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Wrought and Cast Copper Alloys

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1. **Scope**—For convenience, this SAE Information Report is presented in two parts as shown below. To avoid repetition, however, data applicable to both wrought and cast alloys is included only in Part 1.

Part I—Wrought Copper and Copper Alloys

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Part II—Cast Copper Alloys

Types of Casting Alloys
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2. References

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest version of SAE publications shall apply.

2.1.1 SAE PUBLICATION—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J463—Wrought Copper and Copper Alloys

2.1.2 ASTM PUBLICATIONS—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM B 3—Specification for Soft or Annealed Copper Wire

ASTM B 16—Specification for Free-Cutting Brass Rod, Bar, and Shapes for Use in Screw Machines

ASTM B 21—Specification for Naval Brass Rod, Bar, and Shapes

ASTM B 36—Specification for Brass Plate, Sheet, Strip, and Rolled Bar

ASTM B 68—Specification for Seamless Copper Tube, Bright Annealed

ASTM B 75—Specification for Seamless Copper Tube

ASTM B 97—Specification for Copper-Silicon Alloy Plate, Sheet, Strip, and Rolled Bar for General Purposes

ASTM B 98—Specification for Copper-Silicon Alloy Rod, Bar, and Shapes

ASTM B 103—Specification for Phosphor Bronze Plate, Sheet, Strip, and Rolled Bar

ASTM B 111—Specification for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock

ASTM B 121—Specification for Leaded Brass Plate, Sheet, Strip, and Rolled Bar

ASTM B 122—Specification for Copper-Nickel-Tin Alloy, Copper-Nickel-Zinc Alloy (Nickel Silver) and Copper-Nickel Alloy Plate, Sheet, Strip, and Rolled Bar

ASTM B 133—Specification for Copper Rod, Bar, and Shapes

ASTM B 134—Specification for Brass Wire

ASTM B 135—Specification for Seamless Brass Tube

ASTM B 138—Specification for Manganese Bronze Rod, Bar, and Shapes

ASTM B 139—Specification for Phosphor Bronze Rod, Bar, and Shapes

ASTM B 150—Specification for Aluminum Bronze Rod, Bar, and Shapes

ASTM B 151—Specification for Copper-Nickel-Zinc Alloy (Nickel Silver) and Copper-Nickel Rod and Bar

ASTM B 152—Specification for Copper Sheet, Strip, Plate and Rolled Bar

ASTM B 154—Method of Mercurous Nitrate Test for Copper and Copper Alloys

ASTM B 159—Specification for Phosphor Bronze Wire

ASTM B 169—Specification for Aluminum Bronze Plate, Sheet, Strip, and Rolled Bar

ASTM B 171—Specification for Copper-Alloy Condenser Tube Plates

ASTM B 194—Specification for Copper-Beryllium Alloy Plate, Sheet, Strip, and Rolled Bar

ASTM B 196—Specification for Copper-Beryllium Alloy Rod and Bar

ASTM B 280—Specification for Seamless Copper Tube for Air Conditioning and Refrigeration Field Service

ASTM B 283—Specification for Copper and Copper-Alloy Die Forgings (Hot-Pressed)

ASTM B 301—Specification for Free-Cutting Copper Rod and Bar

ASTM B 441—Specification for Copper-Cobalt-Beryllium and Copper-Nickel-Beryllium Rod and Bar

ASTM B 453—Specification for Copper-Zinc-Lead Alloy (Leaded-Brass) Rod

ASTM B 534—Specification for Copper-Cobalt-Beryllium Alloy and Copper-Nickel-Beryllium Alloy Plate, Sheet, Strip, and Rolled Bar

3. Part I—wrought Copper And Copper Alloys—Factors influencing the uses of wrought copper and copper alloys concern electrical conductivity, thermal conductivity, machinability, formability, fatigue characteristics, strength, corrosion resistance, the ease with which alloys can be joined, and the fact that these materials are nonmagnetic. Copper and its alloys also have a wide range of rich, pleasing colors. The only other metal with such distinctive coloring is gold. These materials are all easily finished by buffing, scratch brushing, plating or chemically coloring, or clear protective coating systems.

When it is desired to improve one or more of the important properties of copper, alloying often solves the problem. A wide range of alloys, therefore, has been developed and commercially employed, such as the high copper alloys, brasses, leaded brasses, tin bronzes, heat treatable alloys, copper-nickel alloys, nickel silvers, and special bronzes.

The various types of copper and the principal alloys are listed in Tables I and 3, along with information describing composition, fabricating properties, and applications.

- 3.1 Types of Wrought Copper**—Copper UNS Nos. C11000, C11100, C11300, C11400, C11500, and C11600¹ are either electrolytically or fire-refined, cast in the form of refinery shapes, containing a controlled amount of oxygen for the purpose of obtaining a level set on the top of the casting. It generally contains 0.01–0.04% oxygen, which exists as a coppercuprous oxide eutectic surrounding the crystals of copper. Within these limits, the oxygen has only a very slight effect on the electrical, mechanical, and physical properties of copper. Because of the oxidizing effect of oxygen on impurities, its presence in copper indicates a reduction or elimination of certain impurities which would otherwise have adverse effects on conductivity.

Copper UNS No. C10200 is electrolytically refined and specially produced to be free from cuprous oxide although it is made without the use of residual metallic or metalloidal deoxidizers. Because of its freedom from residual deoxidizers, it has high electrical conductivity.

Copper UNS Nos. C12000 and C12200 are cast in the form of refinery shapes, free from cuprous oxide, produced through the use of metallic or metalloidal deoxidizers. Because it is necessary to use some excess of reducing agent, the electrical and thermal conductivity of the copper is lowered, and this fact should be considered when high conductivity is needed.

Copper UNS Nos. C10200, C12000 and C12200 possess only slightly different mechanical properties from the C11XXX types. They differ little in respect to tensile strength when cold worked to similar extents, but do have somewhat higher ductility and also are not normally subject to hydrogen embrittlement.

- 3.2 Electrical Conductivity**—The greatest single area of use for copper itself results from the high electrical conductivity of the metal. The combination of the property of high electrical conductivity with ease of forming and high corrosion resistance makes copper the preferred material for current-carrying members. The conductivity of copper for electrical conductors is 101% IACS (see Table 2) in the annealed or soft condition. The tensile strength of the soft copper, 220 MPa (32 ksi) can be increased to 345/380 MPa (50/55 ksi) by cold rolling, in which condition the electrical conductivity is decreased to about 97%. Heating such copper above 200 °C for an extended period of time will soften it to a tensile strength of 205/240 MPa (30/35 ksi).

1. Since the nomenclature used in the nonferrous metals trade is not always consistent, copper and copper base alloys are referenced by specification numbers described in SAE J463.

TABLE 1—GENERAL INFORMATION—NAME, NOMINAL COMPOSITION, AND COMPARABLE STANDARDS OF WROUGHT COPPER ALLOYS

Copper or Copper Alloy UNS No. ^a	Name ^b	Nominal Composition Percent by Weight		SAE No.	ASTM Standard No. ^c	Former SAE No.
		Cu	Other			
C10200	Oxygen free copper (OF)	99.9	—	CA102	B75, B152, B280	—
C11000	Electrolytic tough pitch copper (ETP)	99.9	—	CA110	B3, B133, B152, B283	71, 83
C11100	Electrolytic tough pitch, anneal resistant copper	99.9	(Trace elements)	CA111	—	71
C11300	Tough pitch copper with Ag (STP)	99.9	0.03 Ag	CA113	B152	71
C11400	Tough pitch copper with Ag (STP)	99.9	0.04 Ag	CA114	B152	71
C11500	Tough pitch copper with Ag (STP)	99.9	0.06 Ag	CA115	B152	—
C11600	Tough pitch copper with Ag (STP)	99.9	0.09 Ag	CA116	B152	71
C12000	Phosphorus deoxidized copper (DLP)	99.9	0.0008 P	CA120	B68, B75, B152, B280	75
C12200	Phosphorus deoxidized copper (DHP)	99.9	0.02 P	CA122	B68, B75, B152, B280	—
C14500	Phosphorus deoxidized tellurium copper (DPTE)	99.5	0.5 Te, 0.008 P	CA145	B283, B301	—
C14700	Sulfur bearing copper	99.7	0.3 S	CA147	B301	—
C15000	Zirconium copper	99.8	0.15 Zn	CA150	B301	—
C16200	Cadmium copper	99.0	1 Cd	CA162	—	—
C17000	Beryllium copper	98.0	1.7 Be	CA170	B194	—
C17200	Beryllium copper	98.0	1.9 Be	CA172	B194, B196	—
C17500	Beryllium copper	97.0	0.5 Be, 2.5 Co	CA175	B441, B534	—
C17600	Beryllium copper	97.0	0.4 Be, 1.5 Co, 1 Ag	CA176	B441	—
C18400	Chromium copper	99.0	0.8 Cr	CA184	—	—
C18700	Leaded copper	99.0	1 Pb	CA187	B301	—
C19200	High copper alloy	99.0	1 Fe, 0.03 P	CA192	B111	—
C21000	Gilding, 95%	95.0	5 Zn	CA210	B36	—
C22000	Commercial bronze, 90%	90.0	10 Zn	CA220	B36, B135	—
C23000	Red brass, 85%	85.0	15 Zn	CA230	B36, B135	74D, 79A
C24000	Low brass, 80%	80.0	20 Zn	CA240	B36	79B
C26000	Cartridge brass, 70%	70.0	30 Zn	CA260	B36, B134, B135	70A, 74C, 80A
C26800	Yellow brass, 66%	66.0	34 Zn	CA268	B36	70C
C27000	Yellow brass, 65%	65.0	35 Zn	CA270	B134	80B
C33000	Low leaded brass, (tube)	66.0	34 Zn, 0.5 Pb	CA330	B135	74B
C33100	Leaded brass	66.0	33 Zn, 1 Pb	CA331	—	—
C34200	High leaded brass	65.0	33 Zn, 2 Pb	CA342	B121	—
C34500	Leaded brass	63.0	35 Zn, 2 Pb	CA345	B453	—
C35000	Medium leaded brass, 62%	63.0	36 Zn, 1 Pb	CA350	B121, B453	—
C36000	Free cutting brass	62.0	35 Zn, 3 Pb	CA360	B16	72
C37700	Forging brass	60.0	38 Zn, 2 Pb	CA377	B283	88
C46400	Naval brass, unhibited	60.0	39 Zn, 0.8 Sn	CA464	B21, B283	73
C46500	Naval brass, arsenical	60.0	40 Zn, 0.5 As	CA465	—	—
C46600	Naval brass, antimonial	60.0	40 Zn, 0.5 Sb	CA466	—	—
C46700	Naval brass, phosphorized	60.0	40 Zn, 0.5 P	CA467	—	—
C51000	Phosphor bronze, 5% A	95.0	5 Sn, 0.2 P	CA510	B103, B139, B159	77A, 81
C51100	Phosphor bronze	96.0	4 Sn, 0.2 P	CA511	B103	—
C52100	Phosphor bronze, 8% C	92.0	8 Sn, 0.2 P	CA521	B103	77C
C52400	Phosphor bronze, 10% D	90.0	10 Sn, 0.2 P	CA524	B103	—
C54400	Phosphor bronze, B-2	88.0	4 Sn, 4 Zn, 4 Pb	CA544	B103, B139	—
C60800	Aluminum bronze	95.0	5 Al	CA608	B111	—
C61400	Aluminum bronze, D	91.0	7 Al, 2 Fe	CA614	B150, B169	701D
C61800	Aluminum bronze	89.0	10 Al, 1 Fe	CA618	—	—
C62300	Aluminum bronze	88.0	9 Al, 3 Fe	CA623	B150, B283	701B
C62400	Aluminum bronze	86.0	11 Al, 3 Fe	CA624	—	—
C63000	Aluminum bronze	82.0	10 Al, 3 Fe, 5 Ni	CA630	B150, B283	701C
C64200	Aluminum silicon bronze	91.0	7 Al, 2 Si	CA642	B150, B283	—
C65500	High silicon bronze, A	97.0	3 Si	CA655	B97, B98, B283	—

(Table continued on next page)

TABLE 1—GENERAL INFORMATION—NAME, NOMINAL COMPOSITION, AND COMPARABLE STANDARDS OF WROUGHT COPPER ALLOYS (CONTINUED)

Copper or Copper Alloy UNS No. ^a	Name ^b	Nominal Composition Percent by Weight		SAE No.	ASTM Standard No. ^c	Former SAE No.
		Cu	Other			
C67000	Manganese bronze, B	65.0	24 Zn, 4 Mn, 4 Al, 3 Fe	CA670	B138	—
C67300	Manganese bronze	60.0	34 Zn, 3 Mn, 2 Pb, 1 Si	CA673	—	—
C67400	Manganese bronze	58.0	37 Zn, 3 Mn, 1 Al, 1 Si	CA674	—	—
C67500	Manganese bronze, A	58.0	40 Zn, 0.3 Mn, 1 Fe, 1 Sn	CA675	B138	—
C70600	Copper nickel, 10%	90.0	10 Ni	CA706	B111, B171	—
C71000	Copper nickel, 20%	80.0	20 Ni	CA710	B111, B122	—
C71500	Copper nickel, 30%	70.0	30 Ni	CA715	B111, B122, B171	—
C75200	Nickel silver, 65–18	65.0	18 Ni, 17 Zn	CA752	B122, B151	—
C77000	Nickel silver, 55–18	55.0	18 Ni, 27 Zn	CA770	B122, B151	—

^a Unified numbering system.

^b Alloy names are shown for information only, and should not be used. Use the appropriate designation only. (Example: Copper Alloy UNS No. C21000 Copper Alloy).

^c ASTM Standard numbers listed are only those forms or shapes covered in the specification *ed.* for wrought copper or copper alloy.

TABLE 2A—TYPICAL PHYSICAL PROPERTIES OF WROUGHT COPPER ALLOYS

Metric (SI) Units											
Copper or Copper Alloy UNS No.	Melting Point °C		Density g/cm ³ at 20°C	Coefficient of Thermal Expansion/°C × 10 ⁻⁵			Thermal Conductivity W m · K	Electrical Resistivity nΩ · m ^a	Specific Heat J/kg · K	Modulus GPa	
	Liquidus	Solidus		20–100°C	20–200°C	20–300°C				Elastic	Rigid
C10200	1083	—	8.94	1.70	1.73	1.77	391	17.1	385	117	44
C11000	1083	1065	8.91	1.70	1.73	1.77	391	17.1	385	117	44
C11100	1083	1065	8.91	1.70	1.73	1.77	388	17.2	385	117	44
C11300	1082	—	8.91	1.70	1.73	1.77	388	17.2	385	117	44
C11400	1082	—	8.91	1.70	1.73	1.77	388	17.2	385	117	44
C11500	1082	—	8.91	1.70	1.73	1.77	388	17.2	385	117	44
C11600	1082	—	8.91	1.70	1.73	1.77	388	17.2	385	117	44
C12000	1083	—	8.94	1.70	1.73	1.77	386	17.6	385	117	44
C12200	1083	—	8.94	1.70	1.73	1.77	339	20.3	385	117	44
C14500	1075	1051 ^b	8.94	1.71	1.74	1.78	355	18.6	385	117	44
C14700	1076	1067	8.94	1.70	1.73	1.77	374	18.1	385	117	44
C15000	1080	980	8.89	1.63	1.80	2.01	367 ^d	18.6 ^d	385	117	44
C16200	1076	1030	8.89	1.70	1.73	1.77	360	19.2	385	117	44
C17000	980	865	8.26	1.67	1.70	1.78	118	76.8	420	131	50
C17200	980	865	8.26	1.67	1.70	1.78	118	76.8	420	131	50
C17500	1075	1070	8.75	—	1.76	—	234	37.9	420	124	47
C17600	1054	1010	8.75	—	—	—	—	31.6	—	124	47
C18400	1075	1070	8.89	1.76	—	—	324 ^d	21.6 ^d	385	131	50
C18700	1080	953 ^c	8.94	—	—	1.76	377	17.9	385	117	44
C19200	1084	—	8.87	1.62	—	—	216	34.5	385	117	44
C21000	1065	1050	8.86	—	—	1.81	234	30.8	377	117	44
C22000	1045	1020	8.80	—	—	1.84	189	39.2	377	117	44
C23000	1025	990	8.75	—	—	1.87	159	46.6	377	117	44
C24000	1000	965	8.67	—	—	1.91	140	53.9	377	110	41
C26000	955	915	8.53	—	—	1.99	121	61.6	377	110	41
C26800	930	905	8.47	—	—	2.03	116	63.9	377	103	39
C27000	930	905	8.47	—	—	2.03	116	63.9	377	103	39
C33000	940	905	8.50	—	—	2.02	116	66.3	377	103	39
C33100	940	905	8.50	—	—	2.02	116	66.3	377	103	39
C34200	910	885	8.47	—	—	2.02	116	66.3	377	103	39
C34500	915	885	8.45	—	—	2.03	119	66.3	—	69	—
C35000	915	895	8.47	—	—	2.03	116	66.3	377	97	37
C36000	900	885	8.50	—	—	2.05	116	66.3	377	97	37
C37700	895	880	8.44	—	—	2.07	119	63.9	377	103	39
C46400	900	885	8.41	—	—	2.12	116	66.3	377	103	39
C46500	900	885	8.41	—	—	2.12	116	66.3	377	103	39
C46600	900	885	8.41	—	—	2.12	116	66.3	377	103	39
C46700	900	885	8.41	—	—	2.12	116	66.3	377	103	39
C51000	1050	950	8.86	—	—	1.78	69	115.0	377	110	41
C51100	1060	975	8.86	—	—	1.78	83	87.0	377	110	41
C52100	1020	880	8.80	—	—	1.82	62	133.0	377	110	41
C52400	1000	845	8.78	—	—	1.84	50	157.0	377	110	41
C54400	1000	930	8.89	—	—	1.73	87	90.7	377	103	39
C60800	1063	1050	8.17	—	—	1.81	80	100.0	377	121	46
C61300	1045	1040	7.89	—	—	1.62	67	123.0	377	117	44
C61400	1045	1040	7.89	—	—	1.62	67	123.0	377	117	44
C61800	1045	1040	7.53	—	—	1.62	64	133.0	377	117	44
C62300	1045	1040	7.66	—	—	1.62	61	144.0	377	117	44
C62400	1040	1025	7.45	—	—	1.92	54	144.0	377	117	44
C63000	1054	1035	7.58	—	—	1.62	38	192.0	377	117	44
C64200	1005	985	7.69	—	—	1.81	45	186.0	377	110	41
C65500	1025	970	8.53	—	—	1.80	36	246.0	377	103	39
C67000	930	905	7.81	—	—	2.00	24	75.0	—	103	39
C67300	890	845	8.28	—	—	2.00	—	75.0	—	103	39
C67400	885	865	8.08	—	—	2.00	100	75.0	377	97	37
C67500	890	865	8.36	—	—	2.12	106	71.8	377	103	39
C70600	1150	1100	8.94	—	—	1.71	45	191.0	377	124	47
C71000	1200	1150	8.94	—	—	1.64	36	266.0	377	138	52
C71500	1240	1170	8.94	—	—	1.62	29	375.0	377	152	57
C75200	1110	1070	8.73	—	—	1.62	33	287.0	377	124	47
C77000	1055	—	8.70	—	—	1.67	29	314.0	377	124	47

^a See Table 2B for percent IACS electrical conductivity.^b Small amounts of tellurium-rich constituent remains liquid down to 490°C.^c Small amounts of lead-rich constituent remains liquid down to 325°C.^d After precipitation-hardening treatment.

TABLE 2B—TYPICAL PHYSICAL PROPERTIES OF WROUGHT COPPER ALLOYS

Customary Units												
Copper or Copper Alloy UNS No.	Melting Point, °F		Density ^a	Coefficient of Thermal Expansion ^b			Thermal Conductivity ^c	Electrical Resistivity ^d	Electrical Conductivity ^e	Thermal Capacity ^f	Modulus	
	Liquidus	Solidus		68–212°F	68–392°F	68–572°F					Elastic ^g	Rigid ^h
C10200	1981	—	.323	9.4	9.6	9.8	226	10.3	101	.092	17	6.4
C11000	1981	1949	.322	9.4	9.6	9.8	226	10.3	101	.092	17	6.4
C11100	1981	—	.322	9.4	9.6	9.8	224	10.3	101	.092	17	6.4
C11300	1981	—	.322	9.4	9.6	9.8	224	10.3	100	.092	17	6.4
C11400	1981	—	.322	9.4	9.6	9.8	224	10.4	100	.092	17	6.4
C11500	1981	—	.322	9.4	9.6	9.8	224	10.4	100	.092	17	6.4
C11600	1981	—	.322	9.4	9.6	9.8	224	10.4	99	.092	17	6.4
C12000	1981	—	.323	9.4	9.6	9.8	223	10.7	97	.092	17	6.4
C12200	1981	—	.323	9.4	9.5	9.8	196	12.2	85	.092	17	6.4
C14500	1960	1931 ⁱ	.323	9.4	9.6	9.8	205	10.9	95	.092	17	6.4
C14700	1970	1953	.323	9.4	9.6	9.8	216	10.9	95	.092	17	6.4
C15000	1979	—	.323	9.4	9.6	9.8	212 ^k	11.2 ^k	93 ^k	.092	17	6.4
C16200	1969	—	.321	9.4	9.6	9.8	208	11.9	87	.092	17	6.4
C17000	1800	1600	.298	9.3	9.4	9.9	—	47.2	22	—	19	7.3
C17200	1800	1600	.298	9.3	9.4	9.9	—	47.2	22	.100	19	7.3
C17500	1955	1885	.316	—	9.8	—	—	23.1	45	—	18	6.8
C17600	1930	1850	.316	—	9.8	—	—	19.0	50	—	18	6.8
C18400	1967	—	.321	9.4	9.6	9.8	187 ^k	13.0 ^k	80 ^k	.092	19	7.2
C18700	1976	1947 ⁱ	.323	9.4	9.6	9.8	218	10.6	98	.092	17	6.4
C19200	1983	—	.320	9.0	—	—	125	20.8	50	.092	17	6.4
C21000	1950	1920	.320	—	—	10.0	135	18.5	00	.090	17	6.4
C22000	1910	1870	.318	—	—	10.2	109	23.6	44	.090	17	6.4
C23000	1880	1810	.316	—	—	10.4	92	28.0	37	.090	17	6.4
C24000	1830	1770	.313	—	—	10.6	81	32.4	32	.090	16	6.0
C26000	1750	1680	.308	—	—	11.1	70	37.0	28	.090	16	6.0
C26800	1710	1660	.306	—	—	11.3	67	38.4	27	.090	15	5.6
C27000	1710	1660	.306	—	—	11.3	67	38.4	27	.090	15	5.6
C33000	1720	1660	.307	—	—	11.2	67	39.9	26	.090	15	5.6
C33100	1720	1660	.307	—	—	11.2	67	39.9	26	.090	15	5.6
C34200	1670	1630	.306	—	—	11.3	67	39.9	26	.090	15	5.6
C34500	1650	1625	.305	—	—	11.4	69	39.9	26	—	10	—
C35000	1650	1630	.305	—	—	11.4	67	39.9	26	.090	14	5.3
C36000	1650	1630	.307	—	—	11.4	67	39.9	26	.090	14	5.3
C37700	1640	1620	.305	—	—	11.5	69	38.4	27	.090	15	5.6
C46400	1650	1630	.304	—	—	11.8	67	39.9	26	.090	15	5.6
C46500	1650	1630	.304	—	—	11.8	67	39.9	26	.090	15	5.6
C46600	1650	1630	.304	—	—	11.8	67	39.9	26	.090	15	5.6
C46700	1650	1630	.304	—	—	11.8	67	39.9	26	.090	15	5.6
C51000	1920	1750	.320	—	—	9.9	40	69.1	15	.090	16	6.0
C51100	1945	1785	.320	—	—	9.9	48	52.0	20	.090	16	6.0
C52100	1880	1620	.318	—	—	10.1	36	79.8	13	.090	16	6.0
C52400	1830	1550	.317	—	—	10.2	29	94.3	11	.090	16	6.0
C54400	1830	1700	.321	—	—	9.6	50	54.6	19	.090	15	5.6
C60800	1945	1920	.295	—	—	10.0	46	60.0	17	.090	17.5	6.6
C61300	1915	1905	.285	—	—	9.0	39	74.1	14	.090	17	6.4
C61400	1915	1905	.285	—	—	9.0	39	74.1	14	.090	17	6.4
C61800	1910	1900	.274	—	—	9.0	37	79.8	13	—	17	—
C62300	1910	1890	.274	—	9.0	9.4	31	79.8	13	—	16	—
C62400	1910	1895	.274	—	9.0	9.2	34	79.8	13	—	16	—
C63000	1930	1890	.274	—	9.0	9.4	22	138.0	8	.090	17	6.4
C64200	1840	1800	.278	—	—	10.0	26	113.0	8	.090	16	6.0
C65500	1880	1780	.308	—	—	10.0	21	148.0	7	.090	15	5.6
C67000	1710	1665	.282	—	—	11.0	14	86.4	12	—	15	—
C67300	1620	1555	.299	—	—	11.0	—	86.4	12	—	15	—
C67400	1625	1550	.292	—	—	11.0	58	86.4	12	—	14	—
C67500	1630	1590	.302	—	—	11.8	61	43.2	24	.090	15	5.6
C70600	2100	2010	.323	—	—	9.5	26	115.0	9	.090	18	6.8
C71000	2192	2066	.323	—	—	9.1	21	160.0	6	.090	20	7.5
C71500	2260	2140	.323	—	—	9.0	17	225.0	5	.090	22	8.3
C75200	2030	1960	.316	—	—	9.0	19	173.0	6	.090	18	6.8
C77000	1930	—	.314	—	—	9.3	17	189.0	6	.090	18	6.8

^a lb/in³ at 68°F. See Table 2A for specific gravity (g/cm³ at 20°C).^b Per °F at temperature range indicated (multiply factor given by 10⁻⁶).^c Btu/ft²/ft h °F at 68°F.^d (Annealed) ohms (circular mil/ft) at 68°F.^e (Annealed) percent IACS at 68°F (volume basis).^f (Specific heat) Btu/lb/°F at 68°F.^g (Tension) psi (multiply factor given by 10⁶).^h Psi (multiply factor given by 10⁶).ⁱ Small amount of tellurium-rich constituent remains liquid down to 1575°F.^j Small amount of lead-rich constituent remains liquid down to 619°F.^k After precipitation-hardening heat treatment.

TABLE 3—FABRICATION PROPERTIES, OTHER CHARACTERISTICS AND TYPICAL USES

Copper or Copper Alloy UNS No.	Approximate Relative Suitability For Being, Worked ^a		Best Temperature For Hot Working, °C	Approximate Relative Suitability ^a For Being Joined By									Machineability ^c	Type of Chip ^b		Typical Uses	Characteristics
				Soldering	Brazing	Oxyacetylene Welding	Carbon Arc Welding	Gas Shielded Arc Welding	Coated Metal Arc Welding	Resistance Welding							
	Spot	Seam								Butt							
C10200	E	E	760–870	E	E	F	F	G	NR	NR	NR	G	20	L	Thermal and electrical conductors, electronic parts, glass-to-metal seals.	Oxygen-free 100% minimum electrical conductivity, excellent ductility, high purity, no out gassing. Not subject to hydrogen embrittlement. Designated for use where processing involves heating in a reducing atmosphere.	
C11000	E	E	760–870	E	G	NR	F	F	NR	NR	NR	G	20	L	Electrical wiring and components, radiator fins, gaskets, washers, cold heading wire, water defectors, heat plugs, clock cases, plating anodes, screen wire.	Minimum electrical conductivity 100%, highest electrical conductivity of any metal except silver, has very high ductility. Will embrittle when heated to redness in a reducing atmosphere.	
C11100	E	E	760–870	E	G	NR	F	F	NR	NR	NR	G	20	L	Radiator fins.	Has a softening temperature higher than the silver bearing coppers and electrolytic tough pitch copper.	
C11300	E	E	760–780	E	G	NR	F	F	NR	NR	NR	G	20	L	Commutator bars, segments, collector rings and contacts, core and fin stock for radiators.	Minimum electrical conductivity 98%. Resistance to softening increased by presence of silver. Effect increases with increased silver added. Higher silver-content copper used for continued exposure to somewhat higher temperature.	
C11400	E	E	760–780	E	G	NR	F	F	NR	NR	NR	G	20	L			
C11500	E	E	760–870	E	G	NR	F	F	NR	NR	NR	G	20	L			
C11600	E	E	760–870	E	G	NR	F	F	NR	NR	NR	G	20	L			
C12000	E	E	760–870	E	E	G	G	E	NR	NR	NR	G	20	L	Electrical conductors, applications involving welding or brazing.	Regarded as an alternate to Copper UNS No. C10200. More resistant to embrittlement than Copper UNS No. C11000 high electrical conductivity.	
C12200	E	E	760–870	E	E	G	G	E	NR	NR	NR	G	20	L	Tube, all types of hydraulic systems, fuel lines, vacuum lines, air conditioning, heat exchangers, anodes, air, gasoline, hydraulic and oil lines, oil coolers, gage lines.	Slightly improved mechanical properties. Electrical conductivity about 85%. Not subject to hydrogen embrittlement.	
C14500	E	E	760–845	E	E	F	F	G	NR	NR	NR	G	80	S	Forgings and screw machine parts requiring high electrical and thermal conductivity, furnace brazing. Electrical connectors, motor and switch parts, soldering coppers and welding torch tips.	Free machining copper, combined with high electrical conductivity (90–96%).	
C14700	E	E	760–870	E	E	NR	NR	NR	NR	NR	NR	G	80	S	Transformer and circuit-breaker terminals, studs, bolts, nuts and current-carrying parts requiring fine machining.	Free machining copper, combined with high electrical conductivity (90–96%).	
C15000	E	E	760–870	E	G	F	F	F	NR	NR	NR	G	20	L	Resistance welding electrodes. Miscellaneous current-carrying components at elevated temperatures.	Precipitation hardened. Combined high strength and conductivity, and resistance to softening at elevated temperatures.	
C16200	E	G	760–870	E	E	F	F	G	NR	NR	NR	G	20	L	Electrical contacts and terminals, signal relays. Hard temper used for spring contact in small apparatus and resistance welding electrodes.	Moderate high strength and high electrical conductivity.	
C17000	G	G	705–775	G	G	NR	F	G	NR	NR	NR	G	20	L	Leaf springs, electrical contacts, coil springs and bellows requiring severe forming distributor breaker arm, welding tips and welding wheels.	Copper Alloy UNS Nos. C17000, C17200, C17500, and C17600 can develop the highest mechanical properties by heat treatment. Complete range of properties.	
C17200	G	G	705–775	G	G	NR	F	G	NR	NR	NR	G	20	L			
C17500	G	G	760–925	G	G	NR	F	G	NR	NR	NR	G	20	L			
C17600	G	G	760–925	G	G	NR	F	G	NR	NR	NR	G	20	L	Clips, welder tips and wheels.		
C18400	E	E	900–925	G	G	NR	F	G	NR	NR	NR	G	20	L	Spot welding electrodes and wheels, flash welding dies and commutator segments.	Precipitation hardened. Fairly high electrical conductivity. Resistance to softening at elevated temperatures.	
C18700	G	NR	—	E	G	NR	NR	NR	NR	NR	NR	F	80	S	Screw machine parts requiring high electrical and thermal conductivity.	Free machining copper, high electrical conductivity. Unsuitable for hot working.	
C19200	E	E	815–950	E	E	G		E	NR	NR	NR	G	20		Flexible hose, electrical terminals, fuse clips, gaskets, air-conditioning and heat exchanger tubing.	Resistance to softening and also stress corrosion.	

(Table continued on next page)

TABLE 3—FABRICATION PROPERTIES, OTHER CHARACTERISTICS AND TYPICAL USES (CONTINUED)

Copper or Copper Alloy UNS No.	Approximate Relative Suitability For Being Worked ^a		Best Temperature For Hot Working, °C	Approximate Relative Suitability ^a For Being Joined By									Resistance Welding	Machinability ^c	Type of Chip ^b	Typical Uses	Characteristics
				Soldering	Brazing	Oxyacetylene Welding	Carbon Arc Welding	Gas Shielded Arc Welding	Coated Metal Arc Welding	Resistance Welding							
	Spot	Seam								Butt							
											Cold	Hot					
C21000	E	G	760–870	E	E	G	F	G	NR	NR	NR	G	20	L	Emblems, vitreous enamel base, ornamental trim and jewelry.	Copper Alloy UNS Nos. C21000, C22000 and C23000 are generally reddish in color, soft and malleable, higher annealing point than copper and slightly stronger and similar in corrosion resistance. Good for drawing and forming. Resistance to dezincification and season cracking is excellent.	
C22000	E	G	760–870	E	E	G	F	G	NR	NR	NR	G	20	L	Emblems, vitreous enamel base, ornamental trim, jewelry, expansion plugs, valve parts, escutcheon fasteners and spring clips.		
C23000	E	G	790–900	E	E	G	F	G	NR	F	NR	G	30	L	Radiator parts, heat exchanger tubes, tube bends.		
C24000	E	F	815–900	E	E	G	F	G	NR	F	NR	G	30	L	Bellows and water temperature switch housing, flexible hose, pump lines.	Color is light golden, strength and ductility continue to increase.	
C26000	E	F	730–845	E	E	G	F	F	NR	G	NR	G	30	L	Radiator tanks and lockseam tubes, header plates, reflectors, lamp bases, terminals, ground straps, baffles, ammeter shells and speedometer counterweights, washers, wheel covers, trim, carburetor parts.	Color is brass yellow. Greatest ductility of the copper-zinc series. Strength is higher than any of the preceding copper-zinc alloys.	
C26800 C27000	E E	NR NR	— —	E E	E E	G G	F F	F F	NR NR	G G	NR NR	G G	30 30	L L	Radiator cores and tanks, lamp fixtures, socket shells, eyelets, fasteners and grommets, hinges, locks, pins, rivets, screws and springs.	Strength increases and ductility decreases, but is still very good.	
C33000	E	NR	—	E	G	F	F	F	NR	F	NR	F	60	M	Tube carburetor parts, oil cooler tube, radiator and ornamental work, pump and power cylinders and liners.	Provides some degree of machinability, together with moderate cold working properties.	
C33100	E	NR	—	E	G	NR	NR	NR	NR	NR	NR	F	70	M	Keys.	Intended for blanking, piercing, and machining.	
C34200	E	NR	—	E	G	NR	NR	NR	NR	NR	NR	F	90	S	Clock plates and nuts, clock and watch backs, keys, gears and wheels.	Provides increased machinability with moderate cold working properties.	
C34500	F	F	705–790	E	G	NR	NR	NR	NR	NR	NR	F	90	S	Screw machine parts requiring roll threads, knurls or staking operations.	Best combination of machinability and cold working properties.	
C35000	F	NR	—	E	G	NR	NR	NR	NR	NR	NR	F	70	M	Keys.	Intended for blanking, piercing, and machining.	
C36000	NR	F	709–790	E	G	NR	NR	NR	NR	NR	NR	F	100	S	Automatic screw machine parts and carburetor, magneto parts, radiator drums and other fittings, plugs, inserts, gears, pinions, locks.	The standard free cutting brass and its machinability has become the standard by which other alloys are rated.	
C37700	NR	E	650–815	E	G	NR	NR	NR	NR	NR	NR	F	80	S	Forgings and pressings of all kinds. Headings, air conditioning tube fittings, convertible top hardware (latches, hinges, etc.) forged valve bodies.	Excellent hot working properties and widely used as forging rod. At ordinary temperatures it is strong, hard and free cutting.	
C46400	F	E	650–815	E	E	G	F	F	NR	G	F	G	30	L	Aircraft turnbuckle barrels and balls, cold headed parts, forgings, screw machine parts, marine hardware, condenser plates, welding rod, nozzles and fittings.	Excellent hot and fair cold working properties of somewhat higher strength, good salt water corrosion resistance.	
C46500	F	E	650–815	E	E	G	F	F	NR	G	F	G	30	L			
C46600	F	E	650–815	E	E	G	F	F	NR	G	F	G	30	L			
C46700	F	E	650–815	E	E	G	F	F	NR	G	F	G	30	L			
C51000	E	NR	—	E	E	F	G	G	F	G	F	E	20	L	Springs, clips, contacts, terminal wire and bushings, diaphragms and bellows.	C51000 and C52100 have a remarkable combination of strength, ductility and resilience, and fatigue resistance.	
C51100	E	NR	—	E	E	F	G	G	F	G	F	E	20	L			
C52100	G	NR	—	E	E	F	G	G	F	G	F	E	20	L	Bearings, bushings, gears, pinions, shafts, thrust washers, valve parts.	Free cutting, good cold working properties also suitable for blanking, forming and bending.	
C52400	G	NR	—	E	E	F	G	G	F	G	F	E	20	L			
C54400	G	NR	—	E	G	NR	NR	NR	NR	NR	NR	F	80	S			
C60800	G	F	790–870	F	F	NR	—	G	G	G	G	G	20	—	Condenser, evaporator and heat exchanger tubes, ferrules.		

(Table continued on next page)

TABLE 3—FABRICATION PROPERTIES, OTHER CHARACTERISTICS AND TYPICAL USES (CONTINUED)

Copper or Copper Alloy UNS No.	Approximate Relative Suitability For Being Worked ^a		Best Temperature For Hot Working, °C	Approximate Relative Suitability ^a For Being Joined By										Machinability ^c	Type of Chip ^b		
				Soldering	Brazing	Oxyacetylene Welding	Carbon Arc Welding	Gas Shielded Arc Welding	Coated Metal Arc Welding	Resistance Welding							
	Spot	Seam								Butt							
											Cold	Hot					
C61300	G	G	785–925	F	F	NR	G	See Note d	G	G	G	G	20	L	Gibs, wear strips, gears, bushings, nuts, bolts and threaded members.	Good cold working properties and corrosion resistance. High strength and ductility.	
C61400	G	G	785–925	F	F	NR	G	See Note d	G	G	G	G	20	L	Gibs, wear strips, gears, bushings, nuts, bolts and threaded members.	Good cold working properties and corrosion resistance. High strength and ductility.	
C61800	F	G	760–885	F	G	NR	—	G	G	G	G	G	40	—	Bushings, bearings, corrosion applications, welding rod.		
C62300	F	G	730–815	F	F	NR	G	See Note d	G	G	G	G	30	L	Valve guides, spark plug inserts, gears, valve seat inserts, oil plugs and shifter forks.	Good hot working properties; high strength retained well at elevated temperatures; acid and oxidation resistant.	
C62400	NR	E	720–775	F	F	NR	G	See Note d	G	G	G	G	30	L	Valve guides, spark plug inserts, gears, valve seat inserts, oil plugs, shifter forks, wear strips, ball bearings and hydraulic valve components.	Excellent hot working, poor cold working properties; heat treated for high mechanical properties.	
C63000	NR	G	705–760	F	F	NR	G	See Note d	G	G	G	G	20	L	Retractable landing gear, propeller gears, large valve seat inserts, spacer bearings, high pressure pump components.	Very high mechanical properties in the heat treated condition; difficult to cold work; good hot working properties, excellent corrosion resistance.	
C64200	NR	E	705–760	F	F	NR	—	F	F	F	F	F	60	—	Valve stems, gears, bolts, nuts, valve bodies and components.	Free machining, high strength, high corrosion resistance.	
C65500	E	E	705–760	G	E	G	G	E	F	E	E	E	30	L	Hydraulic pressure lines, bolts, clamps, piston rings, rivets and shafting.	Relatively high strength, marked ductility and capability for being both hot and cold worked and joined by all procedures. Excellent corrosion resistance.	
C67000	NR	E	565–745	NR	F	NR	NR	See Note d	G	G	F	G	30	S	Diesel injector nozzles; high pressure hydraulic applications, cams, pistons and other components involving high mechanical loads and sliding contact.	High strength and good wear resistant properties.	
C67300	F	E	625–745	NR	G	NR	NR	NR	NR	NR	NR	F	70	S	Forged water pump impellers; gears, axial piston pump components, bushings and bearings.	Hot forgeable free cutting alloy having fairly high strength and good corrosion resistant properties.	
C67400	F	E	565–745	NR	F	NR	NR	See Note d	G	G	F	G	30	L	Connecting rods, transmission synchronizing stop ring, door striker plates, shifter shoes, differential idler pins, forged water pump impellers, axial piston pump parts, bushings and bearings.	Hot forgeable; high strength alloy with good wear resistant properties and good corrosion resistance.	
C67500	NR	E	625–790	E	E	G	F	F	NR	G	F	G	30	L	Clutch disks, pump rods, shafting, balls, valve stems and bodies.	Strong, rigid and abrasion resistant; adapted to hot forging and pressing, hot-heading and upsetting.	
C70600	G	G	760–980	E	E	F	NR	E	G	G	G	E	20	L	Condenser and heat exchanger tubes.	Used where requirements are severe. Strong, tough and very resistant to general corrosion as well as stress corrosion cracking; also serviceable at higher temperatures than copper and brasses. Well suited for condenser and heat exchanger tube.	
C71000	G	G	760–980	E	E	G	NR	E	E	E	E	E	20	L	Condenser and heat exchanger tubes, ferrules.	Copper Alloy UNS Nos. C71000 and C71500 are used where requirements are severe. Strong, tough and very resistant to general corrosion as well as stress corrosion cracking; also, serviceable at higher temperatures than copper and brasses. Well suited for condenser and heat exchanger tube.	
C71500	G	G	925–1035	E	E	G	NR	E	E	E	E	E	20	L	Automatic oil coolers, heat exchanger tube.		
C75200	E	NR	—	E	E	G	NR	F	NR	G	F	G	20	L	Rivets, screws, name plates, radio dials, etching stock, trim.	Copper Alloy UNS Nos. C75200 and C77000 are manufactured in a wide range of nickel contents. Higher the nickel the more silver white the alloy. 65% copper alloys have good cold working properties and are used for cold drawing, spinning, forming and stamping. The lower copper content alloys (55% Cu) are used for spring application.	
C77000	G	NR	—	E	E	G	NR	F	NR	G	F	G	30	L	Springs, resistance wire.		

^a E = Excellent; G = Good; F = Fair; NR = Not Recommended.^b S = Short; M = Medium; L = Long.^c Approximate relative machinability rating (Free Cutting Brass = 100).^d Consumable electrode excellent. Tungsten are good, with AC preferred.

Silver is added to copper to increase its resistance to softening at elevated temperature without decreasing the electrical conductivity. Cold worked silver-bearing copper (see Table 4) can be heated to about 350 °C for short periods of time without appreciable softening, and is less susceptible to creep rupture in highly stressed situations. Rolling mill practice and amount of silver have an effect upon the softening of such materials.

TABLE 4—TYPICAL SOFTENING TEMPERATURE

Copper UNS No.	Temperature °C
C11000	230
C10200	280
C11400	315
C12200	340
C11100	355

Cadmium added in small amounts (0.10%) to copper results in an alloy having superior resistance to softening at temperatures used in forming automotive radiators. Resistance to softening is retained even after the application of large amounts of cold work. The application of this material permits higher strength solders to be used and allows for the increase of soldering temperature range to a point not feasible with other high conductivity materials. Electrical and thermal conductivities are not appreciably different than for silver bearing copper.

Figure 1 illustrates the softening characteristics of electrolytic copper and silver bearing and cadmium bearing copper alloys in terms of tensile strength for the times and temperatures indicated.

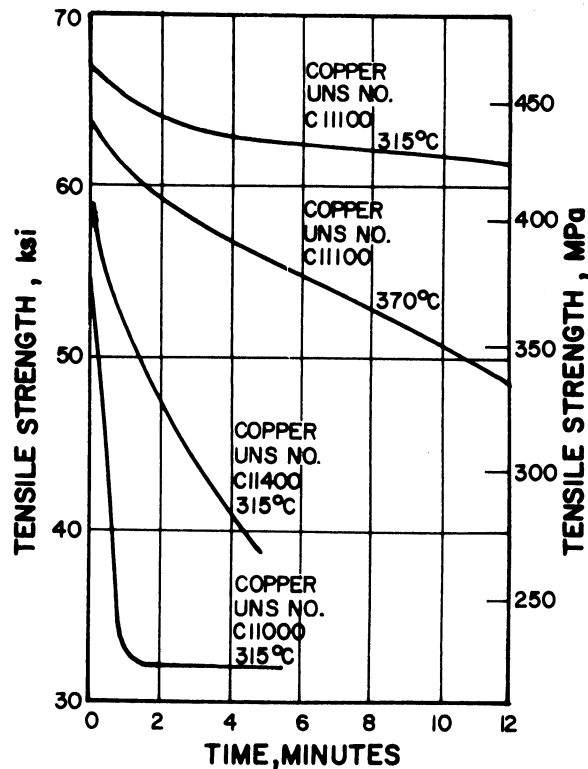


FIGURE 1—SOFTENING CHARACTERISTICS OF THREE COPPERS

The 0.85% silver-bearing alloy is the best, of the three commonly available alloys, to resist creep rupture. The silver-bearing coppers find use in radiator construction where the material is subjected to slightly elevated temperature during soldering operations, also for commutators which are baked to set mica between the copper segments. Copper must not be softened by these treatments.

To prevent embrittlement which takes place with copper should be specified if the material is to be heated much above 425 °C in an atmosphere of reducing gases such as hydrogen. Embrittlement results from the action of the reducing gases with the copper oxide normally present in all C11XXX types.

The addition of chromium to copper produces an alloy with a combination of high tensile strength (485 MPa [70ksi]) and electrical conductivity (80% IACS). Copper Alloy UNS No. C18400 has the ability to retain its mechanical properties and wear resistance to a high degree at elevated temperatures. The copper chromium alloys have found considerable use as fabricated into welding tips and seam welding wheels. Zirconium bearing copper (Copper Alloy UNS No. C 15000) is also finding wide use in high temperature-high strength applications.

Heat treated beryllium bearing copper alloys having tensile strength up to 1345 MPa (195 ksi) and fatigue strengths up to 345 MPa (50 ksi) are available; however, a drop in electrical conductivity to about 50% and high cost must be considered. Where repetitive or cycling operation must be performed, such properties have made application of these alloy economical.

Conducting contacts, springs or other stressed parts that are manufactured by forming may employ chromium or beryllium bearing coppers. The parts are formed by cold working and then strengthened by heat treatment.

The high degree of ductility and toughness of commercially pure copper usually make it unsuited for cutting or machining operations. Copper with lead, tellurium and sulfur were developed to combine the properties of copper with improved machinability. Parts that must be formed by extensive machining and be highly conductive are made from the free machining coppers. Tellurium copper has a 95% electrical conductivity and a machinability rating of 80–90. Sulfur bearing copper has a 95% IACS electrical conductivity and the same machinability rating, whereas lead copper has an electrical conductivity of 98% IACS and a machinability rating of 80. The machinability rating for copper is 20.

Where higher tensile strength 620 MPa (90 ksi) is required along with good machinability (60) and lower electrical conductivity (10%) can be tolerated, aluminum silicon alloys may be used to advantage.

For applications requiring good fatigue properties, the nickel-silver phosphor, or beryllium alloys will serve. These alloys, however, have relatively low electrical conductivity ranging from 5 to 50%.

Copper UNS No. C12000 is also a good choice in the selection of conductor to be used where creep strength is to be considered, as may be the case when the material is to operate at slightly elevated temperature.

- 3.3 Thermal Conductivity**—For the alpha solid solutions of copper alloys at least, the thermal conductivity is a nearly linear function of the electrical conductivity multiplied by the absolute temperature. Good conductor of electricity are also good conductors of heat and poor conductors of electricity are poor conductors of heat.

When high thermal conductivity is of principal importance, the same considerations given electrical conductivity apply.

- 3.4 Mechanical Properties**—Except for the heat treatable alloys, strength is determined mainly by composition and degree of cold work. Mechanical properties of the most important alloys are to be found in Table 10.

Copper and copper alloys containing aluminum, silicon, tin, iron, an manganese, in various combinations and concentrations, are much stronger by virtue of their chemistry than the other coppers or alloys. For heavy sections or parts requiring high strength, inherently stronger alloy should be specified. For lighter or smaller sections which can be made adequately from stronger tempers, other alloys are successful. For example, the tensile strength of Copper Alloy UNS No. C26000 used in the production of radiator tanks can be increased by adjusting the rolling mill procedure from 310 to 365 MPa (45 to 53 ksi) without a harmful reduction in ductility. Similarly Copper Alloy UNS No. C26000 strip 0.11 mm (.0045 in) intended for fabrication into lockseam tube, used in radiator construction, is available in an annealed temper having a tensile strength of about 440 MPa (64 ksi) and an elongation of 32% in 50 mm (2 in). This represents an 18.5% increase in tensile strength without any sacrifice of ductility, compared to material produced by rolled-to-temper methods

The tensile strength of the copper-zinc series of alloys, the most widely used group in the industry, increases in general for any specific temper as the copper content decreases. The alloys also are characterized by extremely high ductility, excellent forming characteristics and ease of finishing. The relationship of the increase of properties with zinc content is shown in Figure 2.

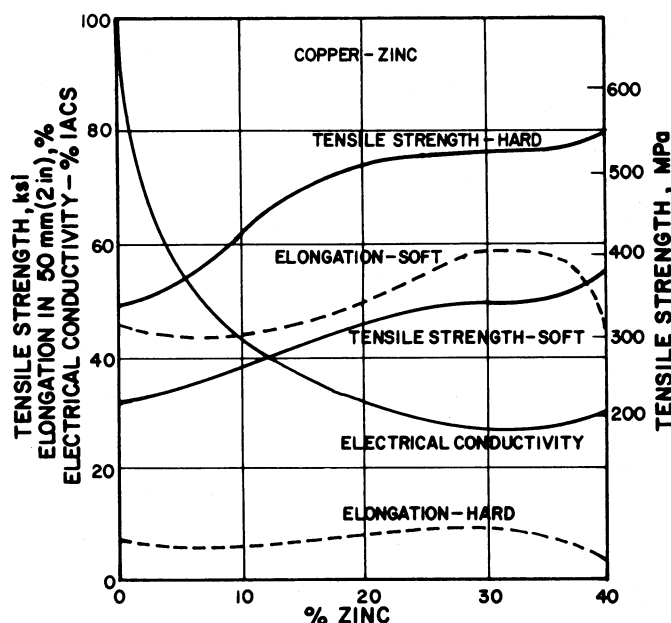


FIGURE 2—RELATIONSHIP OF INCREASE OF PROPERTIES WITH ZINC CONTENT

A series of heat treatable alloys are commercially available and have strength as high as 1380 MPa (200 ksi). These alloys are produced with carefully controlled compositions and contain such elements as chromium, beryllium, nickel, phosphorus and silicon. The attractive diversity of properties obtainable in heat treatable copper alloys can be observed in Table 10.

The copper zirconium alloy (Copper UNS No. C15000) might be included in this group because it does respond to heat treatment; however, its strength is developed primarily through the application of cold working. Heat treatment primarily restores high electrical conductivity and ductility and increases surface hardness. The alloy has found use in the production of welding tips and wheels, stud bases for rectifiers, commutators for motors and electrical switch parts.

One outstanding characteristic of the heat treatable alloys is that they may be formed into articles, such as complex springs, while in the soft or partially work hardened state, and the mechanical properties subsequently improved to their maximum by heat treatment.