

NONFERROUS ALLOYS

Copper and Copper Alloys

Pure copper is a reddish, highly malleable metal, and was one of the first to be found and utilized. Copper and its alloys are widely used because of their excellent electrical and thermal conductivities, outstanding resistance to corrosion, ease of fabrication, and broad ranges of obtainable strengths and special properties. Almost 400 commercial copper and copper-alloy compositions are available from mills as wrought products (rod, plate, sheet, strip, tube, pipe, extrusions, foil, forgings, and wire) and from foundries as castings.

Copper alloys are grouped into several general categories according to composition:

coppers and high-copper alloys; brasses; bronzes; copper nickels; copper-nickel-zinc alloys (nickel silvers); leaded coppers; and special alloys.

The designation system originally developed by the U.S. copper and brass industry for identifying copper alloys used a three-digit number preceded by the letters CA. These designations have now been made part of the Unified Numbering System (UNS) simply by expanding the numbers to five digits preceded by the letter C. Because the old numbers are embedded in the new UNS numbers, no confusion results. UNS C10000 to C79999 are assigned to wrought compositions, and UNS C80000 to C99999 are assigned to castings. The designation system is not a specification, but a method for identifying the composition of mill and foundry products. The precise technical and quality assurance requirements to be satisfied are defined in relevant standard specifications issued by the federal government, the military, and the ASTM.

Classification of Copper and Copper Alloys

Family	Principal Alloying Element	UNS Numbers ^a
Coppers, high-copper alloys		C1xxxx
Brasses	Zn	C2xxxx, C3xxxx, C4xxxx, C66400 to C69800
Phosphor bronzes	Sn	C5xxxx
Aluminum bronzes	Al	C60600 to C64200
Silicon bronzes	Si	C64700 to C66100
Copper nickels, nickel silvers	Ni	C7xxxx

^aWrought alloys.

Cast Copper Alloys.—Generally, casting permits greater latitude in the use of alloying elements than in the fabrication of wrought products, which requires either hot or cold working. The cast compositions of coppers and high-copper alloys have a designated minimum copper content and may include other elements to impart special properties. The cast brasses comprise copper-zinc-tin alloys (red, semired, and yellow brasses); manganese bronze alloys (high-strength yellow brasses); leaded manganese bronze alloys (leaded high-strength yellow brasses); and copper-zinc-silicon alloys (silicon brasses and bronzes).

The cast bronze alloys have four main families: copper-tin alloys (tin bronzes); copper-tin-lead alloys (leaded and high leaded tin bronzes); copper-tin-nickel alloys (nickel-tin bronzes); and copper-aluminum alloys (aluminum bronzes).

The cast copper-nickel alloys contain nickel as the principal alloying element. The leaded coppers are cast alloys containing 20 per cent or more lead.

Table lists the properties and applications of common cast copper alloys.

Table 1. Properties and Applications of Cast Coppers and Copper Alloys

UNS Designation	Nominal Composition (%)	Typical Mechanical Properties, as Cast or Heat Treated ^a				Typical Applications
		Tensile Strength (ksi)	Yield Strength (ksi)	Elongation in 2 in. (%)	Machinability Rating ^b	
Copper Alloys						
C80100	99.95 Cu + Ag min, 0.05 others max	25	9	40	10	Electrical and thermal conductors; corrosion and oxidation-resistant applications.
C80300	99.95 Cu + Ag min, 0.034 Ag min, 0.05 others max	25	9	40	10	Electrical and thermal conductors; corrosion and oxidation-resistant applications.
C80500	99.75 Cu + Ag min, 0.034 Ag min, 0.02 B max, 0.23 others max	25	9	40	10	Electrical and thermal conductors; corrosion and oxidation-resistant applications.
C80700	99.75 Cu + Ag min, 0.02 B max, 0.23 others max	25	9	40	10	Electrical and thermal conductors; corrosion and oxidation-resistant applications.
C80900	99.70 Cu + Ag min, 0.034 Ag min, 0.30 others max	25	9	40	10	Electrical and thermal conductors; corrosion and oxidation-resistant applications.
C81100	99.70 Cu + Ag min, 0.30 others max	25	9	40	10	Electrical and thermal conductors; corrosion and oxidation resistant applications.
High-Copper Alloys						
C81300	98.5 Cu min, 0.06 Be, 0.80 Co, 0.40 others max	(53)	(36)	(11)	20	Higher hardness electrical and thermal conductors.
C81400	98.5 Cu min, 0.06 Be, 0.80 Cr, 0.40 others max	(53)	(36)	(11)	20	Higher hardness electrical and thermal conductors.
C81500	98.0 Cu min, 1.0 Cr, 0.50 others max	(51)	(40)	(17)	20	Electrical and/or thermal conductors used as structural members where strength and hardness greater than that of C80100–81100 are required.

Table 1. (Continued) Properties and Applications of Cast Coppers and Copper Alloys

UNS Designation	Nominal Composition (%)	Typical Mechanical Properties, as Cast or Heat Treated ^a				Typical Applications
		Tensile Strength (ksi)	Yield Strength (ksi)	Elongation in 2 in. (%)	Machinability Rating ^b	
C81700	94.2 Cu min, 1.0 Ag, 0.4 Be, 0.9 Co, 0.9 Ni	(92)	(68)	(8)	30	Electrical and/or thermal conductors used as structural members where strength and hardness greater than that of C80100–81100 are required. Also used in place of C81500 where electrical and/or thermal conductivities can be sacrificed for hardness and strength.
C81800	95.6 Cu min, 1.0 Ag, 0.4 Be, 1.6 Co	50 (102)	25 (75)	20 (8)	20	Resistance-welding electrodes, dies.
C82000	96.8 Cu, 0.6 Be, 2.6 Co	50 (100)	20 (75)	20 (8)	20	Current-carrying parts, contact and switch blades, bushings and bearings, and soldering iron and resistance-welding tips.
C82100	97.7 Cu, 0.5 Be, 0.9 Co, 0.9 Ni	(92)	(68)	(8)	30	Electrical and/or thermal conductors used as structural members where strength and hardness greater than that of C80100–81100 are required. Also used in place of C81500 where electrical and/or thermal conductivities can be sacrificed for hardness and strength.
C82200	96.5 Cu min, 0.6 Be, 1.5 Ni	57 (95)	30 (75)	20 (8)	20	Clutch rings, brake drums, seam-welder electrodes, projection welding dies, spot-welding tips, beam-welder shapes, bushings, water-cooled holders.
C82400	96.4 Cu min, 1.70 Be, 0.25 Co	72 (150)	37 (140)	20 (1)	20	Safety tools, molds for plastic parts, cams, bushings, bearings, valves, pump parts, gears.
C82500	97.2 Cu, 2.0 Be, 0.5 Co, 0.25 Si	80 (160)	45	20 (1)	20	Safety tools, molds for plastic parts, cams, bushings, bearings, valves, pump parts.
C82600	95.2 Cu min, 2.3 Be, 0.5 Co, 0.25 Si	82 (165)	47 (155)	20 (1)	20	Bearings and molds for plastic parts.
C82700	96.3 Cu, 2.45 Be, 1.25 Ni	(155)	(130)	(0)	20	Bearings and molds for plastic parts.
C82800	96.6 Cu, 2.6 Be, 0.5 Co, 0.25 Si	97 (165)	55 (145)	20 (1)	10	Molds for plastic parts, cams, bushings, bearings, valves, pump parts, sleeves.
Red Brasses and Lead Red Brasses						
C83300	93 Cu, 1.5 Sn, 1.5 Pb, 4 Zn	32	10	35	35	Terminal ends for electrical cables.
C83400	90 Cu, 10 Zn	35	10	30	60	Moderate strength, moderate conductivity castings; rotating bands.

Table 1. (Continued) Properties and Applications of Cast Coppers and Copper Alloys

UNS Designation	Nominal Composition (%)	Typical Mechanical Properties, as Cast or Heat Treated ^a				Typical Applications
		Tensile Strength (ksi)	Yield Strength (ksi)	Elongation in 2 in. (%)	Machinability Rating ^b	
C83600	85 Cu, 5 Sn, 5 Pb, 5 Zn	37	17	30	84	Valves, flanges, pipe fittings, plumbing goods, pump castings, water pump impellers and housings, ornamental fixtures, small gears.
C83800	83 Cu, 4 Sn, 6 Pb, 7 Zn	35	16	25	90	Low-pressure valves and fittings, plumbing supplies and fittings, general hardware, air-gas-water fittings, pump components, railroad catenary fittings.
Semired Brasses and Leaded Semired Brasses						
C84200	80 Cu, 5 Sn, 2.5 Pb, 12.5 Zn	35	14	27	80	Pipe fittings, elbows, T's, couplings, bushings, locknuts, plugs, unions.
C84400	81 Cu, 3 Sn, 7 Pb, 9 Zn	34	15	26	90	General hardware, ornamental castings, plumbing supplies and fixtures, low-pressure valves and fittings.
C84500	78 Cu, 3 Sn, 7 Pb, 12 Zn	35	14	28	90	Plumbing fixtures, cocks, faucets, stops, waste, air and gas fittings, low-pressure valve fittings.
C84800	76 Cu, 3 Sn, 6 Pb, 15 Zn	36	14	30	90	Plumbing fixtures, cocks, faucets, stops, waste, air, and gas, general hardware, and low-pressure valve fittings.
Yellow Brasses and Leaded Yellow Brasses						
C85200	72 Cu, 1 Sn, 3 Pb, 24 Zn	38	13	35	80	Plumbing fittings and fixtures, ferrules, valves, hardware, ornamental brass, chandeliers, and irons.
C85400	67 Cu, 1 Sn, 3 Pb, 29 Zn	34	12	35	80	General-purpose yellow casting alloy not subject to high internal pressure. Furniture hardware, ornamental castings, radiator fittings, ship trimmings, battery clamps, valves, and fittings.
C85500	61 Cu, 0.8 Al, bal Zn	60	23	40	80	Ornamental castings.
C85700	63 Cu, 1 Sn, 1 Pb, 34.7 Zn, 0.3 Al	50	18	40	80	Bushings, hardware fittings, ornamental castings.
C85800	58 Cu, 1 Sn, 1 Pb, 40 Zn	55	30	15	80	General-purpose die-casting alloy having moderate strength.
Manganese and Leaded Manganese Bronze Alloys						
C86100	67 Cu, 21 Zn, 3 Fe, 5 Al, 4 Mn	95	50	20	30	Marine castings, gears, gun mounts, bushings and bearings, marine racing propellers.
C86200	64 Cu, 26 Zn, 3 Fe, 4 Al, 3 Mn	95	48	20	30	Marine castings, gears, gun mounts, bushings and bearings.

Table 1. (Continued) Properties and Applications of Cast Coppers and Copper Alloys

UNS Designation	Nominal Composition (%)	Typical Mechanical Properties, as Cast or Heat Treated ^a				Typical Applications
		Tensile Strength (ksi)	Yield Strength (ksi)	Elongation in 2 in. (%)	Machinability Rating ^b	
C86300	63 Cu, 25 Zn, 3 Fe, 6 Al, 3 Mn	115	83	15	8	Extra-heavy duty, high-strength alloy. Large valve stems, gears, cams, low-speed heavy-load bearings, screwdown nuts, hydraulic cylinder-parts.
C86400	59 Cu, 1 Pb, 40 Zn	65	25	20	65	Free-machining manganese bronze. Valve stems, marine fittings, lever arms, brackets, light-duty gears.
C86500	58 Cu, 0.5 Sn, 39.5 Zn, 1 Fe, 1 Al	71	28	30	26	Machinery parts requiring strength and toughness, lever arms, valve stems, gears.
C86700	58 Cu, 1 Pb, 41 Zn	85	42	20	55	High strength, free-machining manganese bronze. Valve stems.
C86800	55 Cu, 37 Zn, 3 Ni, 2 Fe, 3 Mn	82	38	22	30	Marine fittings, marine propellers.
Silicon Bronzes and Silicon Brasses						
C87200	89 Cu min, 4 Si	55	25	30	40	Bearings, bells, impellers, pump and valve components, marine fittings, corrosion-resistant castings.
C87400	83 Cu, 14 Zn, 3 Si	55	24	30	50	Bearings, gears, impellers, rocker arms, valve stems, clamps.
C87500	82 Cu, 14 Zn, 4 Si	67	30	21	50	Bearings, gears, impellers, rocker arms, valve stems, small boat proellers.
C87600	90 Cu, 5.5 Zn, 4.5 Si	66	32	20	40	Valve stems.
C87800	82 Cu, 14 Zn, 4 Si	85	50	25	40	High-strength, thin-wall die castings; brush holders, lever arms, brackets, clamps, hexagonal nuts.
C87900	65 Cu, 34 Zn, 1 Si	70	35	25	80	General-purpose die-casting alloy having moderate strength.
Tin Bronzes						
C90200	93 Cu, 7 Sn	38	16	30	20	Bearings and bushings.
C90300	88 Cu, 8 Sn, 4 Zn	45	21	30	30	Bearings, bushings, pump impellers, piston rings, valve components, seal rings, steam fittings, gears.
C90500	88 Cu, 10 Sn, 2 Zn	45	22	25	30	Bearings, bushings, pump impellers, piston rings, valve components, steam fittings, gears.
C90700	89 Cu, 11 Sn	44 (55)	22 (30)	20 (16)	20	Gears, bearings, bushings.

Table 1. (Continued) Properties and Applications of Cast Coppers and Copper Alloys

UNS Designation	Nominal Composition (%)	Typical Mechanical Properties, as Cast or Heat Treated ^a				Typical Applications
		Tensile Strength (ksi)	Yield Strength (ksi)	Elongation in 2 in. (%)	Machinability Rating ^b	
C90900	87 Cu, 13 Sn	40	20	15	20	Bearings and bushings.
C91000	85 Cu, 14 Sn, 1 Zn	32	25	2	20	Piston rings and bearings.
C91100	84 Cu, 16 Sn	35	25	2	10	Piston rings, bearings, bushings, bridge plates.
C91300	81 Cu, 19 Sn	35	30	0.5	10	Piston rings, bearings, bushings, bridge plates, bells.
C91600	88 Cu, 10.5 Sn, 1.5 Ni	44 (60)	22 (32)	16 (16)	20	Gears.
C91700	86.5 Cu, 12 Sn, 1.5 Ni	44 (60)	22 (32)	16 (16)	20	Gears.
Leaded Tin Bronzes						
C92200	88 Cu, 6 Sn, 1.5 Pb, 4.5 Zn	40	20	30	42	Valves, fittings, and pressure-containing parts for use up to 550°F.
C92300	87 Cu, 8 Sn, 4 Zn	40	20	25	42	Valves, pipe fittings, and high-pressure steam castings. Superior machinability to C90300.
C92500	87 Cu, 11 Sn, 1 Pb, 1 Ni	44	20	20	30	Gears, automotive synchronizer rings.
C92600	87 Cu, 10 Sn, 1 Pb, 2 Zn	44	20	30	40	Bearings, bushings, pump impellers, piston rings, valve components, steam fittings, and gears. Superior machinability to C90500.
C92700	88 Cu, 10 Sn, 2 Pb	42	21	20	45	Bearings, bushings, pump impellers, piston rings, and gears. Superior machinability to C90500.
C92800	79 Cu, 16 Sn, 5 Pb	40	30	1	70	Piston rings.
C92900	82 Cu min, 9 Sn min, 2 Pb min, 2.8 Ni min	47 (47)	26 (26)	20 (20)	40	Gears, wear plates, guides, cams, parts requiring machinability superior to that of C91600 or 91700.
High-Leaded Tin Bronzes						
C93200	83 Cu, 6.3 Sn min, 7 Pb, 3 Zn	35	18	20	70	General-utility bearings and bushings.
C93400	84 Cu, 8 Sn, 8 Pb	32	16	20	70	Bearings and bushings.
C93500	85 Cu, 5 Sn, 9 Pb	32	16	20	70	Small bearings and bushings, bronze backing for babbitt-lined automotive bearings.
C93700	80 Cu, 10 Sn, 10 Pb	35	18	20	80	Bearings for high speed and heavy pressures, pumps, impellers, corrosion-resistant applications, pressure tight castings.

Table 1. (Continued) Properties and Applications of Cast Coppers and Copper Alloys

UNS Designation	Nominal Composition (%)	Typical Mechanical Properties, as Cast or Heat Treated ^a				Typical Applications
		Tensile Strength (ksi)	Yield Strength (ksi)	Elongation in 2 in. (%)	Machinability Rating ^b	
C93800	78 Cu, 7 Sn, 15 Pb	30	16	18	80	Bearings for general service and moderate pressure, pump impellers, and bodies for use in acid mine water.
C93900	79 Cu, 6 Sn, 15 Pb	32	22	7	80	Continuous castings only. Bearings for general service, pump bodies, and impellers for mine waters.
C94300	70 Cu, 5 Sn, 25 Pb	27	13	15	80	High-speed bearings for light loads.
C94400	81 Cu, 8 Sn, 11 Pb, 0.35 P	32	16	18	80	General-utility alloy for bushings and bearings.
C94500	73 Cu, 7 Sn, 20 Pb	25	12	12	80	Locomotive wearing parts; high-low, low-speed bearings.
Nickel-Tin Bronzes						
C94700	88 Cu, 5 Sn, 2 Zn, 5 Ni	50 (85)	23 (60)	35 (10)	30 (20)	Valve stems and bodies, bearings, wear guides, shift forks, feeding mechanisms, circuit breaker parts, gears, piston cylinders, nozzles.
C94800	87 Cu, 5 Sn, 5 Ni	45 (60)	23 (30)	35 (8)	50 (40)	Structural castings, gear components, motion-translation devices, machinery parts, bearings.
Aluminum Bronzes						
C95200	88 Cu, 3 Fe, 9 Al	80	27	35	50	Acid-resisting pumps, bearing, gears, valve seats, guides, plungers, pump rods, bushings.
C95300	89 Cu, 1 Fe, 10 Al	75 (85)	27 (42)	25 (15)	55	Pickling baskets, nuts, gears, steel mill slippers, marine equipment, welding jaws.
C95400	85 Cu, 4 Fe, 11 Al	85 (105)	35 (54)	18 (8)	60	Bearings, gears, worms, bushings, valve seats and guides, pickling hooks.
C95500	81 Cu, 4 Ni, 4 Fe, 11 Al	100 (120)	44 (68)	12 (10)	50	Valve guides and seats in aircraft engines, corrosion-resistant parts, bushings, gears, worms, pickling hooks and baskets, agitators.
C95600	91 Cu, 7 Al, 2 Si	75	34	18	60	Cable connectors, terminals, valve stems, marine hardware, gears, worms, pole-line hardware.
C95700	75 Cu, 2 Ni, 3 Fe, 8 Al, 12 Mn	95	45	26	50	Propellers, impellers, stator clamp segments, safety tools, welding rods, valves, pump casings.
C95800	81 Cu, 5 Ni, 4 Fe, 9 Al, 1 Mn	95	38	25	50	Propeller hubs, blades, and other parts in contact with salt water.

Table 1. (Continued) Properties and Applications of Cast Coppers and Copper Alloys

UNS Designation	Nominal Composition (%)	Typical Mechanical Properties, as Cast or Heat Treated ^a				Typical Applications
		Tensile Strength (ksi)	Yield Strength (ksi)	Elongation in 2 in. (%)	Machinability Rating ^b	
Copper-Nickels						
C96200	88.6 Cu, 10 Ni, 1.4 Fe	45 min	25 min	20 min	10	Components of items being used for seawater corrosion resistance.
C96300	79.3 Cu, 20 Ni, 0.7 Fe	75 min	55 min	10 min	15	Centrifugally cast tailshaft sleeves.
C96400	69.1 Cu, 30 Ni, 0.9 Fe	68	37	28	20	Valves, pump bodies, flanges, elbows used for seawater corrosion resistance.
C96600	68.5 Cu, 30 Ni, 1 Fe, 0.5 Be	(110)	(70)	(7)	20	High-strength constructional parts for seawater corrosion resistance.
Nickel Silvers						
C97300	56 Cu, 2 Sn, 10 Pb, 12 Ni, 20 Zn	35	17	20	70	Hardware fittings, valves and valve trim, statuary, ornamental castings.
C97400	59 Cu, 3 Sn, 5 Pb, 17 Ni, 16 Zn	38	17	20	60	Valves, hardware, fittings, ornamental castings.
C97600	64 Cu, 4 Sn, 4 Pb, 20 Ni, 8 Zn	45	24	20	70	Marine castings, sanitary fittings, ornamental hardware, valves, pumps.
C97800	66 Cu, 5 Sn, 2 Pb, 25 Ni, 2 Zn	55	30	15	60	Ornamental and sanitary castings, valves and valve seats, musical instrument components.
Special Alloys						
C99300	71.8 Cu, 15 Ni, 0.7 Fe, 11 Al, 1.5 Co	95	55	2	20	Glass-making molds, plate glass rolls, marine hardware.
C99400	90.4 Cu, 2.2 Ni, 2.0 Fe, 1.2 Al, 1.2 Si, 3.0 Zn	66 (79)	34 (54)	25	50	Valve stems, marine and other uses requiring resistance to dezincification and dealuminification, propeller wheels, electrical parts, mining equipment gears.
C99500	87.9 Cu, 4.5 Ni, 4.0 Fe, 1.2 Al, 1.2 Si, 1.2 Zn	70 min	40 min	12 min	50	Same as C99400, but where higher yield strength is required.
C99700	56.5 Cu, Al, 1.5 Pb, 12 Mn, 5 Ni, 24 Zn	55	25	25	80	...
C99750	58 Cu, 1 Al, 1 Pb, 20 Mn, 20 Zn	65 (75)	32 (40)	30 (20)	...	...

^a Values in parentheses are for heat-treated condition.

^b Free cutting brass = 100.

Source: Copper Development Association, New York.

Wrought Copper Alloys.—Wrought copper alloys can be utilized in the annealed, cold-worked, stress-relieved, or hardened-by-heat-treatment conditions, depending on composition and end use. The “temper designation” for copper alloys is defined in ASTM Standard Recommended Practice B601, which is applicable to all product forms.

Wrought copper and high-copper alloys, like cast alloys, have a designated minimum copper content and may include other elements to impart special properties. Wrought brasses have zinc as the principal alloying element and may have other designated elements. They comprise the copper–zinc alloys; copper–zinc–lead alloys (lead brasses); and copper–zinc–tin alloys (tin brasses).

Wrought bronzes comprise four main groups: copper–tin–phosphorus alloys (phosphor bronze); copper–tin–lead–phosphorus alloys (lead phosphor bronze); copper–aluminum alloys (aluminum bronzes); and copper–silicon alloys (silicon bronze).

Wrought copper–nickel alloys, like the cast alloys, have nickel as the principal alloying element. The wrought copper–nickel–zinc alloys are known as “nickel silvers” because of their color.

Table 2 lists the nominal composition, properties, and applications of common wrought copper alloys.

Table 2. Properties and Applications of Wrought Coppers and Copper Alloys

Name and Number	Nominal Composition (%)	Strength (ksi)		Elongation in 2 in. (%)	Machinability Rating ^a	Fabricating Characteristics and Typical Applications
		Tensile	Yield			
C10100 Oxygen-free electronic	99.99 Cu	32–66	10–53	55	20	Excellent hot and cold workability; good forgeability. Fabricated by blanking, coining, copper-smithing, drawing and upsetting, hot forging and pressing, spinning, swaging, stamping. Uses: busbars, bus conductors, waveguides, hollow conductors, lead-in wires and anodes for vacuum tubes, vacuum seals, transistor components, glass to metal seals, coaxial cables and tubes, klystrons, microwave tubes, rectifiers.
C10200 Oxygen-free copper	99.95 Cu	32–66	10–53	55	20	Fabricating characteristics same as C10100. Uses: busbars, waveguides.
C10300 Oxygen-free, extra-low phosphorus	99.95 Cu, 0.003 P	32–55	10–50	50	20	Fabricating characteristics same as C10100. Uses: busbars, electrical conductors, tubular bus, and applications requiring good conductivity and welding or brazing properties.
C10400, C10500, C10700 Oxygen-free, silver-bearing	99.95 Cu	32–66	10–53	55	20	Fabricating characteristics same as C10100. Uses: auto gaskets, radiators, busbars, conductivity wire, contacts, radio parts, winding, switches, terminals, commutator segments; chemical process equipment, printing rolls, clad metals, printed-circuit foil.
C10800 Oxygen-free, low phosphorus	99.95 Cu, 0.009 P	32–55	10–50	50	20	Fabricating characteristics same as C10100. Uses: refrigerators, air conditioners, gas and heater lines, oil burner tubes, plumbing pipe and tube, brewery tubes, condenser and heat-exchanger tubes, dairy and distiller tubes, pulp and paper lines, tanks; air, gasoline, and hydraulic lines.
C11000 Electrolytic tough pitch copper	99.90 Cu, 0.04 O	32–66	10–53	55	20	Fabricating characteristics same as C10100. Uses: downspouts, gutters, roofing, gaskets, auto radiators, busbars, nails, printing rolls, rivets, radio parts.
C11000 Electrolytic tough pitch, anneal-resistant	99.90 Cu, 0.04 O, 0.01 Cd	66	...	...	20	Fabricated by drawing and stranding, stamping. Uses: electrical power transmission where resistance to softening under overloads is desired.
C11300, C11400, C11500, C11600 Silver-bearing tough pitch copper	99.90 Cu, 0.04 O, Ag	32–66	10–53	55	20	Fabricating characteristics same as C10100. Uses: gaskets, radiators, busbars, windings, switches, chemical process equipment, clad metals, printed-circuit foil.

Table 2. (Continued) Properties and Applications of Wrought Coppers and Copper

Name and Number	Nominal Composition (%)	Strength (ksi)		Elongation in 2 in. (%)	Machinability Rating ^a	Fabricating Characteristics and Typical Applications
		Tensile	Yield			
C12000, C12100 Phosphorus deoxidized, low residual phosphorus	99.9 Cu	32-57	10-53	55	20	Fabricating characteristics same as C10100. Uses: busbars, electrical conductors, tubular bus, and applications requiring welding or brazing.
C12200, C12210 Phosphorus deoxidized copper, high residual phosphorus	99.90 Cu, 0.02 P	32-55	10-53	55	20	Fabricating characteristics same as C10100. Uses: gas and heater lines; oil burner tubing; plumbing pipe and tubing; condenser, evaporator, heat exchanger, dairy, and distiller tubing; steam and water lines; air, gasoline, and hydraulic lines.
C12500, C12700, C12800, C12900, C13000 Fire-refined tough pitch with silver	99.88 Cu	32-66	10-53	55	20	Fabricating characteristics same as C10100. Uses: same as C11000, Electrolytic tough pitch copper.
C14200 Phosphorus deoxidized, arsenical	99.68 Cu, 0.3 As, 0.02 P	32-55	10-50	45	20	Fabricating characteristics same as C10100. Uses: staybolts, heat-exchanger and condenser tubes.
C14300, C14310 Cadmium copper, deoxidized	99.9 Cu, 0.1 Cd	32-58	11-56	42	20	Fabricating characteristics same as C10100. Uses: anneal-resistant electrical applications requiring thermal softening and embrittlement resistance, lead frames, contacts, terminals, solder-coated and solder-fabricated parts, furnace-brazed assemblies and welded components, cable wrap.
C14500, C14510, C14520 Tellurium bearing	99.5 Cu, 0.50 Te, 0.008 P	32-56	10-51	50	85	Fabricating characteristics same as C10100. Uses: Forgings and screw-machine products, and parts requiring high conductivity, extensive machining, corrosion resistance, copper color, or a combination of these; electrical connectors, motor and switch parts, plumbing fittings, soldering coppers, welding torch tips, transistor bases, and furnace-brazed articles.
C14700, C14710, C14720 Sulfur bearing	99.6 Cu, 0.40 S	32-57	10-55	52	85	Fabricating characteristics same as C10100. Uses: screw-machine products and parts requiring high conductivity, extensive machining, corrosion resistance, copper color, or a combination of these; electrical connectors, motor and switch components, plumbing fittings, cold-headed and machined parts, cold forgings, furnace-brazed articles, screws, soldering coppers, rivets and welding torch tips.
C15000 Zirconium copper	99.8 Cu, 0.15 Zr	29-76	6-72	54	20	Fabricating characteristics same as C10100. Uses: switches, high-temperature circuit breakers, commutators, stud bases for power transmitters, rectifiers, soldering welding tips.
C15500	99.75 Cu, 0.06 P, 0.11 Mg, Ag	40-80	18-72	40	20	Fabricating characteristics same as C10100. Uses: high-conductivity light-duty springs, electrical contacts, fittings, clamps, connectors, diaphragms, electronic components, resistance-welding electrodes.
C15715	99.6 Cu, 0.13 Al ₂ O ₃	52-88	44-84	27	20	Excellent cold workability. Fabricated by extrusion, drawing, rolling, heading, swaging, machining, blanking, roll threading. Uses: integrated-circuit lead frames, diode leads; vacuum, microwave, and x-ray tube components; electrical components; brush springs; commutators, electric generator and motor components.
C15720	99.5 Cu, 0.18 Al ₂ O ₃	64-98	54-96	25	...	Excellent cold workability. Fabricated by extrusion, drawing, rolling, heading, swaging, machining, blanking. Uses: relay and switch springs, lead frames, contact supports, heat sinks, circuit breaker parts, rotor bars, resistance-welding electrodes and wheels, connectors, soldering gun tips.

Table 2. (Continued) Properties and Applications of Wrought Coppers and Copper

Name and Number	Nominal Composition (%)	Strength (ksi)		Elongation in 2 in. (%)	Machinability Rating ^a	Fabricating Characteristics and Typical Applications
		Tensile	Yield			
C15760	98.8 Cu, 0.58 Al ₂ O ₃	70-90	65-87	22	...	Excellent cold workability. Fabricated by extrusion and drawing. Uses: resistance-welding electrodes, soldering gun tips, MIG welding contact tips, continuous-casting molds.
C16200, C16210 Cadmium copper	99.0 Cu, 1.0 Cd	35-100	7-69	57	20	Excellent cold workability; good hot formability. Uses: trolley wires, heating pads, electric-blanket elements, spring contacts, railbands, high-strength transmission lines, connectors, cable wrap, switch-gear components, and waveguide cavities.
C16500	98.6 Cu, 0.8 Cd, 0.6 Sn	40-95	14-71	53	20	Fabricating characteristics same as C16200. Uses: electrical springs and contacts, trolley wire, clips, flat cable, resistance-welding electrodes.
C17000 Beryllium copper	98.3 Cu, 1.7 Be, 0.20 Co	70-190	32-170	45	20	Fabricating characteristics same as C16200. Commonly fabricated by blanking, forming and bending, turning, drilling, tapping. Uses: bellows, Bourdon tubing, diaphragms, fuse clips, fasteners, lock-washers, springs, switch parts, roll pins, valves, welding equipment.
C17200 Beryllium copper	98.1 Cu, 1.9 Be, 0.20 Co	68-212	25-195	48	20	Similar to C17000, particularly for its nonsparking characteristics.
C17300 Beryllium copper	98.1 Cu, 1.9 Be, 0.40 Pb	68-212	25-195	48	50	Combines superior machinability with good fabricating characteristics of C17200.
C17500, C17510 Beryllium copper	96.9 Cu, 2.5 Co, 0.6 Be	45-115	25-110	28	...	Fabricating characteristics same as C16200. Uses: fuse clips, fasteners, springs, switch and relay parts, electrical conductors, welding equipment.
C18200, C18400, C18500 Chromium copper	99.2 Cu	34-86	14-77	40	20	Excellent cold workability, good hot workability. Uses: resistance-welding electrodes, seam-welding wheels, switch gear, electrode holder jaws, cable connectors, current-carrying arms and shafts, circuit-breaker parts, molds, spot-welding tips, flash-welding electrodes, electrical and thermal conductors requiring strength, switch contacts.
C18700 Leaded copper	99.0 Cu, 1.0 Pb	32-55	10-50	45	85	Good cold workability; poor hot formability. Uses: connectors, motor and switch parts, screw-machine parts requiring high conductivity.
C18900	98.7 Cu, 0.8 Sn, 0.3 Si, 0.20 Mn	38-95	9-52	48	20	Fabricating characteristics same as C10100. Uses: welding rod and wire for inert gas tungsten arc and metal arc welding and oxyacetylene welding of copper.
C19000 Copper-nickel-phosphorus alloy	98.6 Cu, 1.1 Ni, 0.3 P	38-115	20-81	50	30	Fabricating characteristics same as C10100. Uses: springs, clips, electrical connectors, power tube and electron tube components, high-strength electrical conductors, bolts, nails, screws, cotter pins, and parts requiring some combination of high strength, high electrical or thermal conductivity, high resistance to fatigue and creep, and good workability.
C19100 Copper-nickel-phosphorus-tellurium alloy	98.2 Cu, 1.1 Ni, 0.5 Te, 0.2 P	36-104	10-92	27	75	Good hot and cold workability. Uses: forgings and screw-machine parts requiring high strength, hardenability, extensive machining, corrosion resistance, copper color, good conductivity, or a combination of these; bolts, bushings, electrical connectors, gears, marine hardware, nuts, pinions, tie rods, turnbuckle barrels, welding torch tips.

Table 2. (Continued) Properties and Applications of Wrought Coppers and Copper

Name and Number	Nominal Composition (%)	Strength (ksi)		Elongation in 2 in. (%)	Machinability Rating ^a	Fabricating Characteristics and Typical Applications
		Tensile	Yield			
C19200	99 Cu, 1.0 Fe, 0.03 P	37-77	11-74	40	20	Excellent hot and cold workability. Uses: automotive hydraulic brake lines, flexible hose, electrical terminals, fuse clips, gaskets, gift hollow ware, applications requiring resistance to softening and stress corrosion, air-conditioning and heat-exchanger tubing.
C19400	97.4 Cu, 2.4 Fe, 0.13 Zn, 0.04 P	45-76	24-73	32	20	Excellent hot and cold workability. Uses: circuit-breaker components, contact springs, electrical clamps, electrical springs, electrical terminals, flexible hose, fuse clips, gaskets, gift hollow ware, plug contacts, rivets, and welded condenser tubes.
C19500	97.0 Cu, 1.5 Fe, 0.6 Sn, 0.10 P, 0.80 Co	80-97	65-95	15	20	Excellent hot and cold workability. Uses: electrical springs, sockets, terminals, connectors, clips, and other current-carrying parts requiring strength.
C21000 Gilding, 95%	95.0 Cu, 5.0 Zn	34-64	10-58	45	20	Excellent cold workability, good hot workability for blanking, coining, drawing, piercing and punching, shearing, spinning, squeezing and swaging, stamping. Uses: coins, medals, bullet jackets, fuse caps, primers, plaques, jewelry base for gold plate.
C22000 Commercial bronze, 90%	90.0 Cu, 10.0 Zn	37-72	10-62	50	20	Fabricating characteristics same as C21000, plus heading and up-setting, roll threading and knurling, hot forging and pressing. Uses: etching bronze, grillwork, screen cloth, weatherstripping, lipstick cases, compacts, marine hardware, screws, rivets.
C22600 Jewelry bronze, 87.5%	87.5 Cu, 12.5 Zn	39-97	11-62	46	30	Fabricating characteristics same as C21000, plus heading and up-setting, roll threading and knurling. Uses: angles, channels, chain, fasteners, costume jewelry, lipstick cases, powder compacts, base for gold plate.
C23000 Red brass, 85%	85.0 Cu, 15.0 Zn	39-105	10-63	55	30	Excellent cold workability; good hot formability. Uses: weather-stripping, conduit, sockets, fasteners, fire extinguishers, condenser and heat-exchanger tubing, plumbing pipe, radiator cores.
C24000 Low brass, 80%	80.0 Cu, 20.0 Zn	42-125	12-65	55	30	Excellent cold workability. Fabricating characteristics same as C23000. Uses: battery caps, bellows, musical instruments, clock dials, pump lines, flexible hose.
C26000, C26100, C26130, C26200 Cartridge brass, 70%	70.0 Cu, 30.0 Zn	44 - 130	11-65	66	...	Excellent cold workability. Uses: radiator cores and tanks, flashlight shells, lamp fixtures, fasteners, screws, springs, grillwork, stencils, plumbing accessories, plumbing brass goods, locks, hinges, ammunition components, plumbing accessories, pins, rivets.
C26800, C27000 Yellow brass	65.0 Cu, 35.0 Zn	46-128	14-62	65	30	Excellent cold workability. Fabricating characteristics same as C23000. Uses: same as C26000 except not used for ammunition.
C28000 Muntz metal, 60%	60.0 Cu, 40.0 Zn	54-74	21-55	52	40	Excellent hot formability and forgeability for blanking, forming and bending, hot forging and pressing, hot heading and upsetting, shearing. Uses: architectural, large nuts and bolts, brazing rod, condenser plates, heat-exchanger and condenser tubing, hot forgings.
C31400 Leaded commercial bronze	89.0 Cu, 1.9 Pb, 0.1 Zn	37-60	12-55	45	80	Excellent machinability. Uses: screws, machine parts, pickling crates.

Table 2. (Continued) Properties and Applications of Wrought Coppers and Copper

Name and Number	Nominal Composition (%)	Strength (ksi)		Elongation in 2 in. (%)	Machinability Rating ^a	Fabricating Characteristics and Typical Applications
		Tensile	Yield			
C31600 Leaded commercial bronze, nickel-bearing	89.0 Cu, 1.9 Pb, 1.0 Ni, 8.1 Zn	37-67	12-59	45	80	Good cold workability; poor hot formability. Uses: electrical connectors, fasteners, hardware, nuts, screws, screw-machine parts.
C33000 Low-leaded brass tube	66.0 Cu, 0.5 Pb, 33.5 Zn	47-75	15-60	60	60	Combines good machinability and excellent cold workability. Fabricated by forming and bending, machining, piercing and punching. Uses: pump and power cylinders and liners, ammunition primers, plumbing accessories.
C33200 High-leaded brass tube	66.0 Cu, 2.0 Pb, 32.0 Zn	47-75	15-60	50	80	Excellent machinability. Fabricated by piercing, punching, and machining. Uses: general-purpose screw-machine parts.
C33500 Low-leaded brass	63.5 Cu, 0.5 Pb, 36 Zn	46-74	14-60	65	60	Similar to C33200. Commonly fabricated by blanking, drawing, machining, piercing and punching, stamping. Uses: butts, hinges, watch backs.
C34000 Medium-leaded brass	63.5 Cu, 1.0 Pb, 35.5 Zn	47-88	15-60	60	70	Similar to C33200. Fabricated by blanking, heading and upsetting, machining, piercing and punching, roll threading and knurling, stamping. Uses: butts, gears, nuts, rivets, screws, dials, engravings, instrument plates.
C34200 High-leaded brass	63.5 Cu, 2.0 Pb, 34.5 Zn	49-85	17-62	52	90	Combines excellent machinability with moderate cold workability. Uses: clock plates and nuts, clock and watch backs, gears, wheels and channel plate.
C35000 Medium-leaded brass	62.5 Cu, 1.1 Pb, 36.4 Zn	45-95	13-70	66	70	Fair cold workability; poor hot formability. Uses: bearing cages, book dies, clock plates, gears, hinges, hose couplings, keys, lock parts, lock tumblers, meter parts, nuts, sink strainers, strike plates, templates, type characters, washers, wear plates.
C35300 High-leaded brass	61.5 Cu, 2.8 Pb, 36.5 Zn	49-85	17-62	52	90	Similar to C34200.
C35600 Extra-high-leaded brass	61.5 Cu, 2.5 Pb, 36 Zn	47-97	17-87	60	100	Excellent machinability. Fabricated by blanking, machining, piercing and punching, stamping. Uses: clock plates and nuts, clock and watch backs, gears, wheels, and channel plate.
C36000 Free-cutting brass	61.5 Cu, 3.1 Pb, 35.4 Zn	49-68	18-45	53	100	Excellent machinability. Fabricated by machining, roll threading, and knurling. Uses: gears, pinions, automatic high-speed screw-machine parts.
C36500 to C36800 Leaded Muntz metal	59.5 Cu, 0.5 Pb, 40.0 Zn	54 (As hot rolled)	20	45	60	Combines good machinability with excellent hot formability. Uses: condenser-tube plates.
C37000 Free-cutting Muntz metal	60.0 Cu, 1.0 Pb, 39.0 Zn	54-80	20-60	40	70	Fabricating characteristics similar to C36500 to 36800. Uses: automatic screw-machine parts.
C37700 Forging brass	59.5 Cu, 2.0 Pb, 38.0 Zn	52 (As extruded)	20	45	80	Excellent hot workability. Fabricated by heading and upsetting, hot forging and pressing, hot heading and upsetting, machining. Uses: forgings and pressings of all kinds.
C38500 Architectural bronze	57.0 Cu, 3.0 Pb, 40.0 Zn	60 (As extruded)	20	30	90	Excellent machinability and hot workability. Fabricated by hot forging and pressing, forming, bending, and machining. Uses: architectural extrusions, store fronts, thresholds, trim, butts, hinges, lock bodies, and forgings.
C40500	95 Cu, 1 Sn, 4 Zn	39-78	12-70	49	20	Excellent cold workability. Fabricated by blanking, forming, and drawing. Uses: meter clips, terminals, fuse clips, contact and relay springs, washers.

Table 2. (Continued) Properties and Applications of Wrought Coppers and Copper

Name and Number	Nominal Composition (%)	Strength (ksi)		Elongation in 2 in. (%)	Machinability Rating ^a	Fabricating Characteristics and Typical Applications
		Tensile	Yield			
C40800	95 Cu, 2 Sn, 3 Zn	42-79	13-75	43	20	Excellent cold workability. Fabricated by blanking, stamping, and shearing. Uses: electrical connectors.
C41100	91 Cu, 0.5 Sn, 8.5 Zn	39-106	11-72	43	20	Excellent cold workability, good hot formability. Fabricated by blanking, forming and bending, drawing, piercing and punching, shearing, spinning, and stamping. Uses: bushings, bearing sleeves, thrust washers, flexible metal hose.
C41300	90.0 Cu, 1.0 Sn, 9.0 Zn	41-105	12-82	45	20	Excellent cold workability; good hot formability. Uses: plater bar for jewelry products, flat springs for electrical switchgear.
C41500	91 Cu, 1.8 Sn, 7.2 Zn	46-81	17-75	44	30	Excellent cold workability. Fabricated by blanking, drawing, bending, forming, shearing, and stamping. Uses: spring applications for electrical switches.
C42200	87.5 Cu, 1.1 Sn, 11.4 Zn	43-88	15-75	46	30	Excellent cold workability; good hot formability. Fabricated by blanking, piercing, forming, and drawing. Uses: sash chains, fuse clips, terminals, spring washers, contact springs, electrical connectors.
C42500	88.5 Cu, 2.0 Sn, 9.5 Zn	45-92	18-76	49	30	Excellent cold workability. Fabricated by blanking, piercing, forming, and drawing. Uses: electrical switches, springs, terminals, connectors, fuse clips, pen clips, weather stripping.
C43000	87.0 Cu, 2.2 Sn, 10.8 Zn	46-94	18-73	55	30	Excellent cold workability; good hot formability. Fabricated by blanking, coining, drawing, forming, bending, heading, and upsetting. Uses: same as C42500.
C43400	85.0 Cu, 0.7 Sn, 14.3 Zn	45-90	15-75	49	30	Excellent cold workability. Fabricated by blanking, drawing, bonding, forming, stamping, and shearing. Uses: electrical switch parts, blades, relay springs, contacts.
C43500	81.0 Cu, 0.9 Sn, 18.1 Zn	46-80	16-68	46	30	Excellent cold workability for fabrication by forming and bending. Uses: Bourdon tubing and musical instruments.
C44300, C44400, C44500 Inhibited admiralty	71.0 Cu, 28.0 Zn, 1.0 Sn	48-55	18-22	65	30	Excellent cold workability for forming and bending. Uses: condenser, evaporator and heat-exchanger tubing, condenser tubing plates, distiller tubing, ferrules.
C46400 to C46700 Naval brass	60.0 Cu, 39.2 Zn, 0.8 Sn	55-88	25-66	50	30	Excellent hot workability and hot forgeability. Fabricated by blanking, drawing, bending, heading and upsetting, hot forging, pressing. Uses: aircraft turnbuckle barrels, balls, bolts, marine hardware, nuts, propeller shafts, rivets, valve stems, condenser plates, welding rod.
C48200 Naval brass, medium- leaded	60.5 Cu, 0.7 Pb, 0.8 Sn, 38.0 Zn	56-75	25-53	43	50	Good hot workability for hot forging, pressing, and machining operations. Uses: marine hardware, screw-machine products, valve stems.
C48500 Leaded naval brass	60.0 Cu, 1.8 Pb, 37.5 Zn, 0.7 Sn	57-75	25-53	40	70	Combines good hot forgeability and machinability. Fabricated by hot forging and pressing, machining. Uses: marine hardware, screw-machine parts, valve stems.
C50500 Phosphor bronze, 1.25% E	98.7 Cu, 1.3 Sn, trace P	40-79	14-50	48	20	Excellent cold workability; good hot formability. Fabricated by blanking, bending, heading and upsetting, shearing and swaging. Uses: electrical contacts, flexible hose, pole-line hardware.

Table 2. (Continued) Properties and Applications of Wrought Coppers and Copper

Name and Number	Nominal Composition (%)	Strength (ksi)		Elongation in 2 in. (%)	Machinability Rating ^a	Fabricating Characteristics and Typical Applications
		Tensile	Yield			
C51000 Phosphor bronze, 5% A	94.8 Cu, 5.0 Sn, trace P	47–140	19–80	64	20	Excellent cold workability. Fabricated by blanking, drawing, bending, heading and upsetting, roll threading and knurling, shearing, stamping. Uses: bellows, Bourdon tubing, clutch discs, cotter pins, diaphragms, fasteners, lock washers, wire brushes, chemical hardware, textile machinery, welding rod.
C51100	95.6 Cu, 4.2 Sn, 0.2 P	46–103	50–80	48	20	Excellent cold workability. Uses: bridge bearing plates, locator bars, fuse clips, sleeve bushings, springs, switch parts, truss wire, wire brushes, chemical hardware, perforated sheets, textile machinery.
C52100 Phosphor bronze, 8% C	92.0 Cu, 8.0 Sn, trace P	55–140	24–80	70	20	Good cold workability for blanking, drawing, forming and bending, shearing, stamping. Uses: generally for more severe service conditions than C51000.
C52400 Phosphor bronze, 10% D	90.0 Cu, 10.0 Sn, trace P	66–147	28	70	20	Good cold workability for blanking, forming and bending, shearing. Uses: heavy bars and plates for severe compression, bridge and expansion plates and fittings, articles requiring good spring qualities, resilience, fatigue resistance, good wear and corrosion resistance.
C54400	88.0 Cu, 4.0 Pb, 4.0 Zn, 4.0 Sn	44–75	19–63	50	80	Excellent machinability; good cold workability. Fabricated by blanking, drawing, bending, machining, shearing, stamping. Uses: bearings, bushings, gears, pinions, shafts, thrust washers, valve parts.
C60800	95.0 Cu, 5.0 Al	60	27	55	20	Good cold workability; fair hot formability. Uses: condenser, evaporator and heat-exchanger tubes, distiller tubes, ferrules.
C61000	92.0 Cu, 8.0 Al	52–60	17–27	45	20	Good hot and cold workability. Uses: bolts, pump parts, shafts, tie rods, overlay on steel for wearing surfaces.
C61300	90.3 Cu, 0.35 Sn, 6.8 Al, 0.35 Sn	70–85	30–58	42	30	Good hot and cold formability. Uses: nuts, bolts, corrosion resistant vessels and tanks, structural components, machine parts, condenser tube and piping systems, marine protective sheathing and fasteners, munitions mixing troughs and blending chambers.
C61400 Aluminum bronze, D	91.0 Cu, 7.0 Al, 2.0 Fe	76–89	33–60	45	20	Similar to C61300.
C61500	90.0 Cu, 8.0 Al, 2.0 Ni	70–145	22–140	55	30	Good hot and cold workability. Fabricating characteristics similar to C52100. Uses: hardware, decorative metal trim, interior furnishings and other articles requiring high tarnish resistance.
C61800	89.0 Cu, 1.0 Fe, 10.0 Al	80–85	39–42.5	28	40	Fabricated by hot forging and hot pressing. Uses: bushings, bearings, corrosion-resistant applications, welding rods.
C61900	86.5 Cu, 4.0 Fe, 9.5 Al	92–152	49–145	30	...	Excellent hot formability for fabricating by blanking, forming, bending, shearing, and stamping. Uses: springs, contacts, and switch components.
C62300	87.0 Cu, 3.0 Fe, 10.0 Al	75–98	35–52	35	50	Good hot and cold formability. Fabricated by bending, hot forging, hot pressing, forming, and welding. Uses: bearings, bushings, valve guides, gears, valve seats, nuts, bolts, pump rods, worm gears, and cams.
C62400	86.0 Cu, 3.0 Fe, 11.0 Al	90–105	40–52	18	50	Excellent hot formability for fabrication by hot forging and hot bending. Uses: bushings, gears, cams, wear strips, nuts, drift pins, tie rods.

Table 2. (Continued) Properties and Applications of Wrought Coppers and Copper

Name and Number	Nominal Composition (%)	Strength (ksi)		Elongation in 2 in. (%)	Machinability Rating ^a	Fabricating Characteristics and Typical Applications
		Tensile	Yield			
C62500	82.7 Cu, 4.3 Fe, 13.0 Al	100 (As extruded)	55	1	20	Excellent hot formability for fabrication by hot forging and machining. Uses: guide bushings, wear strips, cams, dies, forming rolls.
C63000	82.0 Cu, 3.0 Fe, 10.0 Al, 5.0 Ni	90–118	50–75	20	30	Good hot formability. Fabricated by hot forming and forging. Uses: nuts, bolts, valve seats, plunger tips, marine shafts, valve guides, aircraft parts, pump shafts, structural members.
C63200	82.0 Cu, 4.0 Fe, 9.0 Al, 5.0 Ni	90–105	45–53	25	30	Good hot formability. Fabricated by hot forming and welding. Uses: nuts, bolts, structural pump parts, shafting requiring corrosion resistance.
C63600	95.5 Cu, 3.5 Al, 1.0 Si	60–84	...	64	40	Excellent cold workability; fair hot formability. Fabricated by cold heading. Uses: components for pole-line hardware, cold-headed nuts for wire and cable connectors, bolts and screw products.
C63800	95.0 Cu, 2.8 Al, 1.8 Si, 0.40 Co	82–130	54–114	36	...	Excellent cold workability and hot formability. Uses: springs, switch parts, contacts, relay springs, glass sealing, and porcelain enameling.
C64200	91.2 Cu, 7.0 Al, 1.8 Si	75–102	35–68	32	60	Excellent hot formability. Fabricated by hot forming, forging, machining. Uses: valve stems, gears, marine hardware, pole-line hardware, bolts, nuts, valve bodies, and components.
C65100 Low-silicon bronze, B	98.5 Cu, 1.5 Si	40–105	15–71	55	30	Excellent hot and cold workability. Fabricated by forming and bending, heading and upsetting, hot forging and pressing, roll threading and knurling, squeezing and swaging. Uses: hydraulic pressure lines, anchor screws, bolts, cable clamps, cap screws, machine screws, marine hardware, nuts, pole-line hardware, rivets, U-bolts, electrical conduits, heat-exchanger tubing, welding rod.
C65500 High-silicon bronze, A	97.0 Cu, 3.0 Si	56–145	21–71	63	30	Excellent hot and cold workability. Fabricated by blanking, drawing, forming and bending, heading and upsetting, hot forging and pressing, roll threading and knurling, shearing, squeezing and swaging. Uses: similar to C65100 including propeller shafts.
C66700 Manganese brass	70.0 Cu, 28.8 Zn, 1.2 Mn	45.8–100	12–92.5	60	30	Excellent cold formability. Fabricated by blanking, bending, forming, stamping, welding. Uses: brass products resistance welded by spot, seam, and butt welding.
C67400	58.5 Cu, 36.5 Zn, 1.2 Al, 2.8 Mn, 1.0 Sn	70–92	34–55	28	25	Excellent hot formability. Fabricated by hot forging and pressing, machining. Uses: bushings, gears, connecting rods, shafts, wear plates.
C67500 Manganese bronze, A	58.5 Cu, 1.4 Fe, 39.0 Zn, 1.0 Sn, 0.1 Mn	65–84	30–60	33	30	Excellent hot workability. Fabricated by hot forging and pressing, hot heading and upsetting. Uses: clutch discs, pump rods, shafting, balls, valve stems and bodies.
C68700 Aluminum brass, arsenical	77.5 Cu, 20.5 Zn, 2.0 Al, trace As	60	27	55	30	Excellent cold workability for forming and bending. Uses: condenser, evaporator- and heat-exchanger tubing, condenser tubing plates, distiller tubing, ferrules.
C68800	73.5 Cu, 22.7 Zn, 3.4 Al, 0.40 Co	82–129	55–114	36	...	Excellent hot and cold formability. Fabricated by blanking, drawing, forming and bending, shearing and stamping. Uses: springs, switches, contacts, relays, drawn parts.

Table 2. (Continued) Properties and Applications of Wrought Coppers and Copper

Name and Number	Nominal Composition (%)	Strength (ksi)		Elongation in 2 in. (%)	Machinability Rating ^a	Fabricating Characteristics and Typical Applications
		Tensile	Yield			
C69000	73.3 Cu, 3.4 Al, 0.6 Ni, 22.7 Zn	82-130	52-117	35	...	Fabricating characteristics same as C68800. Uses: contacts, relays, switches, springs, drawn parts.
C69400 Silicon red brass	81.5 Cu, 14.5 Zn, 4.0 Si	80-100	40-57	25	30	Excellent hot formability for fabrication by forging, screw-machine operations. Uses: valve stems where corrosion resistance and high strength are critical.
C70400 Copper nickel, 5%	92.4 Cu, 1.5 Fe, 5.5 Ni, 0.6 Mn	38-77	40-76	46	20	Excellent cold workability; good hot formability. Fabricated by forming, bending, and welding. Uses: condensers, evaporators, heat exchangers, ferrules, salt water piping, lithium bromide absorption tubing, shipboard condenser intake systems.
C70600 Copper nickel, 10%	88.6 Cu, 1.4 Fe, 10.0 Ni	44-60	16-57	42	20	Good hot and cold workability. Fabricated by forming and bending, welding. Uses: condensers, condenser plates, distiller tubing, evaporator and heat-exchanger tubing, ferrules.
C71000 Copper nickel, 20%	79.0 Cu, 21.0 Ni	49-95	13-85	40	20	Good hot and cold formability. Fabricated by blanking, forming and bending, welding. Uses: communication relays, condensers, condenser plates, electrical springs, evaporator and heat-exchanger tubes, ferrules, resistors.
C71500 Copper nickel, 30%	69.5 Cu, 30.0 Ni, 0.5 Fe	54-75	20-70	45	20	Similar to C70600.
C72200	82.2 Cu, 16.5 Ni, 0.8 Fe, 0.5 Cr	46-70	18-66	46	...	Good hot and cold formability. Fabricated by forming, bending, and welding. Uses: condenser tubing, heat-exchanger tubing, salt water piping.
C72500	88.2 Cu, 9.5 Ni, 2.3 Sn	55-120	22-108	35	20	Excellent cold and hot formability. Fabricated by blanking, brazing, coining, drawing, etching, forming and bending, heading and upsetting, roll threading and knurling, shearing, spinning, squeezing, stamping, and swaging. Uses: relay and switch springs, connectors, brazing alloy, lead frames, control and sensing bellows.
C73500	72.0 Cu, 10.0 Zn, 18.0 Ni	50-100	15-84	37	20	Fabricating characteristics same as C74500. Uses: hollow ware, medallions, jewelry, base for silver plate, cosmetic cases, musical instruments, name plates, contacts.
C74500 Nickel silver, 65-10	65.0 Cu, 25.0 Zn, 10.0 Ni	49-130	18-76	50	20	Excellent cold workability. Fabricated by blanking, drawing, etching, forming and bending, heading and upsetting, roll threading and knurling, shearing, spinning, squeezing, and swaging. Uses: rivets, screws, slide fasteners, optical parts, etching stock, hollow ware, nameplates, platers' bars.
C75200 Nickel silver, 65-18	65.0 Cu, 17.0 Zn, 18.0 Ni	56-103	25-90	45	20	Fabricating characteristics similar to C74500. Uses: rivets, screws, table flatware, truss wire, zippers, bows, camera parts, core bars, temples, base for silver plate, costume jewelry, etching stock, hollow ware, nameplates, radio dials.
C75400 Nickel silver, 65-15	65.0 Cu, 20.0 Zn, 15.0 Ni	53-92	18-79	43	20	Fabricating characteristics similar to C74500. Uses: camera parts, optical equipment, etching stock, jewelry.
C75700 Nickel silver, 65-12	65.0 Cu, 23.0 Zn, 12.0 Ni	52-93	18-79	48	20	Fabricating characteristics similar to C74500. Uses: slide fasteners, camera parts, optical parts, etching stock, name plates.

Table 2. (Continued) Properties and Applications of Wrought Coppers and Copper

Name and Number	Nominal Composition (%)	Strength (ksi)		Elongation in 2 in. (%)	Machinability Rating ^a	Fabricating Characteristics and Typical Applications
		Tensile	Yield			
C76390	61 Cu, 13 Zn, 24.5 Ni, 1 Pb, 0.5 Sn	90	85	6	40	Fabricated by machining, roll threading, and knurling. Uses: hardware, fasteners, connectors for electronic applications.
C77000 Nickel silver, 55-18	55.0 Cu, 27.0 Zn, 18.0 Ni	60-145	27-90	40	30	Good cold workability. Fabricated by blanking, forming and bending, and shearing. Uses: optical goods, springs, and resistance wire.
C78200	65.0 Cu, 2.0 Pb, 25.0 Zn, 8.0 Ni	53-91	23-76	40	60	Good cold formability. Fabricated by blanking, milling, and drilling. Uses: key blanks, watch plates, watch parts.

^a Free-cutting brass = 100.

Source: Copper Development Association, New York.

Aluminum and Aluminum Alloys

Pure aluminum is a silver-white metal characterized by a slightly bluish cast. It has a specific gravity of 2.70, resists the corrosive effects of many chemicals, and has a malleability approaching that of gold. When alloyed with other metals, numerous properties are obtained that make these alloys useful over a wide range of applications.

Aluminum alloys are light in weight compared with steel, brass, nickel, or copper; can be fabricated by all common processes; are available in a wide range of sizes, shapes, and forms; resist corrosion; readily accept a wide range of surface finishes; have good electrical and thermal conductivities; and are highly reflective to both heat and light.

Characteristics of Aluminum and Aluminum Alloys.—Aluminum and its alloys lose part of their strength at elevated temperatures, although some alloys retain good strength at temperatures from 400 to 500 degrees F. At subzero temperatures, however, their strength increases without loss of ductility so that aluminum is a particularly useful metal for low-temperature applications.

When aluminum surfaces are exposed to the atmosphere, a thin invisible oxide skin forms immediately that protects the metal from further oxidation. This self-protecting characteristic gives aluminum its high resistance to corrosion. Unless exposed to some substance or condition that destroys this protective oxide coating, the metal remains protected against corrosion. Aluminum is highly resistant to weathering, even in industrial atmospheres. It is also corrosion resistant to many acids. Alkalis are among the few substances that attack the oxide skin and therefore are corrosive to aluminum. Although the metal can safely be used in the presence of certain mild alkalis with the aid of inhibitors, in general, direct contact with alkaline substances should be avoided. Direct contact with certain other metals should be avoided in the presence of an electrolyte; otherwise, galvanic corrosion of the aluminum may take place in the contact area. Where other metals must be fastened to aluminum, the use of a bituminous paint coating or insulating tape is recommended.

Aluminum is one of the two common metals having an electrical conductivity high enough for use as an electric conductor. The conductivity of electric-conductor (EC) grade is about 62 per cent that of the International Annealed Copper Standard. Because aluminum has less than one-third the specific gravity of copper, however, a pound of aluminum will go almost twice as far as a pound of copper when used as a conductor. Alloying lowers the conductivity somewhat so that wherever possible the EC grade is used in electric conductor applications. However, aluminum takes a set, which often results in loosening of

screwed connectors, leading to arcing and fires. Special clamping designs are therefore required when aluminum is used for electrical wiring, especially in buildings.

Aluminum has nonsparking and nonmagnetic characteristics that make the metal useful for electrical shielding purposes such as in bus bar housings or enclosures for other electrical equipment and for use around inflammable or explosive substances.

Aluminum can be cast by any method known. It can be rolled to any desired thickness down to foil thinner than paper and in sheet form can be stamped, drawn, spun, or roll-formed. The metal also may be hammered or forged. Aluminum wire, drawn from rolled rod, may be stranded into cable of any desired size and type. The metal may be extruded into a variety of shapes. It may be turned, milled, bored, or otherwise machined in equipment often operating at their maximum speeds. Aluminum rod and bar may readily be employed in the high-speed manufacture of parts made on automatic screw-machine.

Almost any method of joining is applicable to aluminum—riveting, welding, or brazing. A wide variety of mechanical aluminum fasteners simplifies the assembly of many products. Resin bonding of aluminum parts has been successfully employed, particularly in aircraft components.

For the majority of applications, aluminum needs no protective coating. Mechanical finishes such as polishing, sandblasting, or wire brushing meet the majority of needs. When additional protection is desired, chemical, electrochemical, and paint finishes are all used. Vitreous enamels have been developed for aluminum, and the metal may also be electroplated.

Temper Designations for Aluminum Alloys.—The temper designation system adopted by the Aluminum Association and used in industry pertains to all forms of wrought and cast aluminum and aluminum alloys except ingot. It is based on the sequences of basic treatments used to produce the various tempers. The temper designation follows the alloy designation, being separated by a dash.

Basic temper designations consist of letters. Subdivisions of the basic tempers, where required, are indicated by one or more digits following the letter. These digits designate specific sequences of basic treatments, but only operations recognized as significantly influencing the characteristics of the product are indicated. Should some other variation of the same sequence of basic operations be applied to the same alloy, resulting in different characteristics, then additional digits are added.

The basic temper designations and subdivisions are as follows:

—*F*, *as fabricated*: Applies to products that acquire some temper from shaping processes not having special control over the amount of strain-hardening or thermal treatment. For wrought products, there are no mechanical property limits.

—*O*, *annealed, recrystallized (wrought products only)*: Applies to the softest temper of wrought products.

—*H*, *strain-hardened (wrought products only)*: Applies to products that have their strength increased by strain-hardening with or without supplementary thermal treatments to produce partial softening.

The —*H* is always followed by two or more digits. The first digit indicates the specific combination of basic operations, as follows:

—*H1*, *strain-hardened only*: Applies to products that are strain-hardened to obtain the desired mechanical properties without supplementary thermal treatment. The number following this designation indicates the degree of strain-hardening.

—*H2*, *strain-hardened and then partially annealed*: Applies to products that are strain-hardened more than the desired final amount and then reduced in strength to the desired level by partial annealing. For alloys that age-soften at room temperature, the —*H2* tempers have approximately the same ultimate strength as the corresponding —*H3* tempers. For other alloys, the —*H2* tempers have approximately the same ultimate strengths as the corresponding —*H1* tempers and slightly higher elongations. The number following this design-

nation indicates the degree of strain-hardening remaining after the product has been partially annealed.

-H3, strain-hardened and then stabilized: Applies to products which are strain-hardened and then stabilized by a low-temperature heating to slightly lower their strength and increase ductility. This designation applies only to the magnesium-containing alloys that, unless stabilized, gradually age-soften at room temperature. The number following this designation indicates the degree of strain-hardening remaining after the product has been strain-hardened a specific amount and then stabilized.

The second digit following the designations -H1, -H2, and -H3 indicates the final degree of strain-hardening. Numeral 8 has been assigned to indicate tempers having a final degree of strain-hardening equivalent to that resulting from approximately 75 per cent reduction of area. Tempers between -O (annealed) and 8 (full hard) are designated by numerals 1 through 7. Material having an ultimate strength about midway between that of the -O temper and that of the 8 temper is designated by the numeral 4 (half hard); between -O and 4 by the numeral 2 (quarter hard); and between 4 and 8 by the numeral 6 (three-quarter hard). (*Note:* For two-digit -H tempers whose second figure is odd, the standard limits for ultimate strength are exactly midway between those for the adjacent two-digit -H tempers whose second figures are even.) Numeral 9 designates extra-hard tempers.

The third digit, when used, indicates a variation of a two-digit -H temper, and is used when the degree of control of temper or the mechanical properties are different from but close to those for the two-digit -H temper designation to which it is added. (*Note:* The minimum ultimate strength of a three-digit -H temper is at least as close to that of the corresponding two-digit -H temper as it is to the adjacent two-digit -H tempers.) Numerals 1 through 9 may be arbitrarily assigned and registered with the Aluminum Association for an alloy and product to indicate a specific degree of control of temper or specific mechanical property limits. Zero has been assigned to indicate degrees of control of temper or mechanical property limits negotiated between the manufacturer and purchaser that are not used widely enough to justify registration with the Aluminum Association.

The following three-digit -H temper designations have been assigned for wrought products in all alloys:

-H111: Applies to products that are strain-hardened less than the amount required for a controlled H11 temper.

-H112: Applies to products that acquire some temper from shaping processes not having special control over the amount of strain-hardening or thermal treatment, but for which there are mechanical property limits, or mechanical property testing is required.

The following three-digit H temper designations have been assigned for wrought products in alloys containing more than a normal 4 per cent magnesium.

-H311: Applies to products that are strain-hardened less than the amount required for a controlled H31 temper.

-H321: Applies to products that are strain-hardened less than the amount required for a controlled H32 temper.

-H323: Applies to products that are specially fabricated to have acceptable resistance to stress-corrosion cracking.

-H343: Applies to products that are specially fabricated to have acceptable resistance to stress-corrosion cracking.

The following three-digit -H temper designations have been assigned for

Patterned or Embossed Sheet	Fabricated Form
-H114	-O temper
-H124, -H224, -H324	-H11, -H21, -H31 temper, respectively
-H134, -H234, -H334	-H12, -H22, -H32 temper, respectively
-H144, -H244, -H344	-H13, -H23, -H33 temper, respectively
-H154, -H254, -H354	-H14, -H24, -H34 temper, respectively
-H164, -H264, -H364	-H15, -H25, -H35 temper, respectively

Patterned or Embossed Sheet	Fabricated Form
-H174, -H274, -H374	-H16, -H26, -H36 temper, respectively
-H184, -H284, -H384	-H17, -H27, -H37 temper, respectively
-H194, -H294, -H394	-H18, -H28, -H38 temper, respectively
-H195, -H395	-H19, -H39 temper, respectively

—*W*, *solution heat-treated*: An unstable temper applicable only to alloys that spontaneously age at room temperature after solution heat treatment. This designation is specific only when the period of natural aging is indicated.

—*T*, *thermally treated to produce stable tempers other than -F, -O, or -H*: Applies to products that are thermally treated, with or without supplementary strain-hardening, to produce stable tempers. The —*T* is always followed by one or more digits. Numerals 2 through 10 have been assigned to indicate specific sequences of basic treatments, as follows:

—*T1*, *naturally aged to a substantially stable condition*: Applies to products for which the rate of cooling from an elevated temperature-shaping process, such as casting or extrusion, is such that their strength is increased by room-temperature aging.

—*T2*, *annealed (cast products only)*: Designates a type of annealing treatment used to improve ductility and increase dimensional stability of castings.

—*T3*, *solution heat-treated and then cold-worked*: Applies to products that are cold-worked to improve strength, or in which the effect of cold work in flattening or straightening is recognized in applicable specifications.

—*T4*, *solution heat-treated and naturally aged to a substantially stable condition*: Applies to products that are not cold-worked after solution heat treatment, or in which the effect of cold work in flattening or straightening may not be recognized in applicable specifications.

—*T5*, *artificially aged only*: Applies to products that are artificially aged after an elevated-temperature rapid-cool fabrication process, such as casting or extrusion, to improve mechanical properties or dimensional stability, or both.

—*T6*, *solution heat-treated and then artificially aged*: Applies to products that are not cold-worked after solution heat-treatment, or in which the effect of cold work in flattening or straightening may not be recognized in applicable specifications.

—*T7*, *solution heat-treated and then stabilized*: Applies to products that are stabilized to carry them beyond the point of maximum hardness, providing control of growth or residual stress or both.

—*T8*, *solution heat-treated, cold-worked, and then artificially aged*: Applies to products that are cold-worked to improve strength, or in which the effect of cold work in flattening or straightening is recognized in applicable specifications.

—*T9*, *solution heat-treated, artificially aged, and then cold-worked*: Applies to products that are cold-worked to improve strength.

—*T10*, *artificially aged and then cold-worked*: Applies to products that are artificially aged after an elevated-temperature rapid-cool fabrication process, such as casting or extrusion, and then cold-worked to improve strength.

Additional digits may be added to designations —*T1* through —*T10* to indicate a variation in treatment that significantly alters the characteristics of the product. These may be arbitrarily assigned and registered with The Aluminum Association for an alloy and product to indicate a specific treatment or specific mechanical property limits.

These additional digits have been assigned for wrought products in all alloys:

—*T__51*, *stress-relieved by stretching*: Applies to products that are stress-relieved by stretching the following amounts after solution heat-treatment:

Plate	1½ to 3 per cent permanent set
Rod, Bar and Shapes	1 to 3 per cent permanent set
Drawn tube	0.5 to 3 per cent permanent set

Applies directly to plate and rolled or cold-finished rod and bar.

These products receive no further straightening after stretching.

Applies to extruded rod and bar shapes and tube when designated as follows:

–*T*₅₁₀: Products that receive no further straightening after stretching.

–*T*₅₁₁: Products that receive minor straightening after stretching to comply with standard tolerances.

–*T*₅₂, *stress-relieved by compressing*: Applies to products that are stress-relieved by compressing after solution heat-treatment, to produce a nominal permanent set of 2½ per cent.

–*T*₅₄, *stress-relieved by combined stretching and compressing*: Applies to die forgings that are stress relieved by restriking cold in the finish die.

The following two-digit –*T* temper designations have been assigned for wrought products in all alloys:

–*T*₄₂: Applies to products solution heat-treated and naturally aged that attain mechanical properties different from those of the –*T*₄ temper.

–*T*₆₂: Applies to products solution heat-treated and artificially aged that attain mechanical properties different from those of the –*T*₆ temper.

Aluminum Alloy Designation Systems.—Aluminum casting alloys are listed in many specifications of various standardizing agencies. The numbering systems used by each differ and are not always correlatable. Casting alloys are available from producers who use a commercial numbering system and this numbering system is the one used in the tables of aluminum casting alloys given further along in this section.

A system of four-digit numerical designations for wrought aluminum and wrought aluminum alloys was adopted by the Aluminum Association in 1954. This system is used by the commercial producers and is similar to the one used by the SAE; the difference being the addition of two prefix letters.

The first digit of the designation identifies the alloy type: 1) indicating an aluminum of 99.00 per cent or greater purity; 2) copper; 3) manganese; 4) silicon; 5) magnesium; 6) magnesium and silicon; 7) zinc; 8) some element other than those aforementioned; and 9) unused (not assigned at present).

If the second digit in the designation is zero, it indicates that there is no special control on individual impurities; integers 1 through 9 indicate special control on one or more individual impurities.

In the 1000 series group for aluminum of 99.00 per cent or greater purity, the last two of the four digits indicate to the nearest hundredth the amount of aluminum above 99.00 per cent. Thus designation 1030 indicates 99.30 per cent minimum aluminum. In the 2000 to 8000 series groups the last two of the four digits have no significance but are used to identify different alloys in the group. At the time of adoption of this designation system most of the existing commercial designation numbers were used for these last two digits, as for example, 14S became 2014, 3S became 3003, and 75S became 7075. When new alloys are developed and are commercially used these last two digits are assigned consecutively beginning with –01, skipping any numbers previously assigned at the time of initial adoption.

Experimental alloys are also designated in accordance with this system but they are indicated by the prefix X. The prefix is dropped upon standardization.

Table 3 lists the nominal composition of commonly used aluminum casting alloys, and Tables 4a and 4b list the typical tensile properties of separately cast bars. Table 5 shows the product forms and nominal compositions of common wrought aluminum alloys, and Table 6 lists their typical mechanical properties.

Heat-treatability of Wrought Aluminum Alloys.—In high-purity form, aluminum is soft and ductile. Most commercial uses, however, require greater strength than pure alumi-

num affords. This extra strength is achieved in aluminum first by the addition of other elements to produce various alloys, which singly or in combination impart strength to the metal. Further strengthening is possible by means that classify the alloys roughly into two categories, non-heat-treatable and heat-treatable.

Non-heat-treatable alloys: The initial strength of alloys in this group depends upon the hardening effect of elements such as manganese, silicon, iron and magnesium, singly or in various combinations. The non-heat-treatable alloys are usually designated, therefore, in the 1000, 3000, 4000, or 5000 series. These alloys are work-hardenable, so further strengthening is made possible by various degrees of cold working, denoted by the "H" series of tempers. Alloys containing appreciable amounts of magnesium when supplied in strain-hardened tempers are usually given a final elevated-temperature treatment called *stabilizing* for property stability.

Heat-treatable alloys: The initial strength of alloys in this group is enhanced by the addition of alloying elements such as copper, magnesium, zinc, and silicon. These elements singly or in various combinations show increasing solid solubility in aluminum with increasing temperature, so it is possible to subject them to thermal treatments that will impart pronounced strengthening.

The first step, called *heat-treatment* or *solution heat-treatment*, is an elevated-temperature process designed to put the soluble element in solid solution. This step is followed by rapid quenching, usually in water, which momentarily "freezes" the structure and for a short time renders the alloy very workable. Some fabricators retain this more workable structure by storing the alloys at below freezing temperatures until they can be formed. At room or elevated temperatures the alloys are not stable after quenching, however, and precipitation of the constituents from the supersaturated solution begins. After a period of several days at room temperature, termed *aging* or *room-temperature precipitation*, the alloy is considerably stronger. Many alloys approach a stable condition at room temperature, but some alloys, particularly those containing magnesium and silicon or magnesium and zinc, continue to age-harden for long periods of time at room temperature.

Heating for a controlled time at slightly elevated temperatures provides even further strengthening and properties are stabilized. This process is called *artificial aging* or *precipitation hardening*. By application of the proper combination of solution heat-treatment, quenching, cold working and artificial aging, the highest strengths are obtained.

Clad Aluminum Alloys.—The heat-treatable alloys in which copper or zinc are major alloying constituents are less resistant to corrosive attack than the majority of non-heat-treatable alloys. To increase the corrosion resistance of these alloys in sheet and plate form they are often clad with high-purity aluminum, a low magnesium-silicon alloy, or an alloy containing 1 per cent zinc. The cladding, usually from 2½ to 5 per cent of the total thickness on each side, not only protects the composite due to its own inherently excellent corrosion resistance but also exerts a galvanic effect that further protects the core material.

Special composites may be obtained such as clad non-heat-treatable alloys for extra corrosion protection, for brazing purposes, or for special surface finishes. Some alloys in wire and tubular form are clad for similar reasons and on an experimental basis extrusions also have been clad.

Table 3. Nominal Compositions (in per cent) of Common Aluminum Casting Alloys (AA/ANSI)

Alloy Designation)	Product	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Others	
											Each	Total
201.0	S	0.10	0.15	4.0-5.2	0.20-0.50	0.15-0.55	...	...	...	0.15-0.35	0.05 ^a	0.10
204.0	S&P	0.20	0.35	4.2-5.0	0.10	0.15-0.35	...	0.05	0.10	0.15-0.30	0.05 ^b	0.15
208.0	S&P	2.5-3.5	1.2	3.5-4.5	0.50	0.10	...	0.35	1.0	0.25	...	0.50
222.0	S&P	2.0	1.5	9.2-10.7	0.50	0.15-0.35	...	0.50	0.8	0.25	...	0.35
242.0	S&P	0.7	1.0	3.5-4.5	0.35	1.2-1.8	0.25	1.7-2.3	0.35	0.25	0.05	0.15
295.0	S	0.7-1.5	1.0	4.0-5.0	0.35	0.03	...	...	0.35	0.25	0.05	0.15
308.0	P	5.0-6.0	1.0	4.0-5.0	0.50	0.10	...	...	1.0	0.25	0.05	0.50
319.0	S&P	5.5-6.5	1.0	3.0-4.0	0.50	0.10	...	0.35	1.0	0.25	...	0.50
328.0	S	7.5-8.5	1.0	1.0-2.0	0.20-0.6	0.20-0.6	0.35	0.25	1.5	0.25	...	0.50
332.0	P	8.5-10.5	1.2	2.0-4.0	0.50	0.50-1.5	...	0.50	1.0	0.25	...	0.50
333.0	P	8.0-10.0	1.0	3.0-4.0	0.50	0.05-0.50	...	0.50	1.0	0.25	...	0.50
336.0	P	11.0-13.0	1.2	0.50-1.5	0.35	0.7-1.3	...	2.0-3.0	0.35	0.25	0.05	...
355.0	S&P	4.5-5.5	0.6 ^c	1.0-1.5	0.50 ^c	0.40-0.6	0.25	...	0.35	0.25	0.05	0.15
C355.0	S&P	4.5-5.5	0.20	1.0-1.5	0.10	0.40-0.6	...	...	0.10	0.20	0.05	0.15
356.0	S&P	6.5-7.5	0.6 ^c	0.25	0.35 ^c	0.20-0.45	...	...	0.35	0.25	0.05	0.15
356.0	S&P	6.5-7.5	0.20	0.20	0.10	0.25-0.45	...	...	0.10	0.20	0.05	0.15
357.0	S&P	6.5-7.5	0.15	0.05	0.03	0.45-0.6	...	...	0.05	0.20	0.05	0.15
A357.0	S&P	6.5-7.5	0.20	0.20	0.10	0.40-0.7	...	...	0.10	0.04-0.20	0.05 ^d	0.15
443.0	S&P	4.5-6.0	0.8	0.6	0.50	0.05	0.25	...	0.50	0.25	...	0.35
B443.0	S&P	4.5-6.0	0.8	0.15	0.35	0.05	...	...	0.35	0.25	0.05	0.15
A444.0	P	6.5-7.5	0.20	0.10	0.10	0.05	...	...	0.10	0.20	0.05	0.15
512.0	S	1.4-2.2	0.6	0.35	0.8	3.5-4.5	0.25	...	0.35	0.25	0.05	0.15
513.0	P	0.30	0.40	0.10	0.30	3.5-4.5	...	...	1.4-2.2	0.20	0.05	0.15
514.0	S	0.35	0.50	0.15	0.35	3.5-4.5	...	...	0.15	0.25	0.05	0.15
520.0	S	0.25	0.30	0.25	0.15	9.5-10.6	...	...	0.15	0.25	0.05	0.15
705.0	S&P	0.20	0.8	0.20	0.40-0.6	1.4-1.8	0.20-0.40	...	2.7-3.3	0.25	0.05	0.15
707.0	S&P	0.20	0.8	0.20	0.40-0.6	1.8-2.4	0.20-0.40	...	4.0-4.5	0.25	0.05	0.15
710.0	S	0.15	0.50	0.35-0.65	0.05	0.6-0.8	...	...	6.0-7.0	0.25	0.05	0.15
711.0	P	0.30	0.7-1.4	0.35-0.65	0.05	0.25-0.45	...	...	6.0-7.0	0.20	0.05	0.15
712.0	S	0.30	0.50	0.25	0.10	0.50-0.65	0.40-0.6	...	5.0-6.5	0.15-0.25	0.05	0.20
850.0	S&P	0.7	0.7	0.7-1.3	0.10	0.10	...	0.7-1.3	...	0.20	— ^e	0.30
851.0	S&P	2.0-3.0	0.7	0.7-1.3	0.10	0.10	...	0.30-0.7	...	0.20	— ^e	0.30

^a Also contains 0.40-1.0 per cent silver.

^b Also contains 0.05 max. per cent tin.

^c If iron exceeds 0.45 per cent, manganese content should not be less than one-half the iron content.

^d Also contains 0.04-0.07 per cent beryllium.

^e Also contains 5.5-7.0 per cent tin.

S = sand cast; P = permanent mold cast. The sum of those "Others" metallic elements 0.010 per cent or more each, expressed to the second decimal before determining the sum. *Source:* Standards for Aluminum Sand and Permanent Mold Castings. Courtesy of the Aluminum Association.

Characteristics of Principal Aluminum Alloy Series Groups.—1000 series: These alloys are characterized by high corrosion resistance, high thermal and electrical conductivity, low mechanical properties and good workability. Moderate increases in strength may be obtained by strain-hardening. Iron and silicon are the major impurities.

2000 series: Copper is the principal alloying element in this group. These alloys require solution heat-treatment to obtain optimum properties; in the heat-treated condition mechanical properties are similar to, and sometimes exceed, those of mild steel. In some instances artificial aging is employed to further increase the mechanical properties. This treatment materially increases yield strength, with attendant loss in elongation; its effect on tensile (ultimate) strength is not as great. The alloys in the 2000 series do not have as good corrosion resistance as most other aluminum alloys and under certain conditions they may be subject to intergranular corrosion. Therefore, these alloys in the form of sheet are usually clad with a high-purity alloy or a magnesium-silicon alloy of the 6000 series which provides galvanic protection to the core material and thus greatly increases resistance to corrosion. Alloy 2024 is perhaps the best known and most widely used aircraft alloy.

3000 series: Manganese is the major alloying element of alloys in this group, which are generally non-heat-treatable. Because only a limited percentage of manganese, up to about 1.5 per cent, can be effectively added to aluminum, it is used as a major element in only a few instances. One of these, however, is the popular 3003, used for moderate-strength applications requiring good workability.

4000 series: The major alloying element of this group is silicon, which can be added in sufficient quantities to cause substantial lowering of the melting point without producing brittleness in the resulting alloys. For these reasons aluminum-silicon alloys are used in welding wire and as brazing alloys where a lower melting point than that of the parent metal is required. Most alloys in this series are non-heat-treatable, but when used in welding heat-treatable alloys they will pick up some of the alloying constituents of the latter and so respond to heat-treatment to a limited extent. The alloys containing appreciable amounts of silicon become dark gray when anodic oxide finishes are applied, and hence are in demand for architectural applications.

5000 series: Magnesium is one of the most effective and widely used alloying elements for aluminum. When it is used as the major alloying element or with manganese, the result is a moderate to high strength non-heat-treatable alloy. Magnesium is considerably more effective than manganese as a hardener, about 0.8 per cent magnesium being equal to 1.25 per cent manganese, and it can be added in considerably higher quantities. Alloys in this series possess good welding characteristics and good resistance to corrosion in marine atmospheres. However, certain limitations should be placed on the amount of cold work and the safe operating temperatures permissible for the higher magnesium content alloys (over about $3\frac{1}{2}$ per cent for operating temperatures over about 150 deg. F) to avoid susceptibility to stress corrosion.

6000 series: Alloys in this group contain silicon and magnesium in approximate proportions to form magnesium silicide, thus making them capable of being heat-treated. The major alloy in this series is 6061, one of the most versatile of the heat-treatable alloys. Though less strong than most of the 2000 or 7000 alloys, the magnesium-silicon (or magnesium-silicide) alloys possess good formability and corrosion resistance, with medium strength. Alloys in this heat-treatable group may be formed in the -T4 temper (solution heat-treated but not artificially aged) and then reach full -T6 properties by artificial aging.

7000 series: Zinc is the major alloying element in this group, and when coupled with a smaller percentage of magnesium, results in heat-treatable alloys of very high strength. Other elements such as copper and chromium are usually added in small quantities. A notable member of this group is 7075, which is among the highest strength aluminum alloys available and is used in air-frame structures and for highly stressed parts.

Table 4a. Mechanical Property Limits for Commonly Used Aluminum Sand Casting Alloys

Alloy	Temper ^a	Minimum Properties			Typical Brinell Hardness (500 kgf load, 10-mm ball)
		Tensile Strength (ksi)		Elongation In 2 inches (%)	
		Ultimate	Yield		
201.0	T7	60.0	50.0	3.0	110-140
204.0	T4	45.0	28.0	6.0	...
208.0	F	19.0	12.0	1.5	40-70
222.0	O	23.0	...	...	65-95
222.0	T61	30.0	...	...	100-130
242.0	O	23.0	...	...	55-85
242.0	T571	29.0	...	...	70-100
242.0	T61	32.0	20.0	...	90-120
242.0	T77	24.0	13.0	1.0	60-90
295.0	T4	29.0	13.0	6.0	45-75
295.0	T6	32.0	20.0	3.0	60-90
295.0	T62	36.0	28.0	...	80-110
295.0	T7	29.0	16.0	3.0	55-85
319.0	F	23.0	13.0	1.5	55-85
319.0	T5	25.0	...	...	65-95
319.0	T6	31.0	20.0	1.5	65-95
328.0	F	25.0	14.0	1.0	45-75
328.0	T6	34.0	21.0	1.0	65-95
354.0	b	...	...	...	...
355.0	T51	25.0	18.0	...	50-80
355.0	T6	32.0	20.0	2.0	70-105
355.0	T7	35.0	...	...	70-100
355.0	T71	30.0	22.0	...	60-95
C355.0	T6	36.0	25.0	2.5	75-105
356.0	F	19.0	...	2.0	40-70
356.0	T51	23.0	16.0	...	45-75
356.0	T6	30.0	20.0	3.0	55-90
356.0	T7	31.0	29.0	...	60-90
356.0	T71	25.0	18.0	3.0	45-75
A356.0	T6	34.0	24.0	3.5	70-105
443.0	F	17.0	7.0	3.0	25-55
B443.0	F	17.0	6.0	3.0	25-55
512.0	F	17.0	10.0	...	35-65
514.0	F	22.0	9.0	6.0	35-65
520.0	T4 ^c	42.0	22.0	12.0	60-90
535.0	F or T5	35.0	18.0	9.0	60-90
705.0	F or T5	30.0	17.0	5.0	50-80
707.0	T5	33.0	22.0	2.0	70-100
707.0	T7	37.0	30.0	1.0	65-95
710.0	F or T5	32.0	20.0	2.0	60-90
712.0	F or T5	34.0	25.0	4.0	60-90
713.0	F or T5	32.0	22.0	3.0	60-90
771.0	T5	42.0	38.0	1.5	85-115
771.0	T51	32.0	27.0	3.0	70-100
771.0	T52	36.0	30.0	1.5	70-100
771.0	T53	36.0	27.0	1.5	...
771.0	T6	42.0	35.0	5.0	75-105
771.0	T71	48.0	45.0	2.0	105-135
850.0	T5	16.0	...	5.0	30-60
851.0	T5	17.0	...	3.0	30-60
852.0	T5	24.0	18.0	...	45-75

^aF indicates "as cast" condition.

^bMechanical properties for these alloys depend on the casting process. For further information consult the individual foundries.

^cThe T4 temper of Alloy 520.0 is unstable; significant room temperature aging occurs within life expectancy of most castings. Elongation may decrease by as much as 80 percent.

For separately cast test bars.

Source: Standards for Aluminum Sand and Permanent Mold Castings. Courtesy of the Aluminum Association.

Table 4b. Mechanical Property Limits for Commonly Used Aluminum Permanent Mold Casting Alloys

Alloy	Temper ^a	Minimum Properties			Typical Brinell Hardness (500 kgf load, 10-mm ball)
		Tensile Strength (ksi)		Elongation In 2 inches (%)	
		Ultimate	Yield		
204.0	T4	48.0	29.0	8.0	...
208.0	T4	33.0	15.0	4.5	60-90
208.0	T6	35.0	22.0	2.0	75-105
208.0	T7	33.0	16.0	3.0	65-95
222.0	T551	30.0	...	...	100-130
222.0	T65	40.0	...	...	125-155
242.0	T571	34.0	...	...	90-120
242.0	T61	40.0	...	...	95-125
296.0	T6	35.0	...	2.0	75-105
308.0	F	24.0	...	...	55-85
319.0	F	28.0	14.0	1.5	70-100
319.0	T6	34.0	...	2.0	75-105
332.0	T5	31.0	...	...	90-120
333.0	F	28.0	...	...	65-100
333.0	T5	30.0	...	...	70-105
333.0	T6	35.0	...	...	85-115
333.0	T7	31.0	...	...	75-105
336.0	T551	31.0	...	...	90-120
336.0	T65	40.0	...	...	110-140
354.0	T61	48.0	37.0	3.0	...
354.0	T62	52.0	42.0	2.0	...
355.0	T51	27.0	...	...	60-90
355.0	T6	37.0	...	1.5	75-105
355.0	T62	42.0	...	...	90-120
355.0	T7	36.0	...	...	70-100
355.0	T71	34.0	27.0	...	65-95
C355.0	T61	40.0	30.0	3.0	75-105
356.0	F	21.0	...	3.0	40-70
356.0	T51	25.0	...	...	55-85
356.0	T6	33.0	22.0	3.0	65-95
356.0	T7	25.0	...	3.0	60-90
356.0	T71	25.0	...	3.0	60-90
A356.0	T61	37.0	26.0	5.0	70-100
357.0	T6	45.0	...	3.0	75-105
A357.0	T61	45.0	36.0	3.0	85-115
359.0	T61	45.0	34.0	4.0	75-105
359.0	T62	47.0	38.0	3.0	85-115
443.0	F	21.0	7.0	2.0	30-60
B443.0	F	21.0	6.0	2.5	30-60
A444.0	T4	20.0	...	20.0	...
513.0	F	22.0	12.0	2.5	45-75
535.0	F	35.0	18.0	8.0	60-90
705.0	T5	37.0	17.0	10.0	55-85
707.0	T7	45.0	35.0	3.0	80-110
711.0	T1	28.0	18.0	7.0	55-85
713.0	T5	32.0	22.0	4.0	60-90
850.0	T5	18.0	...	8.0	30-60
851.0	T5	17.0	...	3.0	30-60
851.0	T6	18.0	...	8.0	...
852.0	T5	27.0	...	3.0	55-85

^aF indicates "as cast" condition.

For separately cast test bars.

Source: Standards for Aluminum Sand and Permanent Mold Castings. Courtesy of the Aluminum Association.

Table 5. Typical Mechanical Properties of Wrought Aluminum Alloys

Alloy and Temper	Tension				Brinell Hardness Number (500 kg load, 10-mm ball)	Ultimate Shearing Strength (ksi)	Endurance Limit ^a (ksi)
	Strength (ksi)		Elongation in 2 inches (%)				
	Ultimate	Yield	1/16-inch Thick Specimen	1/2-inch Diameter Specimen			
1060-O	10	4	43	...	19	7	3
1060-H12	12	11	16	...	23	8	4
1060-H14	14	13	12	...	26	9	5
1060-H16	16	15	8	...	30	10	6.5
1060-H18	19	18	6	...	35	11	6.5
1100-O	13	5	35	45	23	9	5
1100-H12	16	15	12	25	28	10	6
1100-H14	18	17	9	20	32	11	7
1100-H16	21	20	6	17	38	12	9
1100-H18	24	22	5	15	44	13	9
1350-O	12	4	...	...^b	...	8	...
1350-H12	14	12	...	...	...	9	...
1350-H14	16	14	...	...	...	10	...
1350-H16	18	16	...	...	...	11	...
1350-H19	27	24	...	...^c	...	15	7
2011-T3	55	43	...	15	95	32	18
2011-T8	59	45	...	12	100	35	18
2014-O	27	14	...	18	45	18	13
2014-T4, T451	62	42	...	20	105	38	20
2014-T6, T651	70	60	...	13	135	42	18
Alclad 2014-O	25	10	21	...	...	18	...
Alclad 2014-T3	63	40	20	...	...	37	...
Alclad 2014-T4, T451	61	37	22	...	...	37	...
Alclad 2014-T6, T651	68	60	10	...	...	41	...
2017-O	26	10	...	22	45	18	13
2017-T4, T451	62	40	...	22	105	38	18
2018-T61	61	46	...	12	120	39	17
2024-O	27	11	20	22	47	18	13
2024-T3	70	50	18	...	120	41	20
2024-T4, T351	68	47	20	19	120	41	20
2024-T361 ^d	72	57	13	...	130	42	18
Alclad 2024-O	26	11	20	...	...	18	...
Alclad 2024-T3	65	45	18	...	...	40	...
Alclad 2024-T4, T351	64	42	19	...	...	40	...
Alclad 2024-T361 ^d	67	53	11	...	...	41	...
Alclad 2024-T81, T851	65	60	6	...	...	40	...
Alclad 2024-T861 ^d	70	66	6	...	...	42	...
2025-T6	58	37	...	19	110	35	18
2036-T4	49	28	24	...	...	...	18 ^e
2117-T4	43	24	...	27	70	28	14
2218-T72	48	37	...	11	95	30	...
2219-O	25	11	18	...	...	...	...
2219-T42	52	27	20	...	...	...	...
2219-T31, T351	52	36	17	...	...	...	...
2219-T37	57	46	11	...	...	...	...
2219-T62	60	42	10	...	...	...	15
2219-T81, T851	66	51	10	...	...	...	15

Table 5. (Continued) Typical Mechanical Properties of Wrought Aluminum Alloys

Alloy and Temper	Tension				Brinell Hardness Number (500 kg load, 10-mm ball)	Ultimate Shearing Strength (ksi)	Endurance Limit ^a (ksi)
	Strength (ksi)		Elongation in 2 inches (%)				
	Ultimate	Yield	1/16-inch Thick Specimen	1/2-inch Diameter Specimen			
2219-T87	69	57	10	...	...	...	15
3003-O	16	6	30	40	28	11	7
3003-H12	19	18	10	20	35	12	8
3003-H14	22	21	8	16	40	14	9
3003-H16	26	25	5	14	47	15	10
3003-H18	29	27	4	10	55	16	10
Alclad 3003-O	16	6	30	40	...	11	...
Alclad 3003-H12	19	18	10	20	...	12	...
Alclad 3003-H14	22	21	8	16	...	14	...
Alclad 3003-H16	26	25	5	14	...	15	...
Alclad 3003-H18	29	27	4	10	...	16	...
3004-O	26	10	20	25	45	16	14
3004-H32	31	25	10	17	52	17	15
3004-H34	35	29	9	12	63	18	15
3004-H36	38	33	5	9	70	20	16
3004-H38	41	36	5	6	77	21	16
Alclad 3004-O	26	10	20	25	...	16	...
Alclad 3004-H32	31	25	10	17	...	17	...
Alclad 3004-H34	35	29	9	12	...	18	...
Alclad 3004-H36	38	33	5	9	...	20	...
Alclad 3004-H38	41	36	5	6	...	21	...
3105-O	17	8	24	...	...	12	...
3105-H12	22	19	7	...	...	14	...
3105-H14	25	22	5	...	...	15	...
3105-H16	28	25	4	...	...	16	...
3105-H18	31	28	3	...	...	17	...
3105-H25	26	23	8	...	...	15	...
4032-T6	55	46	...	9	120	38	16
5005-O	18	6	25	...	28	11	...
5005-H12	20	19	10	...	...	14	...
5005-H14	23	22	6	...	...	14	...
5005-H16	26	25	5	...	...	15	...
5005-H18	29	28	4	...	...	16	...
5005-H32	20	17	11	...	36	14	...
5005-H34	23	20	8	...	41	14	...
5005-H36	26	24	6	...	46	15	...
5005-H38	29	27	5	...	51	16	...
5050-O	21	8	24	...	36	15	12
5050-H32	25	21	9	...	46	17	13
5050-H34	28	24	8	...	53	18	13
5050-H36	30	26	7	...	58	19	14
5050-H38	32	29	6	...	63	20	14
5052-O	28	13	25	30	47	18	16
5052-H32	33	28	12	18	60	20	17
5052-H34	38	31	10	14	68	21	18
5052-H36	40	35	8	10	73	23	19
5052-H38	42	37	7	8	77	24	20
5056-O	42	22	...	35	65	26	20

Table 5. (Continued) Typical Mechanical Properties of Wrought Aluminum Alloys

Alloy and Temper	Tension				Brinell Hardness Number (500 kg load, 10-mm ball)	Ultimate Shearing Strength (ksi)	Endurance Limit ^a (ksi)
	Strength (ksi)		Elongation in 2 inches (%)				
	Ultimate	Yield	1/16-inch Thick Specimen	1/2-inch Diameter Specimen			
5056-H18	63	59	...	10	105	34	22
5056-H38	60	50	...	15	100	32	22
5083-O	42	21	...	22	...	25	...
5083-H321, H116	46	33	...	16	...	...	23
5086-O	38	17	22	...	...	23	...
5086-H32, H116	42	30	12	...	...	...	...
5086-H34	47	37	10	...	...	27	...
5086-H112	39	19	14	...	...	...	...
5154-O	35	17	27	...	58	22	17
5154-H32	39	30	15	...	67	22	18
5154-H34	42	33	13	...	73	24	19
5154-H36	45	36	12	...	78	26	20
5154-H38	48	39	10	...	80	28	21
5154-H112	35	17	25	...	63	...	17
5252-H25	34	25	11	...	68	21	...
5252-H38, H28	41	35	5	...	75	23	...
5254-O	35	17	27	...	58	22	17
5254-H32	39	30	15	...	67	22	18
5254-H34	42	33	13	...	73	24	19
5254-H36	45	36	12	...	78	26	20
5254-H38	48	39	10	...	80	28	21
5254-H112	35	17	25	...	63	...	17
5454-O	36	17	22	...	62	23	...
5454-H32	40	30	10	...	73	24	...
5454-H34	44	35	10	...	81	26	...
5454-H111	38	26	14	...	70	23	...
5454-H112	36	18	18	...	62	23	...
5456-O	45	23	...	24	...	...	...
5456-H112	45	24	...	22	...	...	...
5456-H321, H116	51	37	...	16	90	30	...
5457-O	19	7	22	...	32	12	...
5457-H25	26	23	12	...	48	16	...
5457-H38, H28	30	27	6	...	55	18	...
5652-O	28	13	25	30	47	18	16
5652-H32	33	28	12	18	60	20	17
5652-H34	38	31	10	14	68	21	18
5652-H36	40	35	8	10	73	23	19
5652-H38	42	37	7	8	77	24	20
5657-H25	23	20	12	...	40	14	...
5657-H38, H28	28	24	7	...	50	15	...
6061-O	18	8	25	30	30	12	9
6061-T4, T451	35	21	22	25	65	24	14
6061-T6, T651	45	40	12	17	95	30	14
Alclad 6061-O	17	7	25	...	...	11	...
Alclad 6061-T4, T451	33	19	22	...	...	22	...
Alclad 6061-T6, T651	42	37	12	...	...	27	...
6063-O	13	7	...	...	25	10	8
6063-T1	22	13	20	...	42	14	9

Table 5. (Continued) Typical Mechanical Properties of Wrought Aluminum Alloys

Alloy and Temper	Tension				Brinell Hardness Number (500 kg load, 10-mm ball)	Ultimate Shearing Strength (ksi)	Endurance Limit ^a (ksi)
	Strength (ksi)		Elongation in 2 inches (%)				
	Ultimate	Yield	1/16-inch Thick Specimen	1/2-inch Diameter Specimen			
6063-T4	25	13	22	...	...	...	...
6063-T5	27	21	12	...	60	17	10
6063-T6	35	31	12	...	73	22	10
6063-T83	37	35	9	...	82	22	...
6063-T831	30	27	10	...	70	18	...
6063-T832	42	39	12	...	95	27	...
6066-O	22	12	...	18	43	14	...
6066-T4, T451	52	30	...	18	90	29	...
6066-T6, T651	57	52	...	12	120	34	16
6070-T6	55	51	10	...	...	34	14
6101-H111	14	11	...	...	...	...	...
6101-T6	32	28	15	...	71	20	...
6262-T9	58	55	...	10	120	35	13
6351-T4	36	22	20	...	...	...	...
6351-T6	45	41	14	...	95	29	13
6463-T1	22	13	20	...	42	14	10
6463-T5	27	21	12	...	60	17	10
6463-T6	35	31	12	...	74	22	10
7049-T73	75	65	...	12	135	44	...
7049-T7352	75	63	...	11	135	43	...
7050-T73510, T73511	72	63	...	12	...	...	...
7050-T7451 ^f	76	68	...	11	...	44	...
7050-T7651	80	71	...	11	...	47	...
7075-O	33	15	17	16	60	22	...
7075-T6, T651	83	73	11	11	150	48	23
Alclad 7075-O	32	14	17	...	...	22	...
Alclad 7075-T6, T651	76	67	11	...	...	46	...
7178-O	33	15	15	16	...	...	...
7178-T6, T651	88	78	10	11	...	...	...
7178-T76, T7651	83	73	...	11	...	...	...
Alclad 7178-O	32	14	16	...	...	...	...
Alclad 7178-T6, T651	81	71	10	...	...	...	...
8176-H24	17	14	15	...	...	10	...

^a Based on 500,000,000 cycles of completely reversed stress using the R. R. Moore type of machine and specimen.

^b 1350-O wire should have an elongation of approximately 23 per cent in 10 inches.

^c 1350-H19 wire should have an elongation of approximately 1.5 per cent in 10 inches.

^d Tempers T361 and T861 were formerly designated T36 and T86, respectively.

^e Based on 10^7 cycles using flexural type testing of sheet specimens.

^f T7451, although not previously registered, has appeared in the literature and in some specifications as T73651.

The data given in this table are intended only as a basis for comparing alloys and tempers and should not be specified as engineering requirements or used for design purposes. The indicated typical mechanical properties for all except O temper material are higher than the specified minimum properties. For O temper products, typical ultimate and yield values are slightly lower than specified (maximum) values.

Source: Aluminum Standards and Data. Courtesy of the Aluminum Association.

Table 6. Nominal Compositions of Common Wrought Aluminum Alloys

Alloy	Alloying Elements — Aluminum and Normal Impurities Constitute Remainder							
	Si	Cu	Mn	Mg	Cr	Ni	Zn	Ti
1050	...	...	99.50 per cent minimum aluminum			...	...	...
1060	...	...	99.60 per cent minimum aluminum			...	...	...
1100	...	0.12	99.00 per cent minimum aluminum			...	...	...
1145	...	...	99.45 per cent minimum aluminum			...	...	...
1175	...	...	99.75 per cent minimum aluminum			...	...	...
1200	...	...	99.00 per cent minimum aluminum			...	...	...
1230	...	...	99.30 per cent minimum aluminum			...	...	...
1235	...	...	99.35 per cent minimum aluminum			...	...	...
1345	...	...	99.45 per cent minimum aluminum			...	...	...
1350 ^a	...	...	99.50 per cent minimum aluminum			...	...	...
2011 ^b	...	5.5	...	...	...	...	...	...
2014	0.8	4.4	0.8	0.50	...	...	...	...
2017	0.50	4.0	0.7	0.6	...	...	...	...
2018	...	4.0	...	0.7	...	2.0	...	...
2024	...	4.4	0.6	1.5	...	...	...	...
2025	0.8	4.4	0.8	...	...	...	...	...
2036	...	2.6	0.25	0.45	...	...	...	...
2117	...	2.6	...	0.35	...	...	...	...
2124	...	4.4	0.6	1.5	...	...	...	...
2218	...	4.0	...	1.5	...	2.0	...	...
2219 ^c	...	6.3	0.30	...	...	...	...	0.06
2319 ^c	...	6.3	0.30	...	...	...	...	0.15
2618 ^d	0.18	2.3	...	1.6	...	1.0	...	0.07
3003	...	0.12	1.2	...	...	...	...	...
3004	...	...	1.2	1.0	...	...	...	...
3005	...	...	1.2	0.40	...	...	...	...
4032	12.2	0.9	...	1.0	...	0.9	...	...
4043	5.2	...	...	...	...	...	...	...
4045	10.0	...	...	...	...	...	...	...
4047	12.0	...	...	...	...	...	...	...
4145	10.0	4.0	...	...	...	...	...	...
5005	...	...	...	0.8	...	...	...	...
5050	...	...	...	1.4	...	...	...	...
5052	...	...	...	2.5	0.25	...	...	...
5056	...	...	0.12	5.0	0.12	...	...	...
5083	...	...	0.7	4.4	0.15	...	...	...
5086	...	...	0.45	4.0	0.15	...	...	...
5183	...	...	0.8	4.8	0.15	...	...	...
5252	...	...	...	2.5	...	...	...	...
5254	...	...	...	3.5	0.25	...	...	...
5356	...	...	0.12	5.0	0.12	...	...	0.13
5456	...	...	0.8	5.1	0.12	...	...	...
5457	...	...	0.30	1.0	...	...	...	...
5554	...	...	0.8	2.7	0.12	...	...	0.12

Table 6. (Continued) Nominal Compositions of Common Wrought Aluminum Alloys

Alloy	Alloying Elements — Aluminum and Normal Impurities Constitute Remainder							
	Si	Cu	Mn	Mg	Cr	Ni	Zn	Ti
5556	...	...	0.8	5.1	0.12	...	...	0.12
5652	...	...	...	2.5	0.25	...	...	...
5654	...	...	...	3.5	0.25	...	...	0.10
6003	0.7	...	...	1.2	...	...	...	...
6005	0.8	...	...	0.50	...	...	...	...
6053	0.7	...	...	1.2	0.25	...	...	...
6061	0.6	0.28	...	1.0	0.20	...	...	...
6066	1.4	1.0	0.8	1.1	...	...	...	...
6070	1.4	0.28	0.7	0.8	...	...	...	...
6101	0.50	...	...	0.6	...	...	...	...
6105	0.8	...	...	0.62	...	...	...	...
6151	0.9	...	...	0.6	0.25	...	...	...
6201	0.7	...	...	0.8	...	...	...	...
6253	0.7	...	...	1.2	0.25	...	2.0	...
6262 ^e	0.6	0.28	...	1.0	0.09	...	...	...
6351	1.0	...	0.6	0.6	...	...	...	...
6463	0.40	...	...	0.7	...	...	...	...
7005 ^f	...	...	0.45	1.4	0.13	...	4.5	0.04
7008	...	...	...	1.0	0.18	...	5.0	...
7049	...	1.6	...	2.4	0.16	...	7.7	...
7050 ^g	...	2.3	...	2.2	6.2	...	...	...
7072	...	...	...	...	...	...	1.0	...
7075	...	1.6	...	2.5	0.23	...	5.6	...
7108 ^h	...	...	...	1.0	...	...	5.0	...
7178	...	2.0	...	2.8	0.23	...	6.8	...
8017 ⁱ	...	0.15	...	0.03	...	...	...	...
8030 ^j	...	0.22	...	...	...	...	...	...
8177 ^k	...	...	...	0.08	...	...	...	...

^a Formerly designated EC.

^b Lead and bismuth, 0.40 per cent each.

^c Vanadium 0.10 per cent; zirconium 0.18 per cent.

^d Iron 1.1 per cent.

^e Lead and bismuth, 0.6 per cent each.

^f Zirconium 0.14 per cent.

^g Zirconium 0.12 per cent.

^h Zirconium 0.18 per cent.

ⁱ Iron 0.7 per cent.

^j Boron 0.02 per cent.

^k Iron 0.35 per cent.

Source: Aluminum Standards and Data. Courtesy of the Aluminum Association.

Magnesium Alloys

Magnesium Alloys.—Magnesium is the lightest of all structural metals. Silver-white in color, pure magnesium is relatively soft, so is rarely used for structural purposes in the pure state. Principal metallurgical uses for pure magnesium are as an alloying element for aluminum and other metals; as a reducing agent in the extraction of such metals as titanium, zirconium, hafnium, and uranium; as a nodularizing agent in the manufacture of ductile

iron; and as a sulfur removal agent in steel manufacture. Magnesium alloys are made by alloying up to about 10 per cent of other metals and have low density and an excellent combination of mechanical properties, as shown in Table 7a, resulting in high strength-to-weight ratios.

Magnesium alloys are the easiest of all the structural metals to machine, and these alloys have very high weld efficiencies. Magnesium is readily processed by all the standard casting and fabrication techniques used in metalworking, especially by pressure die casting. Because the metal work hardens rapidly, cold forming is limited to mild deformation, but magnesium alloys have excellent working characteristics at temperatures between 300 and 500 degrees F.

These alloys have relatively low elastic moduli, so they will absorb energy with good resistance to dents and high damping capacities. Fatigue strength also is good, particularly in the low-stress, high-cycle range. The alloys can be precipitation hardened, so mechanical properties can be improved by solution heat treatment and aging. Corrosion resistance was greatly improved recently, when methods were found to limit heavy metal impurities to "parts per million."

Applications of Magnesium Alloys.—Magnesium alloys are used in a wide variety of structural applications including industrial, materials handling, automotive, consumer-durable, and aerospace equipment. In industrial machinery, the alloys are used for parts that operate at high speeds, which must have light weight to allow rapid acceleration and minimize inertial forces. Materials handling equipment applications include hand trucks, dockboards, grain shovels, and gravity conveyors. Automotive applications include wheels, gearboxes, clutch housings, valve covers, and brake pedal and other brackets. Consumer durables include luggage, softball bats, tennis rackets, and housings for cameras and projectors. Their high strength-to-weight ratio suits magnesium alloys to use in a variety of aircraft structures, particularly helicopters. Very intricate shapes that are uneconomical to produce in other materials are often cast in magnesium, sometimes without draft. Wrought magnesium alloys are made in the form of bars, forgings, extrusions, wire, sheet, and plate.

Alloy and Temper Designation.—Magnesium alloys are designated by a standard four-part system established by the ASTM, and now also used by the SAE, that indicates both chemical composition and temper. Designations begin with two letters representing the two alloying elements that are specified in the greatest amount; these letters are arranged in order of decreasing percentage of alloying elements or alphabetically if they are present in equal amounts. The letters are followed by digits representing the respective composition percentages, rounded off to whole numbers, and then by a serial letter indicating some variation in composition of minor constituents. The final part, separated by a hyphen, consists of a letter followed by a number, indicating the temper condition. The letters that designate the more common alloying elements are A, aluminum; E, rare earths; H, thorium; K, zirconium; M, manganese; Q, silver; S, silicon; T, tin; Z, zinc.

The letters and numbers that indicate the temper designation are: F, as fabricated; O, annealed; H10, H11, strain hardened; H23, H24, H26, strain hardened and annealed; T4, solution heat treated; T5, artificially aged; T6, solution heat treated and artificially aged; and T8, solution heat treated, cold-worked, and artificially aged.

The nominal composition and typical properties of magnesium alloys are listed in Table 7a.

Table 7a. Nominal Compositions of Magnesium Alloys

Alloy	Al	Zn	Mn ^a	Si	Zr	Ag	Th	Y	Rare Earth
Sand and Permanent Mold (Gravity Die) Castings									
AM100A-T61	10.0	...	0.10	...	...	...	...	...	...
AZ63A-T6	6.0	3.0	0.15	...	...	...	...	...	...
AZ81A-T4	7.6	0.7	0.13	...	...	...	...	...	...
AZ91C-T6	8.7	0.7	0.13	...	...	...	...	...	...
AZ91E-T6 ^b	8.7	0.7	0.17	...	...	...	...	...	...
AZ92A-T6	9.0	2.0	0.10	...	...	...	...	...	...
EZ33A-T5	...	2.6	...	...	0.8	...	...	...	3.3
HK31A-T6	...	0.3	...	...	0.7	...	3.3	...	...
HZ32A-T6	...	2.1	...	...	0.8	...	3.3	...	0.1
K1A-F	...	...	...	...	0.7	...	...	...	...
QE22A-T6	...	...	...	...	0.7	2.5	...	...	2.2
QH21A-T6	...	0.2	...	...	0.7	...	1.1	...	1.1
ZE41A-T5	...	4.3	0.15	...	0.7	...	...	...	1.3
ZE63A-T6	...	5.8	...	...	0.7	...	...	...	2.6
ZH62A-T5	...	5.7	...	...	0.8	...	1.8	...	...
ZK51A-T5	...	4.6	...	...	0.8	...	...	...	...
ZK61A-T6	...	6.0	...	...	0.8	...	...	...	...
WE54A-F	...	...	...	...	0.5	...	...	5.3	3.5
Pressure Die Castings									
AZ91A-F	9.0	0.7	0.13	...	...	...	...	...	...
AZ91B-F ^c	9.0	0.7	0.13	...	...	...	...	...	...
AZ91D-F ^b	9.0	0.7	0.15	...	...	...	...	...	...
AM60A-F	6.0	...	0.13	...	...	...	...	...	...
AM60B-F ^b	6.0	...	0.25	...	...	...	...	...	...
AS41A-F ^d	4.3	...	0.35	1.0	...	...	...	...	...
Extruded Bars and Shapes									
AZ10A-F	1.3	0.4	0.20	...	...	...	...	...	...
AZ31B-F	3.0	1.0	0.20	...	...	...	...	...	...
AZ31C-F	3.0	1.0	0.15	...	...	...	...	...	...
AZ61A-F	6.5	1.0	0.15	...	...	...	...	...	...
AZ80A-T5	8.5	0.5	0.12	...	...	...	...	...	...
HM31A-F	...	...	1.20	...	...	...	3.0	...	...
M1A-F	...	...	1.20	...	...	...	...	...	...
ZK40A-T5	...	4.0	...	...	0.45	...	...	...	...
ZK60A-F	...	5.5	...	...	0.45	...	...	...	...
Sheet and Plate									
AZ31B-H24	3.0	1.0	0.20	...	...	...	...	...	...
AZ31C-H24	3.0	1.0	0.15	...	...	...	...	...	...
HK31A-H24	...	...	...	...	0.7	...	3.3	...	...
HM21A-T8	...	...	0.80	...	...	...	2.0	...	...

^a All manganese values are minimum.^b High-purity alloy, Ni, Fe, and Cu severely restricted.^c 0.30 per cent maximum residual copper is allowed.^d For battery applications.Source: *Metals Handbook*, 9th edition, Vol. 2, American Society for Metals.

Table 7b. Typical Room-Temperature Mechanical Properties of Magnesium Alloys

Alloy	Tensile Strength (ksi)	Yield Strength			Elongation in 2 in. (%)	Shear Strength (ksi)	Hardness Rockwell B ^a
		Tensile (ksi)	Compressive (ksi)	Bearing (ksi)			
Sand and Permanent Mold (Gravity Die) Castings							
AM100A-T61	40	22	22	68	1	...	69
AZ63A-T6	40	14	14	44	12	18	55
AZ81A-T4	40	12	12	35	15	21	55
AZ91C-T6	40	21	21	52	6	21	70
AZ91E-T6 ^b	40	21	21	52	6	21	70
AZ92A-T6	40	22	22	65	3	21	81
EZ33A-T5	23	16	16	40	3	20	50
HK31A-T6	32	15	15	40	8	21	55
HZ32A-T6	27	13	13	37	4	20	55
K1A-F	26	8	8	18	19	8	...
QE22A-T6	38	28	28	...	3	...	80
QH21A-T6	40	30	30	...	4	22	...
ZE41A-T5	30	20	20	51	4	23	62
ZE63A-T6	44	28	28	...	10	...	60-85
ZH62A-T5	35	22	22	49	4	23	70
ZK51A-T5	30	20	20	51	4	22	62
ZK61A-T6	45	28	28	...	10	...	...
WE54A-F	40	29	29	...	4	...	...
Pressure Die Castings							
AZ91A-F	34	23	23	...	3	20	63
AZ91B-FAZ91B-F ^c	34	23	23	...	3	20	63
AZ91D-F ^b	34	23	23	...	3	20	63
AM60A-F	32	19	19	...	8	...	...
AM60B-F ^b	32	19	19	...	8	...	...
AS41A-F ^d	31	20	20	...	6	...	...
Extruded Bars and Shapes							
AZ10A-F	35	21	10	...	10	...	...
AZ31B-F	38	29	14	33	15	19	49
AZ31C-F	38	29	14	33	15	19	49
AZ61A-F	45	33	19	41	16	20	60
AZ80A-T5	55	40	35	...	7	24	82
HM31A-F	42	33	27	50	10	22	...
M1A-F	37	26	12	28	12	18	44
ZK40A-T5	40	37	20	...	4	...	...
ZK60A-F	51	41	36	59	11	26	88
Sheet and Plate							
AZ31B-H24	42	32	26	47	15	23	73
AZ31C-H24	42	32	26	47	15	23	73
HK31A-H24	38	30	23	41	9	...	68
HM21A-T8	34	25	19	39	11	18	...

^a 500 kg load, 10-mm ball.^b High-purity alloy, Ni, Fe, and Cu severely restricted.^c 0.30 per cent maximum residual copper is allowed.^d For battery applications.Source: *Metals Handbook*, 9th edition, Vol. 2, American Society for Metals.

Nickel and Nickel Alloys

Nickel is a white metal, similar in some respects to iron but with good oxidation and corrosion resistances. Nickel and its alloys are used in a variety of applications, usually requiring specific corrosion resistance or high strength at high temperature. Some nickel alloys exhibit very high toughness; others have very high strength, high proportional limits, and high moduli compared with steel. Commercially, pure nickel has good electrical, magnetic, and magnetostrictive properties. Nickel alloys are strong, tough, and ductile at cryogenic temperatures, and several of the so-called nickel-based superalloys have good strength at temperatures up to 2000 degrees F.

Most wrought nickel alloys can be hot and cold-worked, machined, and welded successfully; an exception is the most highly alloyed nickel compound—forged nickel-based superalloys—in which these operations are more difficult. The casting alloys can be machined or ground, and many can be welded and brazed.

There are five categories into which the common nickel-based metals and alloys can be separated: the pure nickel and high nickel (over 94 per cent Ni) alloys; the nickel–molybdenum and nickel–molybdenum–chromium superalloys, which are specifically for corrosive or high-temperature, high-strength service; the nickel–molybdenum–chromium–copper alloys, which are also specified for corrosion applications; the nickel–copper (Monel) alloys, which are used in actively corrosive environments; and the nickel–chromium and nickel–chromium–iron superalloys, which are noted for their strength and corrosion resistance at high temperatures.

Descriptions and compositions of some commonly used nickel and high nickel alloys are shown in Table 8.

Titanium and Titanium Alloys

Titanium is a gray, light metal with a better strength-to-weight ratio than any other metal at room temperature, and is used in corrosive environments or in applications that take advantage of its light weight, good strength, and nonmagnetic properties. Titanium is available commercially in many alloys, but multiple requirements can be met by a single grade of the commercially pure metal. The alloys of titanium are of three metallurgical types: alpha, alpha–beta, and beta, with these designations referring to the predominant phases present in the microstructure.

Titanium has a strong affinity for hydrogen, oxygen, and nitrogen gases, which tend to embrittle the material; carbon is another embrittling agent. Titanium is outstanding in its resistance to strongly oxidizing acids, aqueous chloride solutions, moist chlorine gas, sodium hypochlorite, and seawater and brine solutions. Nearly all nonaircraft applications take advantage of this corrosion resistance. Its uses in aircraft engine compressors and in airframe structures are based on both its high corrosion resistance and high strength-to-weight ratio.

Procedures for forming titanium are similar to those for forming stainless steel. Titanium and its alloys can be machined and abrasive ground; however, sharp tools and continuous feed are required to prevent work hardening. Tapping is difficult because the metal galls.

Titanium castings can be produced by investment or graphite mold methods; however, because of the highly reactive nature of the metal in the presence of oxygen, casting must be done in a vacuum.

Generally, titanium is welded by gas-tungsten arc or plasma arc techniques, and the key to successful welding lies in proper cleaning and shielding. The alpha–beta titanium alloys can be heat treated for higher strength, but they are not easily welded. Beta and alpha–beta alloys are designed for formability; they are formed in the soft state, and then heat treated for high strength.

The properties of some wrought titanium alloys are shown in Table 9.

Table 8. Common Cast and Wrought Nickel and High Nickel Alloys — Designations, Compositions, Typical Properties, and Uses

UNS Designation	Description and Common Name	Nominal Composition (Weight %)	Typical Room-Temperature Properties			Form	Typical Uses
			Tensile (ksi)	0.2% Yield (ksi)	Elong. (%)		
N02200	Commercially pure Ni (Nickel 200)	99.5 Ni	67	22	47	Wrought	Food processing and chemical equipment.
N04400	Nickel-copper alloy (Monel 400)	65 Ni, 32 Cu, 2 Fe	79	30	48	Wrought	Valves, pumps, shafts, marine fixtures and fasteners, electrical and petroleum refining equipment.
N05500	Age-hardened Ni-Cu alloy (Monel K 500)	65 Ni, 30 Cu, 2 Fe, 3 Al + Ti	160	111	24	Wrought	Pump shafts, impellers, springs, fasteners, and electronic and oil well components.
N06002	Ni-Cr Alloy (Hastelloy X)	60 Ni, 22 Cr, 19 Fe, 9 Mo, 0.6 W	114	52	43	Wrought	Turbine and furnace parts, petrochemical equipment.
N06003	Ni-Cr alloy (Nichrome V)	80 Ni, 20 Cr	100	60	30	Wrought	Heating elements, resistors, electronic parts.
N06333	Ni-Cr alloy (RA 333)	48 Ni, 25 Cr, 18 Fe, 3 Mo, 3 W, 3 Co	100	50	50	Wrought	Turbine and furnace parts.
N06600	Ni-Cr alloy (Inconel 600)	75 Ni, 15 Cr, 10 Fe	90	36	47	Wrought	Chemical, electronic, food processing and heat treating equipment; nuclear steam generator tubing.
N06625	Ni-Cr alloy (Inconel 625)	61 Ni, 21 Cr, 2 Fe, 9 Mo, 4 Nb	142	86	42	Wrought	Turbine parts, marine and chemical equipment.
N07001	Age-hardened Ni-Cr alloy (Waspalloy)	58 Ni, 20 Cr, 14 Co, 4 Mo, 3 Al, 1.3 Ti, B, Zr	185	115	25	Wrought	Turbine parts.
N07500	Age-hardened Ni-Cr alloy (Udimet 500)	52 Ni, 18 Cr, 19 Co, 4 Mo, 3 Al, 3 Ti, B, Zr	176	110	16	Wrought & Cast	Turbine parts.

Table 8. (Continued) Common Cast and Wrought Nickel and High Nickel Alloys — Designations, Compositions, Typical Properties, and

UNS Designation	Description and Common Name	Nominal Composition (Weight %)	Typical Room-Temperature Properties			Form	Typical Uses
			Tensile (ksi)	0.2% Yield (ksi)	Elong. (%)		
N07750	Age-hardened Ni-Cr alloy (Inconel X-750)	73 Ni, 16 Cr, 7 Fe, 2.5 Ti, 1 Al, 1 Nb	185	130	20	Wrought	Turbine parts, nuclear reactor springs, bolts, extrusion dies, forming tools.
N08800	Ni-Cr-Fe alloy (Incoloy 800)	32 Ni, 21 Cr, 46 Fe, 0.4 Ti, 0.4 Al	87	42	44	Wrought	Heat exchangers, furnace parts, chemical and power plant piping.
N08825	Ni-Cr-Fe alloy (Incoloy 825)	42 Ni, 22 Cr, 30 Fe, 3 Mo, 2 Cu, 1 Ti, Al	91	35	50	Wrought	Heat treating and chemical handling equipment.
N09901	Age-hardened Ni-Cr-Fe alloy (Incoloy 901)	43 Ni, 12 Cr, 36 Fe, 6 Mo, 3 Ti + Al, B	175	130	14	Wrought	Turbine parts.
N10001	Ni-Mo alloy (Hastelloy B)	67 Ni, 28 Mo, 5 Fe	121	57	63	Wrought	Chemical handling equipment.
N10004	Ni-Cr-Mo alloy (Hastelloy W)	59 Ni, 5 Cr, 25 Mo, 5 Fe, 0.6 V	123	53	55	Wrought	Weld wire for joining dissimilar metals, engine repair and maintenance.
N10276	Ni-Cr-Mo alloy (Hastelloy C-276)	57 Ni, 15 Cr, 16 Mo, 5 Fe, 4 W, 2 Co	116	52	60	Wrought	Chemical handling equipment.
N13100	Ni-Co alloy (IN 100)	60 Ni, 10 Cr, 15 Co, 3 Mo, 5.5 Al, 5 Ti, 1 V, B, Zr	147	123	9	Cast	Turbine parts.

Table 9. Mechanical Properties of Wrought Titanium Alloys

Nominal Composition (%)	Condition	Tensile Strength (ksi)	Room Temperature		Reduction in Area (%)
			Yield Strength (ksi)	Elongation (%)	
Commercially Pure					
99.5 Ti	Annealed	48	35	30	55
99.2 Ti	Annealed	63	50	28	50
99.1 Ti	Annealed	75	65	25	45
99.0 Ti	Annealed	96	85	20	40
99.2 Ti ^a	Annealed	63	50	28	50
98.9 ^b	Annealed	75	65	25	42
Alpha Alloys					
5 Al, 2.5 Sn	Annealed	125	117	16	40
5 Al, 2.5 Sn (low O ₂)	Annealed	117	108	16	...
Near Alpha Alloys					
8 Al, 1 Mo, 1 V	Duplex annealed	145	138	15	28
11 Sn, 1 Mo, 2.25 Al, 5.0 Zr, 1 Mo, 0.2 Si	Duplex annealed	160	144	15	35
6 Al, 2 Sn, 4 Zr, 2 Mo	Duplex annealed	142	130	15	35
5 Al, 5 Sn, 2 Zr, 2 Mo, 0.25 Si	975°C (1785°F) (½ h), AC 595°C (1100°F)(2 h), AC	152	140	13	...
6 Al, 2 Nb, 1 Ta, 1 Mo	As rolled 2.5 cm (1 in.) plate	124	110	13	34
6 Al, 2 Sn, 1.5 Zr, 1 Mo, 0.35 Bi, 0.1 Si	Beta forge + duplex anneal	147	137	11	...
Alpha-Beta Alloys					
8 Mn	Annealed	137	125	15	32
3 Al, 2.5 V	Annealed	100	85	20	...
6 Al, 4 V	Annealed	144	134	14	30
	Solution + age	170	160	10	25
6 Al, 4 V (low O ₂)	Annealed	130	120	15	35
6 Al, 6 V, 2 Sn	Annealed	155	145	14	30
	Solution + age	185	170	10	20
7 Al, 4 Mo	Solution + age	160	150	16	22
6 Al, 2 Sn, 4 Zr, 6 Mo	Solution + age	184	170	10	23
6 Al, 2 Sn, 2 Zr, 2 Mo, 2 Cr, 0.25 Si	Solution + age	185	165	11	33
10 V, 2 Fe, 3 Al	Solution + age	185	174	10	19
Beta Alloys					
13 V, 11 Cr, 3 Al	Solution + age	177	170	8	...
	Solution + age	185	175	8	...
8 Mo, 8 V, 2 Fe, 3 Al	Solution + age	190	180	8	...
3 Al, 8 V, 6 Cr, 4 Mo, 4 Zr	Solution + age	210	200	7	...
	Annealed	128	121	15	...
11.5 Mo, 6 Zr, 4.5 Sn	Solution + age	201	191	11	...

^a Also contains 0.2 Pd.^b Also contains 0.8 Ni and 0.3 Mo.

Source: Titanium Metals Corp. of America and RMI Co.

Copper-Silicon and Copper-Beryllium Alloys

Everdur.—This copper-silicon alloy is available in five slightly different nominal compositions for applications that require high strength, good fabricating and fusing qualities, immunity to rust, free-machining and a corrosion resistance equivalent to copper. The following table gives the nominal compositions and tensile strengths, yield strengths, and per cent elongations for various tempers and forms.

Table 10. Nominal Composition and Properties of Everdur

Desig. No.	Nominal Composition					Temper ^a	Strength		Elongation (%)
	Cu	Si	Mn	Pb	Al		Tensile (ksi)	Yield (ksi)	
655	95.80	3.10	1.10	...	...	A	52	15	35 ^b
						HRA	50	18	40
						CRA	52	18	35
						CRHH	71	40	10
						CRH	87	60	3
						H	70 to 85	38 to 50	17 to 8 ^b
651	98.25	1.50	0.25	...	...	AP	38	10	35
						HP	50	40	7
						XHB	75 to 85	45 to 55	8 to 6 ^b
661	95.60	3.00	1.00	0.40	...	A	52	15	35 ^b
						H	85	50	13 to 8 ^b
6552	94.90	4.00	1.10	...	...	AC	45	...	15
637	90.75	2.00	...	...	7.25	A	75 to 90	37.5 to 45	12 to 9 ^b

^a Symbols used are: HRA for hot-rolled and annealed tank plates; CRA for cold-rolled sheets and strips; CRHH for cold-rolled half hard strips; and CRH for cold-rolled hard strips. For round, square, hexagonal, and octagonal rods: A for annealed; H for hard; and XHB for extra-hard bolt temper (in coils for cold-heading). For pipe and tube: AP for annealed; and HP for hard.

^b Per cent elongation in 4 times the diameter or thickness of the specimen. All other values are per cent elongation in 2 inches.

Designation numbers are those of the American Brass Co.

The values given for the tensile strength, yield strength, and elongation are all minimum values. Where ranges are shown, the first values given are for the largest diameter or largest size specimens. Yield strength values were determined at 0.50 per cent elongation under load.

Copper-Beryllium Alloys.—Alloys of copper and beryllium present health hazards. Particles produced by machining may be absorbed into the body through the skin, the mouth, the nose, or an open wound, resulting in a condition requiring immediate medical attention. Working of these alloys requires protective clothing or other shielding in a monitored environment. Copper-beryllium alloys involved in a fire give off profuse toxic fumes that must not be inhaled.

These alloys contain copper, beryllium, cobalt, and silver, and fall into two groups. One group whose beryllium content is greater than one per cent is characterized by its high strength and hardness and the other, whose beryllium content is less than one per cent, by its high electrical and thermal conductivity. The alloys have many applications in the electrical and aircraft industries or wherever strength, corrosion resistance, conductivity, non-magnetic and nonsparking properties are essential. Beryllium copper is obtainable in the form of strips, rods and bars, wire, platers, bars, billets, tubes, and casting ingots.

Composition and Properties: Table 11 lists some of the more common wrought alloys and gives some of their mechanical properties.

Table 11. Wrought Copper-Beryllium Properties

Alloy ^a	Form	Temper ^b	Heat Treatment	Tensile Strength (ksi)	Yield Strength 0.2% Offset (ksi)	Elongation in 2 in. (%)	
25	Rod, Bar, and Plate	A	...	60-85	20-30	35-60	
		½ H or H	...	85-130	75-105	10-20	
		AT	3 hr at 600°F or mill heat treated	165-190	145-175	3-10	
		½ HT or HT	2 hr at 600°F or mill heat treated	175-215	150-200	2-5	
	Wire	A	...	58-78	20-35	35-55	
		¼ H	...	90-115	70-95	10-35	
		½ H	...	110-135	90-110	5-10	
		¾ H	...	130-155	110-135	2-8	
		AT	3 hr at 600°F	165-190	145-175	3-8	
		¼ HT	2 hr at 600°F	175-205	160-190	2-5	
165	Rod, Bar, and Plate	A	...	60-85	20-30	35-60	
		½ H or H	...	85-130	75-105	10-20	
		AT	3 hr at 650°F or mill heat treated	150-180	125-155	4-10	
		½ HT or HT	2 hr at 650°F or mill heat treated	165-200	135-165	2-5	
	10	Rod, Bar, and Plate	A	...	35-55	20-30	20-35
			½ H or H	...	65-80	55-75	10-15
			AT	3 hr at 900°F or mill heat treated	100-120	80-100	10-25
50	Rod, Bar, and Plate	½ HT or HT	2 hr at 900°F or mill heat treated	110-130	100-120	8-20	
		50	Rod, Bar, and Plate	A	...	35-55	20-30	20-35
½ H or H	...	65-80		55-75	10-15		
AT	3 hr at 900°F or mill heat treated	100-120	80-100	10-25			
½ HT or HT	2 hr at 900°F or mill heat treated	110-130	100-120	8-20			
35	Rod, Bar, and Plate	A	...	35-55	20-30	20-35	
		½ H or H	...	65-80	55-75	10-15	
		AT	3 hr at 900°F or mill heat treated	100-120	80-100	10-25	
½ HT or HT	2 hr at 900°F or mill heat treated	110-130	100-120	8-20			

^a Composition (in per cent) of alloys is as follows: alloy 25: 1.80-2.05 Be, 0.20-0.35 Co, balance Cu; alloy 165: 1.6-1.8 Be, 0.20-0.35 Co, balance Cu; alloy 10: 0.4-0.7 Be, 2.35-2.70 Co, balance Cu; alloy 50, 0.25-0.50 Be, 1.4-1.7 Co, 0.9-1.1 Ag, balance Cu; alloy 35, 0.25-0.50 Be, 1.4-1.6 Ni, balance Cu.

^b Temper symbol designations: A, solution annealed; H, hard; HT, heat-treated from hard; At, heat-treated from solution annealed.