

COPPER-CHROMIUM

Cu CrI

Common name: Chromium Copper

A copper alloy containing chromium, that can be strengthened by heat treatment. Material solution heat treated at high temperature has a soft supersaturated alpha-phase structure, and subsequent precipitation hardening at lower temperature precipitates finely dispersed secondary chromium in the matrix. In this condition, the alloy exhibits high strength and hardness, combined with good conductivity. Cold working before or after precipitation hardening can further improve strength and hardness. The improved properties are retained at relatively high temperatures. The most commonly used wrought forms are plate, strip, rod and forgings.

COMPOSITION (weight %)

Cr	0.5-1.2
Cu	rem.

1 SOME TYPICAL USES

Electrical

Cable connectors; switchgear and circuit-breaker parts; electronic tube grid-support wire and rod; commutator bars and end rings for electric motors; transistor bases and parts for electronic devices; contact wheels.

Mechanical

Spot welding electrodes; seam welding wheels and tips; contact pads for in-line butt-welding of strip; electrode holders and arms; oxygen-jet tips; disc brakes; soldering-iron tips.

2 PHYSICAL PROPERTIES

The "solution heat treated" and "precipitation hardened" conditions referred to in this section relate to material with or without cold work. When no specific condition is quoted, the value shown is applicable to material in all conditions of heat treatment and working.

		Metric Units	English Units
2.1	Density at 20 °C 68 °F (solution heat treated or precipitation hardened)	8.9 g/cm ³	0.320 lb/in ³
2.2	Melting range	1 070-1 080 °C	1 960-1 975 °F
2.3	Coefficient of thermal expansion (linear) at:		
	20 to 100 °C 68 to 212 °F	0.000 017 per °C	0.000 009 per °F
	20 " 300 °C 68 " 572 °F	0.000 018 " "	0.000 010 " "
	20 " 600 °C 68 " 1 112 °F	0.000 020 " "	0.000 011 " "
2.4	Specific heat (thermal capacity) at:		
	20 °C 68 °F	0.09 cal/g °C	0.09 Btu/lb °F
2.5	Thermal conductivity at:		
	20 °C 68 °F (solution heat treated)	~0.40 cal cm/cm ² s °C	~97 Btu ft/ft ² h °F
	20 °C 68 °F (precipitation hardened)	0.72-0.82 "	175-200 "
	200 °C 392 °F (" ")	~0.84 "	~203 "
	300 °C 572 °F (" ")	~0.86 "	~208 "
2.6	Electrical conductivity (volume) at:		
	20 °C 68 °F (solution heat treated)	~20 m/ohm mm ²	~35 % IACS
	20 °C 68 °F (precipitation hardened)	44-49 "	75-85 " "
	100 °C 212 °F (" ")	35-39 "	60-68 " "
	200 °C 392 °F (" ")	27-31 "	47-53 " "
	300 °C 572 °F (" ")	23-25 "	39-43 " "
2.7	Electrical resistivity (volume) at:		
	20 °C 68 °F (solution heat treated)	~0.049 ohm mm ² /m	~30 ohms (circ mil/ft)
	20 °C 68 °F (precipitation hardened)	~4.9 microhm cm	~1.9 microhm in
	100 °C 212 °F (" ")	0.023-0.020 ohm mm ² /m	14-12 ohms (circ mil/ft)
	200 °C 392 °F (" ")	2.3-2.0 microhm cm	0.91-0.80 microhm in
	300 °C 572 °F (" ")	0.029-0.025 ohm mm ² /m	17-15 ohms (circ mil/ft)
		2.9-2.5 microhm cm	1.1-1.0 microhm in
		0.037-0.033 ohm mm ² /m	22-20 ohms (circ mil/ft)
		3.7-3.3 microhm cm	1.4-1.3 microhm in
		0.044-0.040 ohm mm ² /m	27-24 ohms (circ mil/ft)
		4.4-4.0 microhm cm	1.7-1.6 microhm in
2.8	Temperature coefficient of electrical resistance at:		
	20 °C 68 °F (solution heat treated)	0.001 4 per °C (35% IACS)	0.000 8 per °F (35% IACS)
	applicable over range from 0 to 100 °C 32 to 212 °F		
	20 °C 68 °F (precipitation hardened)	0.003 1 " " (75 " ")	0.001 7 " " (75 " ")
	applicable over range from 0 to 100 °C 32 to 212 °F	0.003 5 " " (85 " ")	0.001 9 " " (85 " ")
2.9	Modulus of elasticity (tension) at 20 °C 68 °F:		
	solution heat treated	11 000 kg/mm ²	15 600 000 lb/in ²
	precipitation hardened	14 000-16 000 kg/mm ²	19 900 000-22 800 000 lb/in ²
2.10	Modulus of rigidity (torsion) at 20 °C 68 °F:		
	solution heat treated	4 100 kg/mm ²	5 800 000 lb/in ²
	precipitation hardened	5 200-5 900 kg/mm ²	7 400 000-8 400 000 lb/in ²

N.B.: The values shown in Section 2, which have been appropriately rounded in view of the composition range involved, are based on selected literature references; the melting range covers the highest liquidus and lowest solidus temperatures over the composition range quoted.

INDEX NUMBERS RELATE TO LITERATURE REFERENCES (see page 12); INDEX LETTERS RELATE TO FOOTNOTES AT END OF TABLE

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3 FABRICATION PROPERTIES

The information given in this table is for general guidance only, since many factors influence fabrication techniques. The values shown are approximate only, since those used in practice are dependent upon form and size of metal, equipment available, techniques adopted and properties required in the material.

For further information on heat treatment and the related properties of this alloy, see General Data Sheet No. 4.

		Metric Units	English Units
3.1	Casting temperature range	1 160–1 250 °C	2 120–2 280 °F
3.2	Heat treatment conditions		
3.2.1	Solution heat treatment		
3.2.1.1	Temperature range	950–1 000 °C	1 740–1 830 °F
3.2.1.2	Time at temperature		60–15 min.
3.2.1.3	Type of furnace		Muffle
3.2.1.4	Cooling		Water quench
3.2.2	Interstage annealing temperature range	700– 850 °C	1 290–1 560 °F
3.2.3	Precipitation hardening		
3.2.3.1	Temperature range	425– 500 °C	795– 930 °F
3.2.3.2	Time at temperature		4 – 2 h
3.2.3.3	Type of furnace		Muffle
3.2.3.4	Cooling		Air
3.3	Hot working temperature range	750– 900 °C	1 380–1 650 °F
3.4	Hot formability		Good
3.5	Cold formability		
	Solution heat treated		Good
	Precipitation hardened		Fair
3.6	Cold reduction		
	Solution heat treated		75% max.
	Precipitation hardened		35% max.
3.7	Machinability:	See General Data Sheet No. 2	
	Machinability rating (free-cutting brass = 100)		
	Precipitation hardened		30%
3.8	Joining methods: ^(a)	See General Data Sheet No. 3.3	
	Soldering		Good
	Brazing		Fair
	Oxy-acetylene welding		Not recommended
	Carbon-arc welding		Not recommended
	Gas-shielded arc welding		Fair
	Coated metal-arc welding		Not recommended
	Resistance welding: spot and seam		Fair
	butt		Fair

^(a) These processes, involving the application of heat, are generally restricted to solution-heat-treated material, but soldering must be carried out after precipitation hardening to avoid melting of the joint.

4 NATIONAL SPECIFICATIONS FOR MANUFACTURED FORMS
and ISO Recommendation

Country	Designation of Standards	Designation of Material in Standards	Specification for Chemical Composition ^(a)	Plate Sheet Strip	Rod	Wire	Tube	Sections / Shapes	Forgings
Australia . . .	SAA	—	—	—	—	—	—	—	—
Belgium . . .	NBN	—	—	—	—	—	—	—	—
Canada . . .	CSA	—	—	—	—	—	—	—	—
Chile	NCh (INDITECNOR)	Cu Cr	245 of. 68	—	—	—	259 of. 70	—	—
France	NF	—	—	—	—	—	—	—	—
Germany	DIN	CuCr	17 666	17 670	17 672	17 677	17 671	17 674	17 673 17 678
India	IS	—	—	—	—	—	—	—	—
Italy	UNI	—	—	—	—	—	—	—	—
Japan	JIS	—	—	—	—	—	—	—	—
Netherlands . .	N or NEN ^(b)	—	—	—	—	—	—	—	—
South Africa . .	SABS	—	—	—	—	—	—	—	—
Spain	UNE	—	—	—	—	—	—	—	—
Sweden	SIS	—	—	—	—	—	—	—	—
Switzerland . .	VSM	—	—	—	—	—	—	—	—
United Kingdom	BS	A2/1	—	—	4577	—	—	—	4577
United States .	ASTM	No. 182	—	—	—	F 9	—	—	—
International Organisation for Standardization	ISO	Cu Cr1	R 1336	—	—	—	—	—	—

^(a) Applicable when the chemical composition is not given in the specifications for wrought forms.

^(b) Older specifications bear prefix N; for new specifications the NEN prefix is used.

5 MECHANICAL PROPERTIES

5.1 Mechanical properties at room temperature

Tensile properties	see tables 5.1.1/2/3.1/3.2
Hardness	„ „ 5.1.1/2/3.1/3.2
Shear strength	„ „ 5.1.1/2/3.1/3.2
Modulus of elasticity (tension)	see 2.9
Modulus of rigidity (torsion)	„ 2.10

5.2 Mechanical properties at low temperature

Tensile properties	see tables 5.2.1.1/2
Impact properties	„ „ 5.2.1.1/2

5.3 Mechanical properties at elevated temperature

Short-time tensile properties	see tables 5.3.1.1/2
Impact properties	see table 5.3.1.2
Creep properties	see tables 5.3.2.1/2/3

5.4 Fatigue properties

Fatigue strength at room temperature	see tables 5.4.1.1/2
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5.1 MECHANICAL PROPERTIES AT ROOM TEMPERATURE ^(a)
5.1.1 Typical Tensile Properties and Hardness Values—Metric Units

This table is representative of practice in many European countries. For British and American practices, see tables 5.1.2 and 5.1.3, respectively.

The values shown represent reasonable approximations for general engineering use, taking account of variations in composition and manufacturing procedures. For design purposes, national specifications should be consulted.

For a given temper, individual elongation values may show some variation above or below the typical values indicated.

The mechanical properties of this alloy are largely dependent upon heat treatment conditions. For further information, see General Data Sheet No. 4.

Form	Temper	Tensile Strength kg/mm ²	Proof Stress 0.2% offset kg/mm ²	Elongation		Hardness		Shear Strength kg/mm ²	Typical Size Related to Properties Shown ^(b)
				%	gauge length	Brinell	Vickers		
Plate Sheet Strip	Solution Heat Treated	24	10	30	5.65√S ₀	65	68	17	—
	Solution Heat Treated and Cold Worked to Typical Tempers	30	18	7	5.65√S ₀	110	115	21	1–10 mm thick 0.2–1 mm thick
		41	30	4	50 mm	125	130	27	
	Precipitation Hardened	42	30	15	5.65√S ₀	110	115	—	—
	Precipitation Hardened after Cold Working to Typical Tempers	45	38	14	5.65√S ₀	140	145	—	1–10 mm thick 0.2–1 mm thick
53		45	8	50 mm	160	170	—		
Precipitation Hardened and Cold Worked to Typical Tempers	42	37	12	5.65√S ₀	130	135	—	3–10 mm thick 1–3 mm thick 0.2–1 mm thick	
	47	42	8	50 mm	140	145	—		
55	51	51	2	50 mm	160	170	—		
	Rod ^(c)	Solution Heat Treated	24	10	30	5.65√S ₀	65	68	17
Solution Heat Treated and Cold Worked to Typical Tempers		35	23	15	5.65√S ₀	120	125	24	2–50 mm diam. or equivalent area 2–10 mm diam. or equivalent area
		44	36	10	5.65√S ₀	130	135	29	
Precipitation Hardened		45	32	12	5.65√S ₀	110	115	—	2–50 mm diam. or equivalent area
Precipitation Hardened after Cold Working to Typical Tempers		45	38	14	5.65√S ₀	135	140	—	25–50 mm diam. or equivalent area 2–25 mm diam. or equivalent area 2–5 mm diam. or equivalent area
	48	42	10	5.65√S ₀	140	145	—		
52	46	8	5.65√S ₀	150	160	—			
Precipitation Hardened and Cold Worked to Typical Tempers	48	43	8	5.65√S ₀	140	145	—	25–50 mm diam. or equivalent area 2–25 mm diam. or equivalent area 2–5 mm diam. or equivalent area	
	55	51	4	5.65√S ₀	150	160	—		
	58	55	2	5.65√S ₀	165	175	—		
Sections ^(c) Shapes	Solution Heat Treated	24	10	30	5.65√S ₀	65	68	17	—
	Precipitation Hardened	45	32	12	5.65√S ₀	110	115	—	—
	Precipitation Hardened after Cold Working to Typical Tempers	48	42	10	5.65√S ₀	130	135	—	—
Forgings ^(c)	Solution Heat Treated	24	10	30	5.65√S ₀	65	68	17	—
	Precipitation Hardened	37	25	15	5.65√S ₀	100	105	—	—

(a) It will be noted that tables 5.1.1, 5.1.2 and 5.1.3, giving typical tensile properties and hardness values in Metric, SI and English, and American units respectively, are not directly comparable. This is because the properties quoted reflect to some extent the metalworking techniques, specification practices, and testing procedures in the countries concerned, and in view of the different sizes of products referred to in these tables. Individual manufacturers of semi-fabricated products, can, however, normally meet the requirements of any national standard.

(b) It is possible to obtain sizes outside the ranges given in this column, but information on their mechanical properties should be obtained from the metal manufacturers.

(c) The mechanical properties will be largely dependent upon the size and cross-sectional area or complexity of the product.

5.1.2 Typical Tensile Properties and Hardness Values—SI and English Units

This table is based on British practice. For other European and American practices, see tables 5.1.1 and 5.1.3, respectively.

The values shown represent reasonable approximations for general engineering use, taking account of variations in composition and manufacturing procedures. For design purposes, national specifications should be consulted.

For a given temper, individual elongation values may show some variation above or below the typical values indicated.

The mechanical properties of this alloy are largely dependent upon heat treatment conditions. For further information, see General Data Sheet No. 4.

Form	Temper	Tensile Strength		Proof Stress 0.1% Offset		Elongation		Vickers Hardness	Shear Strength		Typical Size Related to Properties Shown ^(b)
		hbar	ton/in ²	hbar	ton/in ²	%	gauge length		hbar	ton/in ²	
Plate Strip	Solution Heat Treated	23	15	5	3	40 45	5.65√S ₀ 50 mm (2 in.)	70	15	10	—
	Precipitation Hardened after Solution Heat Treatment	37	24	25	16	20 22	5.65√S ₀ 50 mm (2 in.)	120	25	16	—
	Precipitation Hardened after Cold Working to Typical Tempers ^(a)	42	27	32	21	18 20	5.65√S ₀ 50 mm (2 in.)	135	—	—	0.5–12 mm (0.02–0.5 in.) thick
		45	29	37	24	17	50 mm (2 in.)	145	—	—	0.5–6 mm (0.02–0.25 in.) thick
		49	32	42	27	12	50 mm (2 in.)	155	—	—	0.5–1 mm (0.02–0.04 in.) thick
	Rod ^(c)	Solution Heat Treated	23	15	5	3	40	5.65√S ₀	70	15	10
Precipitation Hardened after Solution Heat Treatment		39	25	26	17	18	5.65√S ₀	120	26	17	—
Precipitation Hardened after Cold Drawing to Typical Tempers ^(a)		43	28	34	22	18	5.65√S ₀	135	—	—	25–50 mm (1–2 in.) diam. or equivalent area
		46	30	37	24	15	5.65√S ₀	145	—	—	10–25 mm (0.375–1 in.) diam. or equivalent area
	49	32	42	27	10	5.65√S ₀	155	—	—	3–10 mm (0.125–0.375 in.) diam. or equivalent area	
Wire	— ^(d)	—	—	—	—	—	—	—	—	—	—
Sections ^(c) (Extruded)	Solution Heat Treated	23	15	5	3	40	5.65√S ₀	70	15	10	—
	Precipitation Hardened after Cold Drawing to Typical Temper ^(a)	42	27	32	21	15	5.65√S ₀	135	—	—	—
Forgings ^(c)	Solution Heat Treated	23	15	5	3	40	5.65√S ₀	70	15	10	—
	Precipitation Hardened after Solution Heat Treatment	37	24	25	16	20	5.65√S ₀	120	25	16	—
	Precipitation Hardened after Cold Working ^(a)	43	28	34	22	15	5.65√S ₀	130	—	—	—

(a) Solution heat treated, cold worked and finally precipitation hardened.

(b) It is possible to obtain sizes outside the ranges given in this column, but information on their mechanical properties should be obtained from the metal manufacturers.

(c) The mechanical properties will be largely dependent upon the size and cross-sectional area or complexity of the product.

(d) The processing schedule for wire normally results in material with higher conductivity and lower mechanical strength values than are typical for other wrought forms.

N.B.: It is also possible to cold work precipitation-hardened material, thereby increasing its strength and hardness over the typical values quoted above; information on these properties can be obtained from the manufacturers. Such material may, however, be unsuitable for service conditions involving mechanical stresses at moderately elevated temperatures (see Sergeant, R. M. Cavity Formation in Copper Alloys. J. Inst. Metals, Vol. 96 (1968), pp. 197–201). It is recommended that users of copper-chromium alloys should consult the manufacturers in the selection of appropriate material for specific applications.

5.1.3 Typical Tensile Properties and Hardness Values—American Units

This table is based on American practice and the temper designations shown are those referred to in ASTM and other American Standards. For British and other European countries' practices, see tables 5.1.2 and 5.1.1, respectively.

The values shown represent reasonable approximations for general engineering use, taking account of variations in composition and manufacturing procedures. For design purposes, national specifications should be consulted.

For a given temper, individual elongation values may show some variations above or below the typical values indicated.

The mechanical properties of this alloy are largely dependent upon heat treatment conditions. For further information, see General Data Sheet No. 4.

5.1.3.1 Solution-heat-treated material

Form	Temper	Tensile Strength psi	Yield Strength 0.5% extension under load psi	Elongation		Rockwell Hardness			Shear Strength psi	Typical Size Related to Properties Shown ^(a)
				%	gauge length	F	B	30 T		
Flat Products (Plate, Sheet, Strip, Bar and Flat Wire)	Hot Rolled and Quenched	33 000	10 000	40	2 in.	65	20	30	23 000	0.250 in. thick
	Solution Heat Treated	34 000 30 000	19 000 10 000	41 42	2 in. 2 in.	70 65	25 20	33 30	23 000 21 000	0.040 in. thick 0.250 in. thick
	Solution Heat Treated and Cold Worked Quarter Hard	39 000	37 000	19	2 in.	97	70	63	28 000	0.040 in. thick
	Hard	47 000	45 000	7	2 in.	99	75	67	33 000	"
	Extra Hard	54 000	51 000	6	2 in.	103	80	70	37 000	"
	Extra Spring	58 000	55 000	6	2 in.	103	82	71	40 000	"
	Half Hard	43 000	40 000	7	2 in.	98	72	65	30 000	0.250 in. thick
	Hard	52 000	51 000	2	2 in.	103	80	70	36 000	"
Rod ^(b)	Hot Rolled and Quenched	33 000	10 000	40	2 in.	65	20	30	23 000	0.250 in. thick
	Solution Heat Treated	45 000 35 000	14 000 15 000	40 40	2 in. 2 in.	65 70	20 25	30 33	31 000 23 000	0.250 in. diam. 1 in. diam.
	Solution Heat Treated and Cold Worked Hard	62 000	59 000	11	2 in.	99	75	67	44 000	0.250 in. diam.
	Spring	70 000	64 000	7	2 in.	103	80	70	48 000	"
	Extra Spring Hard	74 000 61 000	72 000 57 000	5 10	2 in. 2 in.	103 99	82 75	72 67	50 000 43 000	" 1 in. diam.
Tube	Solution Heat Treated	33 000	10 000	40	2 in.	65	20	30	23 000	2 in. O.D. × 0.250 in. wall
	Solution Heat Treated and Cold Worked Half Hard	43 000	40 000	7	2 in.	98	72	65	30 000	2 in. O.D. × 0.250 in. wall
Shapes ^(b)	Hot Worked and Quenched	33 000	10 000	40	2 in.	65	20	30	23 000	—
	Solution Heat Treated	35 000	15 000	40	2 in.	70	25	33	23 000	—
	Solution Heat Treated and Cold Worked Half Hard	43 000	40 000	7	2 in.	98	72	65	30 000	—
Forgings ^(b)	Hot Forged and Quenched	38 000	20 000	40	2 in.	75	30	35	27 000	—
	Solution Heat Treated	36 000	14 000	45	2 in.	70	25	33	25 000	—

(continued on opposite page)

5.1.3.2. Precipitation-Hardened Material

Form	Temper ^(c)	Tensile Strength psi	Yield Strength 0.5% extension under load psi	Elongation		Rockwell Hardness			Shear Strength psi	Typical Size Related to Properties Shown ^(a)	
				%	gauge length	F	B	30 T			
Flat Products (Plate, Sheet, Strip, Bar and Flat Wire)	Precipitation Hardened	56 000	45 000	15	2 in.	98	72	65	40 000	0.250 in. thick	
	Precipitation Hardened after Cold Working	Quarter Hard	57 000	46 000	18	2 in.	98	73	65	40 000	0.040 in. thick
		Hard	64 000	55 000	16	2 in.	105	84	73	43 000	"
		Extra Hard	67 000	59 000	14	2 in.	107	88	75	47 000	"
		Extra Spring	73 000	65 000	13	2 in.	108	91	77	50 000	"
		Half Hard	62 000	57 000	9	2 in.	99	75	67	44 000	0.250 in. thick
Hard	67 000	63 000	6	2 in.	107	88	75	47 000	"		
Rod ^(b)	Precipitation Hardened	63 000	45 000	25	2 in.	93	63	58	45 000	1 in. diam.	
	Precipitation Hardened after Cold Working	Hard	73 000	65 000	17	2 in.	103	82	72	50 000	0.250 in. diam.
		Spring	79 000	72 000	15	2 in.	106	85	74	68 000	"
		Extra Spring	86 000	83 000	13	2 in.	107	89	76	70 000	"
		Hard	72 000	61 000	20	2 in.	103	80	70	49 000	1 in. diam.
Tube	Precipitation Hardened	50 000	40 000	15	2 in.	97	70	63	35 000	2 in. O.D. × 0.250 in. wall	
	Precipitation Hardened after Cold Working Half Hard	64 000	47 000	10	2 in.	103	80	70	40 000	2 in. O.D. × 0.250 in. wall	
Shapes ^(b)	Precipitation Hardened	50 000	40 000	15	2 in.	57	70	63	35 000	—	
	Precipitation Hardened after Cold Working Half Hard	64 000	47 000	10	2 in.	103	80	70	40 000	—	
Forgings ^(b)	Precipitation Hardened	64 000	48 000	25	2 in.	103	80	70	45 000	—	

(a) It is possible to obtain sizes different from those given in this column, but information on their mechanical properties should be obtained from the metal manufacturers.

(b) The mechanical properties will be largely dependent upon the size and cross-sectional area or complexity of the product.

(c) It is possible to cold work precipitation hardened material, but the properties obtained will be largely dependent upon the treatment previously received. Information on these properties should be obtained from the metal manufacturers.

5.2 MECHANICAL PROPERTIES AT LOW TEMPERATURE

5.2.1 Tensile Properties—Impact Properties

5.2.1.1 Solution-Heat-Treated Material

Form	Temper	Testing Temperature		Tensile Strength			Proof Stress kg/mm ²	Elongation		Reduction of Area %	Impact Strength kg m/cm ²
		°C	°F	kg/mm ²	ton/in ²	psi		%	gauge length		
Rod ⁽¹⁾ 18 mm diam. 0.71 in. diam.	Solution ^(c) Heat Treated and Cold Worked 59%	20	68	42	26.5	59 500	40 ^(a)	13	5.65√S ₀	77	17.5 ^(b)
		-100	-148	47	30	67 000	45 ^(a)	17	5.65√S ₀	72	18.5 ^(b)
		-200	-328	54	34.5	77 000	50 ^(a)	21	5.65√S ₀	70	19.4 ^(b)

5.2.1.2 Precipitation-Hardened Material

Form	Temper	Testing Temperature		Tensile Strength			Proof Stress kg/mm ²	Elongation		Reduction of Area %	Impact Strength kg m/cm ²
		°C	°F	kg/mm ²	ton/in ²	psi		%	gauge length		
Rod ⁽¹⁾ 18 mm diam. 0.71 in. diam.	Precipitation ^(c) Hardened after Cold Working 59%	20	68	54	34.5	77 000	48 ^(a)	16	5.65√S ₀	60	17.2 ^(b)
		-100	-148	62	39.5	88 000	53 ^(a)	20	5.65√S ₀	63	18.5 ^(b)
		-200	-328	70	44.5	99 500	59 ^(a)	22	5.65√S ₀	65	19.7 ^(b)

(a) Quoted as 'yield point' in original document, but offset strain not defined.

(b) Type of notch not stated in original document; therefore not possible to convert impact strength values to ft lb.

(c) Alloy containing 0.45% Cr.

N.B.:—Original values are printed in **bold type**; other values are converted.

—Data not available: Proof stress, 0.1% and 0.2% offset,
Yield strength, 0.5% extension under load.

—Further data can be obtained from the following paper:

■ Brechna, H. Materials in Electromagnets and Their Properties. Proc. 2nd. Internat. Conf. on Magnet Technology, Oxford, England. (1967). Rutherford Lab. (1967), pp. 305-329.

5.3 MECHANICAL PROPERTIES AT ELEVATED TEMPERATURE

5.3.1 Short-time Tensile Properties—Impact Properties

5.3.1.1 Solution-Heat-Treated Material

Form	Temper	Testing Temperature		Tensile Strength			Elongation	
		°C	°F	kg/mm ²	ton/in ²	psi	%	gauge length
Rod ⁽²⁾ 19 mm diam. 0.75 in. diam.	Solution Heat Treated	20	68	26.5	16.8	37 500	35	2 in.
		250	482	21	13.4	30 000	37	2 in.
		350	662	21	13.2	29 500	44	2 in.
		450	842	18.5	11.6	26 000	33	2 in.
		550	1 022	15	9.6	21 500	10	2 in.

5.3.1.2 Precipitation-Hardened Material

Form	Temper	Testing Temperature		Tensile Strength			Proof Stress			Elongation		Impact Strength	
		°C	°F	kg/mm ²	ton/in ²	psi	0.2% offset kg/mm ²	0.1% offset ton/in ²	Yield Strength 0.5% ext. under load psi	%	gauge length	kg m cm ²	ft lb
Plate ⁽³⁾ 20 mm 0.79 in.	Precipitation Hardened	20	68	42.5	27	60 500	37.5	—	—	18.5	5.65√S ₀	—	—
		280	536	32.5	20.5	46 000	30.7	—	—	10.5	5.65√S ₀	—	—
		320	608	31.4	20	44 500	30.0	—	—	8	5.65√S ₀	—	—
		350	662	30.5	19.5	43 500	29.5	—	—	5	5.65√S ₀	—	—
Strip ⁽⁴⁾ 2.4 mm 0.096 in.	Precipitation Hardened after Cold Working 63%	20	68	50	31.5	71 000	45.0 ^(a)	—	—	16	2 in.	—	—
		288	550	35	22.5	50 000	32.3 ^(a)	—	—	4.2	2 in.	—	—
Strip ⁽⁵⁾ 6 mm 0.24 in.	Precipitation Hardened after Cold Working	20	68	52	33	74 000	42	—	—	17	10.3√S ₀	—	—
		200	392	42.8	27	61 000	—	—	—	10	10.3√S ₀	—	—
		300	572	28.5	18	40 500	—	—	—	7	10.3√S ₀	—	—
Rod ⁽⁶⁾ 7 mm diam. 0.28 in. diam.	Precipitation Hardened	20	68	49.0	31	69 500	43.0	—	—	14	5.65√S ₀	—	—
		100	212	46.0	29	65 500	35.2	—	—	12	5.65√S ₀	—	—
		200	392	40.5	25.5	57 500	27.0	—	—	8.5	5.65√S ₀	—	—
		300	572	35.0	22	50 000	22.0	—	—	4	5.65√S ₀	—	—
		400	752	32.3	20.5	46 000	11.0	—	—	2	5.65√S ₀	—	—
500	932	27.5	17.5	39 000	7.2	—	—	0.5	5.65√S ₀	—	—		
Rod ⁽²⁾ 19 mm diam. 0.75 in. diam.	Precipitation Hardened	20	68	38	24.2	54 000	—	—	—	21	2 in.	—	—
		250	482	33.5	21.4	48 000	—	—	—	10	2 in.	—	—
		350	662	30.5	19.3	43 000	—	—	—	5	2 in.	—	—
		450	842	28.5	18.1	40 500	—	—	—	5	2 in.	—	—
		550	1 022	21.5	13.6	30 500	—	—	—	3	2 in.	—	—
Rod ⁽⁷⁾ 27 mm diam. 1.1 in. diam.	Precipitation Hardened	20	68	47.5	30.2	67 500	23.4	22.5	24.2	16.25	4√S ₀	—	—
		250	482	29.5	18.6	41 500	18.1	17.5	^(b)	3.5	4√S ₀	—	—
		300	572	25.5	16.3	36 500	16.25	16.1	^(b)	3.75	4√S ₀	—	—
		350	662	24.5	15.7	35 000	15.6	15.5	15.65	3.1	4√S ₀	—	—
Rod ⁽⁸⁾ 0-50 mm diam. 0.79-2.0 in. diam.	Precipitation Hardened after Cold Working 20%	20	68	52	33	74 000	46	—	—	18	5.65√S ₀	—	—
		100	212	46	29	65 500	42	—	—	16	5.65√S ₀	—	—
		200	392	41	26	58 500	37	—	—	11	5.65√S ₀	—	—
		300	572	36	23	51 000	34	—	—	6	5.65√S ₀	—	—
		400	752	33	21	47 000	31	—	—	4	5.65√S ₀	—	—

(continued on opposite page)

5.3.1.2 Precipitation-Hardened Material (continued)

Form	Temper	Testing Temperature		Tensile Strength			Proof Stress			Elongation		Impact Strength	
		°C	°F	kg/mm ²	ton/in ²	psi	0.2% offset kg/mm ²	0.1% offset ton/in ²	Yield Strength 0.5% ext. under load psi	%	gauge length	kg m cm ²	ft lb
Rod ⁽⁹⁾	Precipitation Hardened after Cold Working 69%	20	68	—	—	—	—	—	—	—	—	5.07 ^(c)	22.0 ^(c)
		250	482	—	—	—	—	—	—	—	—	4.84 ^(c)	21.0 ^(c)
		400	752	—	—	—	—	—	—	—	—	4.84 ^(c)	21.0 ^(c)
		500	932	—	—	—	—	—	—	—	—	3.68 ^(c)	16.0 ^(c)
	Precipitation Hardened after Cold Working 84%	20	68	51	32.5	72 500	—	—	—	76 ^(d)	—	—	—
		200	392	41	26	58 000	—	—	—	63 ^(d)	—	—	—
		250	482	39.5	25	56 000	—	—	—	53 ^(d)	—	—	—
		300	572	37	23.5	52 500	—	—	—	40 ^(d)	—	—	—
		350	662	34.5	22	49 000	—	—	—	33 ^(d)	—	—	—
		400	752	31	19.5	44 000	—	—	—	26 ^(d)	—	—	—
		450	842	30	19	42 500	—	—	—	18 ^(d)	—	—	—
		500	932	24.5	15.5	35 000	—	—	—	13 ^(d)	—	—	—
		600	1 112	5.5	3.5	8 000	—	—	—	37 ^(d)	—	—	—
		Rod ⁽¹⁰⁾	Precipitation Hardened after Cold Working	20	68	55	35	78 000	53	—	—	8	5.65√S ₀
100	212			53	33.5	75 500	50	—	—	9	5.65√S ₀	—	—
200	392			48	30.5	68 500	45	—	—	8	5.65√S ₀	—	—
300	572			43	27.5	61 000	40	—	—	6	5.65√S ₀	—	—
400	752			37	23.5	52 500	35	—	—	4	6.65√S ₀	—	—
500	932			30	19	42 500	28	—	—	5	5.65√S ₀	—	—
600	1 112			22	14	31 500	19	—	—	8	5.65√S ₀	—	—
700	1 292			10	6.5	14 000	8	—	—	17	5.65√S ₀	—	—
800	1 472			4	2.5	5 500	2	—	—	55	5.65√S ₀	—	—

(a) This value was originally reported in psi; in this table it is given in kg/mm² to 3 significant figures.

(b) Specimen fractured before 0.5% proof stress was reached.

(c) Sub-sized Charpy specimen; keyhole notch; cross-sectional area at the notch 0.6 cm².

(d) Reduction of area %

N.B.—Original values are printed in **bold type**; other values are converted.

—All converted values for impact strength are to be taken as indicative only; the impact energy has been converted from ft lb into kg m/cm² taking into account the actual cross-sectional area of the specimen at the notch.

—Further data can be obtained from the following papers:

■ Shapton, R.W. Discussion at CDA Symposium on Recent Developments in the Use of Copper in the Electrical Industry. Copper Development Association, England (1960), pp. 127-132 (figs. 7 and 8 give graphed tensile data up to 300°C for longitudinal and transverse test specimens, notched and un-notched).

■ Dooley, J., Hewett, D. N. and Rutherford, N. B. Copper-Zirconium: An Alloy for Advanced Electrical Design. CDA Symposium on the Effect of Research and Design on the Use of Copper in the Electrical Industry. Copper Development Association, England (1962), pp. 45-75. (table 7 gives tensile data for Strip at temperatures up to 300°C; alloy containing 0.8% Cr, condition not stated).

■ Hodge, W. and Nippert, P. W. Zirconium-Copper Raises Level of Commutator Performance. Elec. Mnftg., Vol. 57 (1956), June, pp. 95-97, 354. (includes tensile data for copper-chromium at 288°C; test specimens parallel and transverse to rolling direction).

■ Mizuno, K. Study on the Precipitation-Hardenable Copper-Zirconium-Chromium Alloy. Sumitomo Light Metal Tech. Rept., Vol. 3 (1962), pp. 55-62. (includes tensile data up to 600°C for copper - 0.6% Cr alloy, precipitation hardened after cold working 40%).

■ Bunge, G., Honak, E. R. and Nielsch, W. Über die Eigenschaften einer technisch verwendbaren Kupfer-Chrom Legierung. Z. Metallkunde, Vol. 44 (1953), pp. 71-76 (includes tensile data up to 300°C).

■ Saarivirta, M. J. High-Conductivity Copper-Rich Cu-Zr Alloys. Trans. Met. Soc. AIME, Vol. 218 (1960), pp. 431-437 (includes tensile data at 400°C for copper - 0.86% Cr alloy precipitation hardened after cold working 85%).

■ Morecock, A. E. and Fox, D. K. Zirconium-Copper Alloy; High Strength and Conductivity. Metal Progress, Vol. 79 (1961), pp. 75-77 (includes tensile data for precipitation-hardened and cold-worked copper-chromium alloy at temperatures up to 400°C).

5.3.2 CREEP PROPERTIES
5.3.2.1 Original Creep Data

Form	Temper	Testing Temperature		Stress			Duration h	Total Extension % (a)	Intercept %	Min. Creep Rate % per 1 000 h
		°C	°F	kg/mm ²	ton/in ²	psi				
Plate (3) 20 mm 0.79 in.	Precipitation Hardened	280	536	20	22	12.7	28 400	1.7 (c)	—	—
				21	22	13.3	29 900	2 (c)	—	—
				15	18	9.5	21 300	2 (c)	—	—
Plate (3) 20 mm 0.79 in.	Precipitation Hardened	320	608	15	18	11.4	25 600	2.5 (c)	—	—
				20	20	12.7	28 400	2.2 (c)	—	—
				12	15	7.6	17 100	3.3 (c)	—	—
Plate (3) 20 mm 0.79 in.	Precipitation Hardened	350	662	12	15	9.5	21 300	2.2 (c)	—	—
				18	18	11.4	25 600	2.2 (c)	—	—
				20	20	12.7	28 400	1.7 (c)	—	—
Strip (4) 2.4 mm 0.096 in.	Precipitation Hardened after Cold Working 63%	288	550	21.1	28.1	13.4	30 000	> 300 (b)	—	—
				35.2	45.2	22.3	40 000	11 (b)	—	—
				17.9	25.9	17.9	50 000	0.1 (b)	—	—
Rod (6) 28 in. diam.	Precipitation Hardened after Cold Working	200	392	12.5	15.0	7.9	17 800	1 000 (c)	—	—
				12.5	15.0	9.5	21 300	1 000 (c)	—	—
				11.1	17.5	11.1	24 900	1 000 (c)	—	—
Rod (6) 28 in. diam.	Precipitation Hardened after Cold Working	300	572	15.0	15.0	9.5	21 300	1 000 (c)	—	—
				12.7	12.7	15.9	35 600	1 000 (c)	—	—
				25.0	25.0	15.9	35 600	0.88 (c)	—	—
Rod (11) 63 in. diam.	Precipitation Hardened after Cold Working 36%	80	176	37.8 (f)	36.2 (f)	24.0	53 800	0.4 (b)	—	—
				39.4 (f)	39.4 (f)	25.0	56 000	0.57 (b)	—	—
				44.1 (f)	42.5 (f)	28.0	62 700	8.8 (b)	—	—
Rod (11) 63 in. diam.	Precipitation Hardened after Cold Working 36%	80	176	43.4 (f)	43.4 (f)	27.6	61 700	1.0 (b)	—	—
				39.4 (f)	39.4 (f)	25.0	56 000	14 (b)	—	—
				29.0	29.0	29.0	65 000	0.33 (b)	—	—
Rod (11) 63 in. diam.	Precipitation Hardened after Cold Working 36%	80	176	44.1 (f)	42.5 (f)	27.0	60 400	32.7 (b)	—	—
				42.5 (f)	42.5 (f)	27.0	60 400	32.7 (b)	—	—
				39.4 (f)	39.4 (f)	25.0	56 000	255 (b)	—	—
Rod (12) 35 in. diam.	Precipitation Hardened after Cold Working 60.5%	343	650	7.0	8.8	4.5	10 000	1 125	0.10	0.008 9
				14.1	14.1	8.9	20 000	1 250	0.22	0.09
				14.1	14.1	8.9	20 000	1 400	0.31	0.255
Rod (7) 7 mm diam.	Precipitation Hardened	250	482	25.8	19.4	16.4	36 700	0.1 (b)	—	—
				12.3	12.3	12.3	27 600	0.5 (b)	—	—
				10.0	10.0	10.0	22 400	7 (b)	—	—
Rod (7) 7 mm diam.	Precipitation Hardened	300	572	18.1	14.2	11.5	25 800	0.33 (b)	—	—
				9.0	9.0	9.0	20 200	3 (b)	—	—
				6.0	6.0	6.0	13 400	87.5 (b)	—	—
Rod (7) 7 mm diam.	Precipitation Hardened	350	662	12.6	11.0	8.0	17 900	0.1 (b)	—	—
				6.3	6.3	6.0	13 400	2.5 (b)	—	—
				4.7	4.7	3.0 (b)	6 700	1 270 (b)	—	—

(continued on opposite page)

5.3.2.1 Original Creep Data (continued)

Form	Temper	Testing Temperature		Stress			Duration h	Total Extension % ^(a)	Intercept %	Min. Creep Rate % per 1 000 h
		°C	°F	kg/mm ²	ton/in ²	psi				
Rod ⁽⁹⁾	Precipitation Hardened after Cold Working 84%	400	752	16.9	10.7	24 000	250 ^(b)	—	—	—
				18.3	11.6	26 000	93 ^(b)	—	—	—
				21.1	13.4	30 000	2 ^(b)	—	—	—
Wire ⁽¹³⁾ 1.6 mm diam. 0.064 in. diam.	Precipitation Hardened after Cold Working 58% then Cold Worked 63%	200	392	33.0	21.0	47 000	600 ^(b)	—	—	—
				35.2	22.3	50 000	30 ^(b)	—	—	—
				40.1	25.4	57 000	0.7 ^(b)	—	—	—

(a) Total extension = Initial Extension + Total creep = Initial Extension + Intercept + (Minimum Creep Rate x Duration).

(b) Rupture test.

(c) Total creep = Total extension - Initial extension.

(d) Elongation, % on $5.65 \sqrt{S_0}$.

(e) Specimen broke on loading.

(f) This value was originally reported in hbar; in this table it is given in kg/mm² to 3 significant figures.

(g) Elongation, % on 1 in.

(h) Stress-rupture test on creep machine.

(k) Test discontinued.

N.B.—Original values are printed in **bold type**; other values are converted.

—Data are available only for precipitation-hardened material.

—Further data can be obtained from the following papers:

■ Shapton, R. W. Discussion at CDA Symposium on Recent Developments in the Use of Copper in the Electrical Industry. Copper Development Association, England (1960), pp. 127-132 (fig. 10 gives graphed creep data for material stressed at 15 ton/in² for up to 1 000 h at 250°C).

■ Dooley, J., Hewett, D. N. and Rutherford, N. B. Copper-Zirconium: An Alloy for Advanced Electrical Design. CDA Symposium on the Effect of Research and Design on the Use of Copper in the Electrical Industry. Copper Development Association, England (1962), pp. 45-75. (fig. II gives graphed creep data for 33% cold-worked material stressed at 15 ton/in² for up to 1100 h at 225°C).

■ Sergeant, R. M. Cavity Formation in Copper Alloys. J. Inst. Metals, Vol. 96 (1968), pp. 197-201 (graphed stress-rupture data in temperature range 50-360°C for material in 5 different tempers).

■ Hodge, W. and Nippert, P. W. Zirconium-Copper Raises Level of Commutator Performance. Elec. Mnfng., Vol. 57 (1956), June, pp. 95-97, 354 (includes rupture strengths of notched and un-notched copper-chromium; test specimens parallel and transverse to rolling direction).

■ Priestler, P., Whitwham, D. and Herenguel, J. Fragilisation Sous Contrainte Maintenu à Chaud de l'Alliage Cu - 0.8% Cr. Mém. Sci. Rev. Mét., Vol. 68 (1971), pp. 665-676.

5.3.2.2 Stress for Designated Creep Rate

Form	Temper	Testing Temperature		Stress for Designated Creep Rate					
		°C	°F	0.01% per 1 000 h			0.1% per 1 000 h		
				kg/mm ²	ton/in ²	psi	kg/mm ²	ton/in ²	psi
Plate ⁽³⁾ 20 mm 0.79 in.	Precipitation Hardened	280	536	7.7	4.9	11 000	16.5	10.5	23 500
		320	608	3.2	2.0	4 600	10.8	6.9	15 400
		350	662	2.7	1.7	3 800	8.6	5.5	12 200
Rod ⁽¹²⁾ 19 mm diam. 0.735 in. diam.	Precipitation Hardened after Cold Working 60.5% then Cold Worked 4%	343	650	6.0	3.8	8 500	—	—	—

N.B.—Original values are printed in **bold type**; other values are converted.

—Data are available only for precipitation-hardened material.

5.3.2.3 Stress for Designated Extension

Form	Temper	Testing Temperature		Stress for Designated Extension											
		°C	°F	0.1% in 1 000 h			0.2% in 1 000 h			0.1% in 2 000 h			0.2% in 2 000 h		
				kg/mm ²	ton/in ²	psi	kg/mm ²	ton/in ²	psi	kg/mm ²	ton/in ²	psi	kg/mm ²	ton/in ²	psi
Rod ⁽¹⁴⁾	Precipitation Hardened after Cold Working	200	392	14.5	9.2	20 600	17.5	11.1	24 900	12.0	7.6	17 100	14.0	8.9	19 900

N.B.—Original values are printed in **bold type**; other values are converted.

—Data are available only for precipitation-hardened material.

—Further data can be obtained from the following paper:

■ Opie, W. R., Hsu, Y. T. and Smith, R. J. Properties of Cu-Mg-Zr and Cu-Cr-Zr-Mg Alloys with Improved Conductivity/Strength Characteristics. J. Inst. Metals, Vol. 98 (1970), pp. 204-207.

5.4 FATIGUE PROPERTIES

5.4.1 Fatigue Strength at Room Temperature

5.4.1.1 Solution-Heat-Treated Material

Form	Temper	Number of Cycles $\times 10^6$	Metric Units kg/mm ²		English Units ton/in ²		American Units psi	
			Tensile Strength	Fatigue Strength	Tensile Strength	Fatigue Strength	Tensile Strength	Fatigue Strength
Rod ⁽¹⁵⁾ 13 mm diam. 0.5 in. diam.	Solution Heat Treated and Cold Worked 91.8%	300	51	18 ^(a)	32.5	11.5 ^(a)	72 800	25 800 ^(a)

5.4.1.2 Precipitation-Hardened Material

Form	Temper	Number of Cycles $\times 10^6$	Metric Units kg/mm ²		English Units ton/in ²		American Units psi	
			Tensile Strength	Fatigue Strength	Tensile Strength	Fatigue Strength	Tensile Strength	Fatigue Strength
Rod ⁽¹⁵⁾ 13 mm diam. 0.5 in. diam.	Precipitation Hardened after Cold Working 91.8%	300	54.5	19.5 ^(a)	34.5	12.5 ^(a)	77 400	28 000 ^(a)
Rod ⁽⁸⁾ 25 mm diam. 1 in. diam.	Precipitation Hardened after Cold Working 20%	20	45	16 ^(b)	28.5	10 ^(b)	64 000	23 000 ^(b)
— ⁽¹⁶⁾ ^(c)	As Received	50	48	14 ^(d)	30.5	8.8 ^(d)	68 500	19 500 ^(d)

(a) Rotating-beam test.

(b) Rotating-cantilever test. Short test bar.

(c) Form not stated in original document.

(d) Rotating-bending test.

N.B.: Original values are printed in **bold type**; others values are converted.

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- (8) Private communication from Hohenzollernsche Hüttenverwaltung, Germany.
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