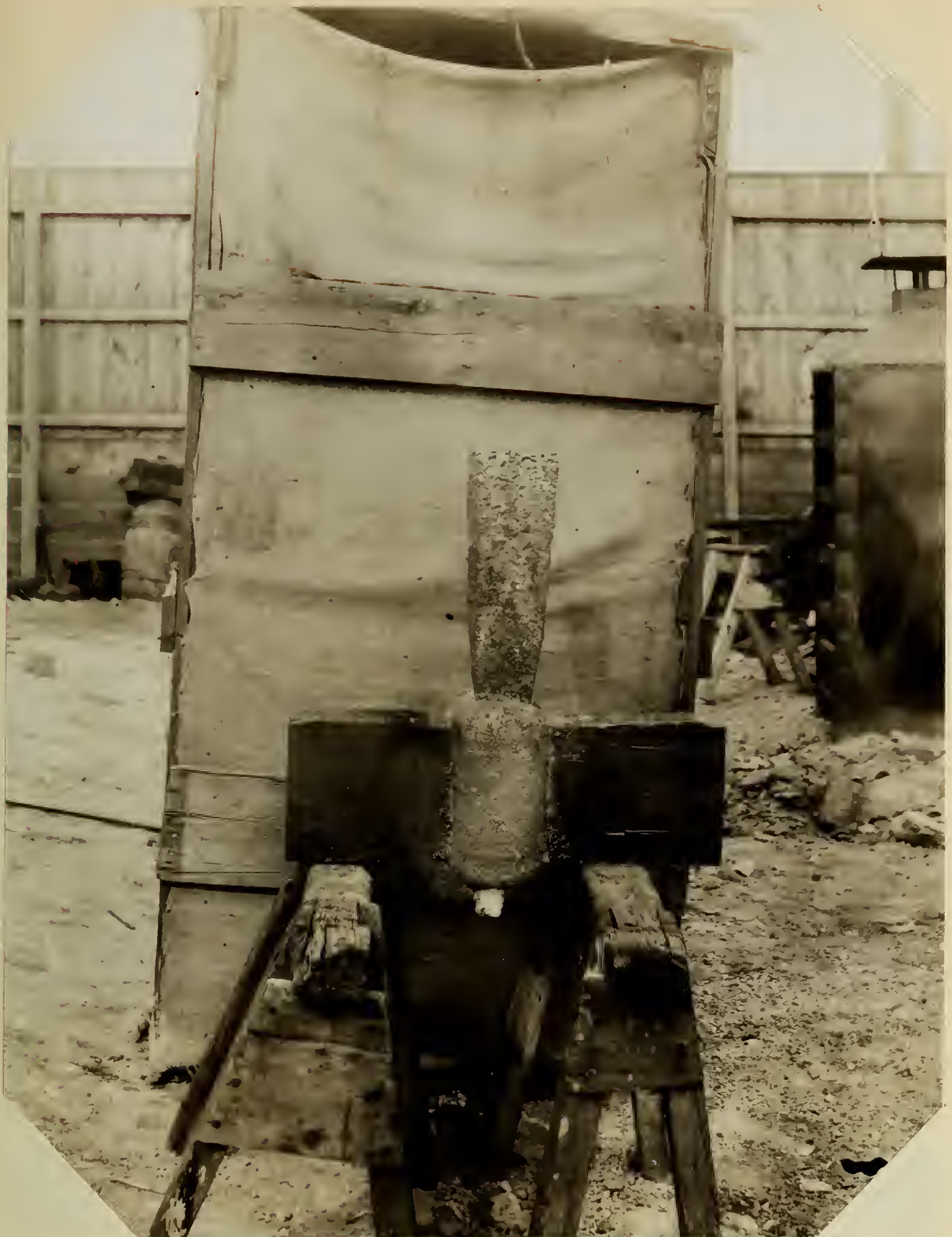


Fig. 48.

Finished test weld on two steel sections, each 8 1/2" X 4 1/8". Picture shows riser and bottom of pouring gate.

[illegible]

Fig. 49.

Weld shown in Fig. 48 after being split open and planed down, showing perfect amalgamation of the metal.

Fig. 50.

Weld on the rocker arm of a pumping engine belonging to the S. S. Apache of the Clyde Line.

Company, brings the steel back to its normal condition previous to welding, and the extreme heat produced by the superheated liquid steel has no bad effect on the welded pieces provided the weld is annealed properly. Referring to the two welds which had been annealed and the collar machined off, because of the low carbon content of the Thermit steel, C = .1, and possibly because of the weld not being annealed evenly, the break occurred very near the weld. In both cases, however, there was perfect amalgamation of the metal, with the exception of a small blowhole in one of the pieces.

As an example of perfect amalgamation of the Thermit steel with the pieces welded, Figures 48 and 49 showing a test weld made by the Goldschmidt Thermit Co. at their works in Jersey City, may be consulted.

Thermit is not an explosive as is supposed by many. It can be thrown into the fire and it will not burn, neither will a hot rod or a match ignite it without the ignition powder is present.

The celerity with which Thermit repairs can be made makes it now a possibility to make locomotive repairs in any roundhouse, mend broken parts of a steamship in any dock or on board, to have continuous pipe lines without joints, and to make continuous rail bonds, sound, both mechanically and electrically.