OXYGEN-FREE COPPER

Cu-OF

Common name . . . : Oxygen-Free High-Conductivity Copper

Commercially-pure high-conductivity copper made by remelting and pouring electrodeposited copper in a protective gas atmosphere or in vacuum. No oxygen is absorbed by the copper, which is thus free from oxide and deoxidants. The copper is cast into various shapes for hot and cold working to wrought forms, and is not susceptible to embrittlement when heated in a reducing atmosphere.

COMPOSITION (weight %)

Cu (+ Ag) . . . . 99.95 min.

1 SOME TYPICAL USES

Electrical:

A wide range of specialised applications such as radar and other electronic equipment, anodes for vacuum tubes, lead-in wires for lamps and vacuum tubes, glass-to-metal seals in electronic equipment, thermostatic control valves, rotor conductors for particularly large generators and motors, waveguides and flexible cables, cords and leads; electrical equipment for service at elevated temperatures in the presence of *reducing gases; anodes for electroplating, particularly in cyanide baths.*

Miscellaneous:

Suitable for any application where high conductivity is required, and which may involve heating in reducing gases either during joining processes or in service.

2 PHYSICAL PROPERTIES

	Metric Units	English Units
2.1 Density at 20 °C *68 °F*	8.9 g/cm³	0.321 lb/in³
2.2 Melting point	1 083 °C	1 981 °F
2.3 Coefficient of thermal expansion (linear) at:		
— 253 °C *— 423 °F* (1)	0.000 000 3 per °C	0.000 000 17 per °F
— 183 °C *— 297 °F* (1)	0.000 009 5 » »	0.000 005 28 » »
— 191 to 16 °C *— 312 to 61 °F* (2)	0.000 014 1 » »	0.000 007 83 » »
25 to 100 °C *77 to 212 °F* (2)	0.000 016 8 » »	0.000 009 33 » »
20 to 200 °C *68 to 392 °F* (3)	0.000 017 3 » »	0.000 009 61 » »
20 to 300 °C *68 to 572 °F* (4)	0.000 017 7 » »	0.000 009 83 » »
2.4 Specific heat (thermal capacity) at:		
— 253 °C *— 423 °F* (2)	0.003 1 cal/g °C	0.003 1 Btu/lb °F
— 150 °C *— 238 °F* (2)	0.067 4 »	0.067 4 »
— 50 °C *— 58 °F* (2)	0.086 2 »	0.086 2 »
20 °C *68 °F* (2)	0.092 1 »	0.092 1 »
100 °C *212 °F* (2)	0.093 9 »	0.093 9 »
200 °C *392 °F* (2)	0.096 3 »	0.096 3 »
2.5 Thermal conductivity at:		
— 253 °C *— 423 °F* (5)	2.63 cal cm/cm² s °C	635 Btu ft/ft² h °F
— 200 °C *— 328 °F* (5)	1.25 »	300 »
— 183 °C *— 297 °F* (5)	1.13 »	270 »
— 100 °C *— 148 °F* (6)	1.04 »	252 »
20 °C *68 °F*	0.94 »	227 »
100 °C *212 °F*	0.92 »	223 »
200 °C *392 °F* (6)	0.91 »	220 »
300 °C *572 °F*	0.90 »	217 »
2.6 Electrical conductivity (volume) at:		
— 200 °C *— 328 °F* (annealed) (a)	460 (b) m/ohm mm²	800 (b) % IACS
— 100 °C *— 148 °F* (») (a)	110 (b) »	190 (b) » »
20 °C *68 °F* (»)	58.00 - 58.9 »	100.0 - 101.5 » »
100 °C *212 °F* (») (a)	44 »	76 » »
200 °C *392 °F* (») (a)	34 »	58 » »
20 °C *68 °F* (fully cold worked) (a)	56.3 »	97.0 » »

continued overleaf

INDEX NUMBERS RELATE TO LITERATURE REFERENCES (see page 10); INDEX LETTERS RELATE TO FOOTNOTES AT END OF TABLE

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DATA SHEET No. A 4 Cu-OF

2 PHYSICAL PROPERTIES (continued)

	Metric Units		English Units	
2.7 Electrical resistivity (volume) at:				
— 200 °C — *328 °F* (annealed) [a]	0.002 2 [b] 0.22 [b]	ohm mm²/m microhm cm	1.3 [b] 0.085 [b]	ohms (circ mil/ft) microhm in
— 100 °C — *148 °F* (») [a]	0.009 1 [b] 0.91 [b]	ohm mm²/m microhm cm	5.5 [b] 0.36 [b]	ohms (circ mil/ft) microhm in
20 °C *68 °F* (»)	0.017 241 - 0.017 0 1.724 1 - 1.70	ohm mm²/m microhm cm	10.371 - 10.2 0.678 8 - 0.669	ohms (circ mil/ft) microhm in
100 °C *212 °F* (») [a]	0.022 7 2.27	ohm mm²/m microhm cm	13.6 0.89	ohms (circ mil/ft) microhm in
200 °C *392 °F* (») [a]	0.029 5 2.95	ohm mm²/m microhm cm	17.7 1.16	ohms (circ mil/ft) microhm in
20 °C *68 °F* (fully cold worked) [a]	0.017 8 1.78	ohm mm²/m microhm cm	10.7 0.700	ohms (circ mil/fl) microhm in
2.8 Temperature coefficient of electrical resistance at: [c]				
20 °C *68 °F* (annealed) applicable over range from — 100 to 200 °C *— 148 to 392 °F*	0.003 93 per °C (100 % IACS)		0.002 18 per °F (100 % IACS)	
20 °C *68 °F* (fully cold worked) applicable over range from 0 to 100 °C *32 to 212 °F*	0.003 81 » » (97 % IACS)		0.002 12 » » (97 % IACS)	
2.9 Modulus of elasticity (tension) at 20 °C *68 °F*:				
annealed	12 000	kg/mm²	17 000 000	lb/in²
cold worked	12 000 - 13 500	»	17 000 000 - 19 000 000	»
2.10 Modulus of rigidity (torsion) at 20 °C *68 °F*:				
annealed	4 500	kg/mm²	6 400 000	lb/in²
cold worked	4 500 - 5 000	»	6 400 000 - 7 000 000	»

(a) Based on annealed copper having a conductivity of 100 % IACS (58.00 m/ohm mm²) at 20 °C *(68 °F)*.

(b) Approximate value.

(c) — The temperature coefficients of resistance given can be used for calculating resistances within the temperature range shown, but these relate only to calculations based on a reference temperature of 20 °C *(68 °F)*.
If it is more convenient to base calculations upon some other reference temperature, different temperature coefficients of resistance must be applied; for example, in the case of annealed copper (100 % IACS), the temperature coefficient of resistance at 20 °C *(68 °F)* is 0.003 93 per °C *(0.002 18 per °F)*, whereas at 0 °C *(32 °F)* the value is 0.004 265 per °C *(0.002 37 per °F)*.

— The change in resistance of annealed copper with temperature is essentially linear over a very wide range of temperature. Thus, although a range of only 0 to 100 °C *(32 to 212 °F)* is usually quoted for the temperature coefficient at 20 °C *(68 °F)*, the same coefficient may be used for calculations within the wider range of — 100 to 200 °C *(— 148 to 392 °F)* without introducing an error greater than 1 %.
Comparatively little information is available on the resistance/temperature relationship for cold-worked copper and there is, therefore, less justification for extending the range for its coefficient beyond 0 to 100 °C *(32 to 212 °F)*.

— The temperature coefficient of resistance of copper can be assumed to be directly proportional to the conductivity value. Thus, for copper of 101 % IACS conductivity, the coefficient can be deduced by adding 1 % to the value relating to copper of 100 % IACS conductivity, i.e. the temperature coefficient corresponding to 101 % IACS conductivity can be taken to be 0.003 97 per °C *(0.002 20 per °F)*. However, as the use of this modified coefficient changes the calculated value of resistance at 100 °C *(212 °F)* by less than 0.5 %, adjustment of the temperature coefficient to take account of minor variations in conductivity is rarely considered to be worth while.

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.

	Metric Units	English Units
3.1 Casting temperature range [a]	1 120 - 1 200 °C	2 050 - 2 190 °F
3.2 Annealing temperature range	200 - 650 °C	390 - 1 200 °F
Stress relieving temperature range	150 - 200 °C	300 - 390 °F
3.3 Hot working temperature range	750 - 950 °C	1 400 - 1 750 °F
3.4 Hot formability	Good	
3.5 Cold formability	Excellent	
3.6 Cold reduction between anneals	95 % max.	
3.7 Machinability:	See General Data Sheet No. 2	
Machinability rating (free-cutting brass = 100)	20	
3.8 Joining methods:	See General Data Sheet No. 3.1	
Soldering	Excellent	
Brazing	Excellent	
Oxy-acetylene welding	Fair	
Carbon-arc welding	Fair	
Gas-shielded arc welding	Good	
Coated metal-arc welding	Not recommended	
Resistance welding: spot and seam	Not recommended	
butt	Good	

(a) Optimum casting temperature range 1 120 - 1 150 °C *(2 050 - 2 100 °F)*.

4 NATIONAL SPECIFICATIONS FOR MANUFACTURED FORMS

Country	Designation of Standards	Designation of Material in Standards	Specification for Chemical Composition[a]	Plate Sheet Strip	Rod	Wire	Tube	Forgings	Sections / Shapes
Australia	SAA	—	—	AS-H17	—	—	—	—	—
Belgium	NBN	Cu OF	—	266.01	266.01	266.01	266.01	—	266.01
Canada	CSA	Cu-OF 102	—	—	—	—	HC.7.1	—	—
Chile	INDITECNOR	Cu-OF	244 p	196 ch	—	360 ch 361 ch 362 ch 364 ch	395 ch	—	—
France	NF	Cu/c1	A53-100	A53-601	A53-301	C31-111 C31-112	A53-501	A53-301	A53-301
Germany	DIN	SE-Cu(2.0070)	1787	17670	17672	17672	17671	17673	17674
Italy	UNI	Cu-OF	5649	—	—	—	—	—	—
Netherlands . .	N or NEN[b]	Cu-OF	NEN 6023	—	—	N173	NEN 2263	—	—
South Africa . .	SABS	—	—	—	—	—	—	—	—
Spain	UNE	—	—	—	—	—	—	—	—
Sweden	SIS	Cu-OF	—	—	14 50 11	—	14 50 11	—	—
Switzerland . . .	VSM	Cu-OF	10826	11852	11852	11852	11852	—	11852
United Kingdom .	BS	C103	1861	899 1432 2875 2870	1433 2874	2873	1977 2871	—	2874
United States[c] .	ASTM	OF	—	B48 B124 B133 B152 B187 B272	B12 B49 B124 B133 B187	B1 B2 B3 B33 B189 B298	B42 B68 B75 B188 B280 B395	B283	B124 B133 B187

(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.
(c) In the United States, bar and flat wire are covered under the Plate-Sheet-Strip column.

5 MECHANICAL PROPERTIES

5.1 Mechanical properties at room temperature

Tensile properties	see tables 5.1.1/2/3
Hardness	» » 5.1.1/2/3
Shear strength	» » 5.1.1/2/3
Modulus of elasticity (tension)	see 2.9
Modulus of rigidity (torsion)	» 2.10

5.2 Mechanical properties at low temperature

Tensile properties	see table 5.2.1
Impact properties	» » 5.2.1

5.3 Mechanical properties at elevated temperature

Short-time tensile properties	see table 5.3.1
Creep properties	» » 5.3.2

5.4 Fatigue properties

Fatigue strength at room temperature	see table 5.4.1

5.1 MECHANICAL PROPERTIES AT ROOM TEMPERATURE [a]

5.1.1 Typical Tensile Properties and Hardness Values - Metric Units

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 below or above the typical values indicated.

Form	Temper	Tensile Strength kg/mm²	Proof Stress 0.2 % offset kg/mm²	Elongation %	Elongation gauge length	Hardness Brinell	Hardness Vickers	Shear Strength kg/mm²	Typical Size Related to Properties Shown [b]
Plate Sheet Strip	Annealed	22	5	48	$5.65\sqrt{S_o}$	45	50	16	—
	Hot Rolled	23	8	40	$5.65\sqrt{S_o}$	55	60	16	—
	Typical Cold Worked Tempers	27	18	25	$5.65\sqrt{S_o}$	75	80	18	0.2 - 10 mm thick
		32	27	12	$5.65\sqrt{S_o}$	90	100	19	0.2 - 6 mm thick
		38	34	6	$5.65\sqrt{S_o}$	105	115	20	0.2 - 1.5 mm thick
Rod	Annealed	22	5	45	$5.65\sqrt{S_o}$	45	50	16	—
	Typical Cold Worked Tempers	28	19	20	$5.65\sqrt{S_o}$	75	80	18	6 - 40 mm diam. or up to 1 250 mm² area
		34	28	10	$5.65\sqrt{S_o}$	95	105	19	6 - 20 mm diam. or up to 300 mm² area
Wire	Annealed	23	—	37	200 mm	—	—	16	over 3 mm diam.
		24	—	35	200 mm	—	—	16	3 - 1 mm diam.
		26	—	28	200 mm	—	—	17	1 - 0.5 mm diam.
		—	—	26	200 mm	—	—	—	0.5 - 0.2 mm diam.
	Typical Cold Drawn Tempers	38	—	—	—	—	—	20	over 6 mm diam.
		42	—	—	—	—	—	22	6 - 3 mm diam.
		45	—	—	—	—	—	23	up to 3 mm diam.
Tube	Annealed	24	6	45	$5.65\sqrt{S_o}$	45	50	16	—
	Typical Cold Drawn Tempers	27	18	30	$5.65\sqrt{S_o}$	75	80	18	10 - 200 mm O.D. up to 10 mm wall
		32	27	15	$5.65\sqrt{S_o}$	90	100	19	10 - 100 mm O.D. up to 6 mm wall
		35	30	8	$5.65\sqrt{S_o}$	100	110	20	10 - 50 mm O.D. up to 2 mm wall
		38	35	6	$5.65\sqrt{S_o}$	105	115	20	up to 25 mm O.D. up to 1 mm wall
Forgings	Hot Worked	23	6	35	$5.65\sqrt{S_o}$	50	55	16	—
Sections / Shapes	Hot Worked	24	8	35	$5.65\sqrt{S_o}$	50	55	16	—
	Typical Cold Worked Tempers [c]	27	18	20	$5.65\sqrt{S_o}$	75	80	18	—
		32	27	10	$5.65\sqrt{S_o}$	90	100	19	—

(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, English and American units, respectively, are not directly comparable. This is because the properties quoted reflect to some extent the metalworking techniques and specification practices of the countries concerned.

(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 suppliers.

(c) The mechanical properties will be largely dependent upon the complexity and cross-section of the product.

5.1.2 Typical Tensile Properties and Hardness Values - English Units

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 below or above the typical values indicated.

Form	Temper	Tensile Strength ton/in²	Proof Stress 0.1 % offset ton/in²	Elongation %	Elongation gauge length	Vickers Hardness	Shear Strength ton/in²	Typical Size Related to Properties Shown [a]
Plate Sheet Strip	Annealed	14	3	50	2 in.	50	10	—
	Hot Rolled	15	6	45	2 in.	65	10	over 0.25 in. thick
	Typical Cold Worked Tempers	16	9	45	2 in.	75	11	0.006 - 0.5 in. thick
		17	14	30	2 in.	85	11	0.006 - 0.25 in. thick
		23	20	10	2 in.	110	13	0.006 - 0.1 in. thick
Rod	Annealed	14	3	50	$5.65\sqrt{S_o}$	50	10	—
	Typical Cold Worked Tempers	17	13	30	$5.65\sqrt{S_o}$	85	11	0.25 - 1 in. diam. or up to 1 in² area
		20	16	17	$5.65\sqrt{S_o}$	105	12	»
Wire	Annealed	14	—	35	10 in.	—	10	over 0.05 in. diam.
		15	—	30	10 in.	—	10	over 0.036 up to 0.05 in. diam.
		16	—	25	10 in.	—	11	over 0.02 up to 0.036 in. diam.
		—	—	20	10 in.	—	—	over 0.005 up to 0.02 in. diam.
	Typical Cold Drawn Tempers	26	—	—	—	—	14	over 0.104 in. diam.
		29	—	—	—	—	15	over 0.064 up to 0.104 in. diam.
		30	—	—	—	—	15	up to 0.064 in. diam.
Tube	Annealed	15	5	50	2 in.	50	10	—
	Typical Cold Drawn Tempers	17	10	45	2 in.	80	11	4 - 8 in. O.D. up to 0.5 in. wall
		20	17	20	2 in.	100	12	»
		18	12	30	2 in.	85	12	0.5 - 4 in. O.D. up to 0.2 in. wall
		24	21	10	2 in.	110	13	»
Forgings	Hot Worked	15	6	35	$5.65\sqrt{S_o}$	60	10	—
Sections (extruded)	Typical Cold Drawn Tempers [b]	16	11	27	$5.65\sqrt{S_o}$	80	10	—
		20	16	15	$5.65\sqrt{S_o}$	105	12	—

(a) 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 suppliers.

(b) The mechanical properties will be largely dependent upon the complexity and cross-section of the product.

5.1.3 Typical Tensile Properties and Hardness Values - American Units

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 below or above the typical values indicated.

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)	As Hot Rolled	34 000	10 000	45	2 in.	45	—	—	23 000	0.040 in. thick
	Annealed	32 000	10 000	45	2 in.	40	—	—	22 000	0.040 in. thick
	Cold Worked									
	Light Cold Rolled	36 000	28 000	30	2 in.	60	10	25	25 000	0.040 in. thick
	Half Hard	42 000	36 000	14	2 in.	84	40	50	26 000	»
	Hard	50 000	45 000	6	2 in.	90	50	57	28 000	»
	Spring	55 000	50 000	4	2 in.	94	60	63	29 000	»
	Extra Spring	57 000	53 000	4	2 in.	95	62	64	29 000	»
	Light Cold Rolled	36 000	28 000	40	2 in.	60	10	—	25 000	0.250 in. thick
	Hard	50 000	45 000	12	2 in.	90	50	—	28 000	»
	Hard	45 000	40 000	20	2 in.	85	45	—	26 000	1.0 in. thick
Rod	As Hot Rolled	32 000	10 000	55	2 in.	40	—	—	22 000	1.0 in. diam.
	Soft	32 000	10 000	55	2 in.	40	—	—	22 000	1.0 in. diam.
	Cold Worked Hard	48 000	44 000	16	2 in.	87	47	—	27 000	1.0 in. diam.
Wire	Annealed-Soft	40 000	—	17	10 in.	—	—	—	—	0.008 - 0.020 in. diam.
		38 000	—	23	10 in.	—	—	—	—	0.021 - 0.039 in. diam.
		35 000	—	27	10 in.	—	—	—	—	0.040 - 0.118 in. diam.
		35 000	—	33	10 in.	—	—	—	—	over 0.118 in. diam.
	Cold Worked									
	Medium Hard Drawn	56 000	—	1	60 in.	—	—	—	—	0.008 - 0.039 in. diam.
	Hard Drawn	67 000	—	1	60 in.	—	—	—	—	»
	Medium Hard Drawn	54 000	—	1.5	60 in.	—	—	—	—	0.040 - 0.118 in. diam.
	Hard Drawn	65 000	—	1	60 in.	—	—	—	—	»
	Medium Hard Drawn	49 000	—	2.5	10 in.	—	—	—	—	over 0.118 in. diam.
	Hard Drawn	57 000	—	2	10 in.	—	—	—	—	»
Tube	Annealed	32 000	10 000	45	2 in.	40	—	—	22 000	1.0 in. O.D. x 0.065 in. wall
	Cold Worked									
	Light Drawn	40 000	32 000	25	2 in.	77	35	45	26 000	1.0 in. O.D. x 0.065 in. wall
	Drawn	42 000	35 000	17	2 in.	85	—	—	27 000	»
	Hard Drawn	55 000	50 000	8	2 in.	95	60	63	29 000	»
Forgings	As Forged	33 000	11 000	45	2 in.	37	—	—	23 000	—
Shapes	As Hot Rolled	32 000	10 000	50	2 in.	40	—	—	22 000	0.50 in. thick
	Annealed-Soft	32 000	10 000	50	2 in.	40	—	—	22 000	0.50 in. thick
	Cold Worked [b] Hard	40 000	32 000	30	2 in.	—	35	—	26 000	0.50 in. thick

(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 suppliers.

(b) The mechanical properties will be largely dependent upon the complexity and cross-section of the product.

5.2 MECHANICAL PROPERTIES AT LOW TEMPERATURE

5.2.1 Tensile Properties - Impact Properties

Form	Temper	Testing Temperature		Tensile Strength			Proof Stress			Elongation		Reduction of Area %	Impact Strength	
		°C	°F	kg/mm²	ton/in²	psi	0.2 % offset kg/mm²	0.1 % offset ton/in²	Yield Strength 0.5% ext. under load psi	%	gauge length		kg m/cm²	ft lb
Sheet [7] **0.25 mm 0.01 in.**	Annealed (grain size 0.014 mm)	Room	Room	22	14	**31 500**	—	**4.46** [a]	—	**40.0**	2 in.	—	—	—
		— 78	— 108	28	18	**40 000**	—	**4.50** [a]	—	**43.6**	2 in.	—	—	—
		— 196	— 321	39.5	24.5	**55 000**	—	**6.70** [a]	—	**51.5**	2 in.	—	—	—
		— 253	— 423	45.5	29	**65 000**	—	**8.95** [a]	—	**57.5**	2 in.	—	—	—
Sheet [8] **3.2 mm 0.125 in.**	Annealed (grain size 0.045 mm)	+ 24	+ 75	21.5	14	**30 920**	**7.47** [b]	—	**11 440**	**53.5**	2 in.	**95.0**	—	—
		— 40	— 40	25.5	16	**35 750**	**8.88** [b]	—	**13 270**	**55.8**	2 in.	**79.0**	—	—
		— 68	— 90	26.5	17	**37 800**	**7.73** [b]	—	**11 770**	**56.3**	2 in.	**79.7**	—	—
		— 196	— 321	36	23	**51 100**	**7.52** [b]	—	**11 500**	**58.3**	2 in.	**74.5**	—	—
	Cold Worked 5 - 7 %	+ 24	+ 75	23	14.5	**32 720**	**17.6** [b]	—	**25 350**	**44.0**	2 in.	**90.1**	—	—
		— 40	— 40	27	17	**38 050**	**18.6** [b]	—	**26 750**	**46.8**	2 in.	**74.3**	—	—
		— 68	— 90	28	18	**40 050**	**19.6** [b]	—	**28 080**	**40.0**	2 in.	**80.3**	—	—
		— 196	— 321	38	24	**54 000**	**21.3** [b]	—	**30 900**	**43.3**	2 in.	**61.0**	—	—
Sheet [8] **6.35 mm 0.25 in.**	Annealed (grain size 0.048 mm)	+ 24	+ 75	21.5	13.5	**30 620**	**6.47** [b]	—	**9 930**	**62.2**	2 in.	**77.4**	—	—
		— 40	— 40	24.5	15.5	**34 930**	**7.95** [b]	—	**12 080**	**60.8**	2 in.	**82.2**	—	—
		— 68	— 90	26	16.5	**36 730**	**6.73** [b]	—	**10 250**	**63.0**	2 in.	**79.4**	—	—
		— 196	— 321	35	22	**49 800**	**5.99** [b]	—	**9 720**	**68.5**	2 in.	**72.4**	—	—
	Cold Worked 5 - 7 %	+ 24	+ 75	22.5	14	**31 750**	**16.2** [b]	—	**23 250**	**53.6**	2 in.	**77.7**	—	—
		— 40	— 40	25.5	16	**35 980**	**16.6** [b]	—	**23 980**	**51.0**	2 in.	**78.8**	—	—
		— 68	— 90	27	17	**38 600**	**18.0** [b]	—	**25 650**	**55.5**	2 in.	**79.3**	—	—
		— 196	— 321	37	23.5	**52 400**	**19.4** [b]	—	**27 800**	**61.8**	2 in.	**71.9**	—	—
Rod [9] **4.5 mm diam. 0.177 in. diam.**	Annealed	Room	Room	22.5	14.5	**32 200**	**7.66** [b]	—	—	**53.8**	4 D	**86.2**	18.1 [c]	**52.5** [c]
		— 78	— 108	27.5	17.5	**39 100**	**8.16** [b]	—	—	**53.2**	4 D	**84.5**	19.7 [c]	**57.0** [c]
		— 197	— 323	36.5	23.5	**52 200**	**9.00** [b]	—	—	**60.1**	4 D	**84.1**	22.6 [c]	**65.5** [c]
		— 253	— 423	42.5	27	**60 700**	**9.21** [b]	—	—	**68.9**	4 D	**83.0**	21.9 [c]	**63.5** [c]
Rod [7] **19 mm diam. 0.75 in. diam.**	Cold Worked 40 %	Room	Room	37	23.5	**52 500**	**34.0** [b]	—	—	**20**	1 in.	**75**	—	—
		— 78	— 108	40	25.5	**57 200**	**38.0** [b]	—	—	**21**	1 in.	**80**	—	—
		— 196	— 321	48.5	31	**69 000**	**42.0** [b]	—	—	**36**	1 in.	**80**	—	—
		— 253	— 423	53.5	34.5	**77 000**	**44.3** [b]	—	—	**55**	1 in.	**80**	—	—
Square Wire [7] **2 mm 0.08 in.**	Annealed (grain size 0.011 mm)	Room	Room	25.5	16.5	**35 800**	—	—	—	**36**	1.2 in.	**90**	—	—
		— 78	— 108	30	19	**44 000**	—	—	—	**40**	1.2 in.	**85**	—	—
		— 196	— 321	41	26	**58 000**	—	—	—	**44**	1.2 in.	**83**	—	—
		— 253	— 423	50.5	32	**72 000**	—	—	—	**45**	1.2 in.	**82**	—	—

(a) This value was originally reported in psi; in this table it is given in ton/in² to 3 significant figures.

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

(c) Charpy V — notch, 55 x 10 x 5 mm subsize specimens; partially fractured samples (25 % fracture area); cross-sectional area 0.4 cm².

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 paper:

— McClintock, R.M., and Gibbons, H.P. Mechanical Properties of Structural Materials at Low Temperatures. U.S. Nat. Bureau of Standards Monograph 13 (1961).

5.3. MECHANICAL PROPERTIES AT ELEVATED TEMPERATURE

5.3.1 Short-Time Tensile Properties

Form	Temper	Testing Temperature		Tensile Strength			Proof Stress		Elongation % on 2 in
		°C	°F	kg/mm²	ton/in²	psi	0.2 % offset kg/mm²	Yield Strength 0.5 % ext. under load psi	
Sheet (8) 3.2 - 6.35 mm 0.125 - 0.25 in.	Annealed (grain size 0.045 mm)	24	75	21.5	13.5	**30 680**	**7.50** (a)	**11 380**	**56.3**
		100	212	19.5	12.5	**27 490**	**7.37** (a)	**11 090**	**55.4**
		204	400	16.5	10.5	**23 100**	**6.74** (a)	**10 100**	**56.9**
	Cold Worked 5 - 7 %	24	75	22	14	**31 600**	**15.6** (a)	**22 500**	**50.7**
		100	212	20	12.5	**28 340**	**15.0** (a)	**21 720**	**46.8**
		204	400	16	10.5	**23 940**	**13.2** (a)	**19 070**	**45.6**
Rod (8) 3.2 mm diam. 0.125 in. diam.	Annealed (grain size 0.025 mm)	24	75	24	15.5	**34 500**	4.78 (a)	**7 900**	**50.0**
		149	300	—	—	—	—	**6 800**	—
		204	400	—	—	—	—	**6 500**	—
		260	500	—	—	—	—	**5 800**	—
	Cold Worked 84 %	24	75	38.5	24.5	**54 500**	34.1 (a)	**49 500**	**9.0**
		149	300	—	—	—	—	**43 000**	—
		204	400	—	—	—	—	**19 700**	—
		260	500	—	—	—	—	**7 400**	—
Rod (10) 12.8 mm diam. 0.505 in. diam.	Annealed (grain size 0.025 mm)	24	75	22.5	14.5	**31 900**	**8.58** (a)	—	**51.0**
		43	110	21.5	13.5	**30 750**	**5.13** (a)	—	**62.5**
		121	250	19	12	**27 000**	**4.71** (a)	—	**65.0**
		149	300	18	11.5	**25 850**	**4.92** (a)	—	**62.5**
		260	500	14.5	9.5	**20 750**	**3.30** (a)	—	**50.0**
		315	600	12	8	**17 350**	**2.67** (a)	—	**40.0**
		371	700	10.5	6.5	**15 050**	**2.95** (a)	—	**34.0**
		426	800	8.5	5.5	**11 850**	**2.64** (a)	—	**29.0**
		482	900	7	4.5	**9 800**	**2.11** (a)	—	**31.0**
		648	1 200	3	2	**4 000**	**0.527** (a)	—	—
		815	1 500	1.5	1	**2 025**	**0.352** (a)	—	**24.0**
	Cold Worked 40 %	24	75	36	23	**51 100**	**35.4** (a)	—	**11.0**
		43	110	35.5	22.5	**50 400**	**33.7** (a)	—	**16.0**
		121	250	32.5	21	**46 500**	**31.5** (a)	—	**15.5**
		149	300	31	20	**44 450**	**29.8** (a)	—	**14.0**
		260	500	24	15	**34 000**	**20.3** (a)	—	**8.0**
		315	600	13.5	8.5	**19 100**	**4.57** (a)	—	**35.0**
		371	700	11	7	**15 400**	**2.11** (a)	—	**39.5**
		426	800	9	5.5	**12 500**	**2.11** (a)	—	**36.0**
		482	900	7	4.5	**9 700**	**0.703** (a)	—	**39.5**
		648	1 200	3	2	**4 075**	**0.527** (a)	—	**30.5**
		815	1 500	1.5	1	**2 040**	**0.281** (a)	—	**14.5**

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

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

— Further data can be obtained from the following papers:

- Lorig, C.H., Dahle, F.B., and Roberts, D.A. The Mechanical Properties of Copper at Elevated Temperatures. Metals and Alloys Vol. 9 (1938), No. 3. March (1938), pp. 63-67, 72.
- References (8) and (10) in the bibliography on page 10.

— The 0.1 % proof stress values are not available.

5.3.2 Creep Properties

Form	Temper	Testing Temperature °C	Testing Temperature °F	Stress kg/mm²	Stress ton/in²	Stress psi	Duration 1 000 h	Total Extension % (a)	Intercept %	Min. Creep Rate in % per 1 000 h
Strip (11) 2.54 mm 0.1 in.	Cold Worked 25 %	130	266	10	6.5	14 000	1.55	0.167 5	0.138	0.012
				14	9	20 000	1.55	0.295	0.228	0.026 5
		225	437	5.5	3.5	8 000	2.30	0.273	0.153	0.044 5
				10	6.5	14 000	2.75	1.58	0.278	0.375
				14	9	20 000	0.275	2.4 (b)	—	3.44
Rod (8) 3.2 mm diam. 0.125 in. diam.	Annealed (grain size 0.025 mm)	149	300	1.5	1	2 100	6.40	0.053	0.024	0.001 7
				2	1.5	3 050	6.50	0.128	0.049	0.007 5
				3	2	4 550	6.00	0.510	0.290	0.023
				4	2.5	6 000	6.50	1.370	0.847	0.040
				5.5	3.5	7 950	5.10	2.490	1.560	0.083
		204	400	1	0.7	1 300	6.00	0.072	0.022	0.006 5
				1.5	1	2 050	6.50	0.213	0.054	0.021
				2	1.5	3 100	6.00	0.580	0.256	0.049
				4	2	4 050	6.50	1.295	0.725	0.078
				4.5	3	6 100	6.50	1.459	2.65	0.12
				5	3.5	7 400	5.00	4.580	2.670	0.215
	Cold Worked 84 %	149	300	5.5	3.5	7 900	6.00	0.102	0.002	0.008 2
				5.5	3.5	7 900	9.43	0.130	0.002	0.008 2
				7	4.5	9 950	6.50	0.167	— 0.041	0.022 (c)
				14	9	20 000	5.70	2.574	— 5.33	1.36 (c)
				17.5	11	25 100	3.05	2.582	— 9.42	3.88 (c)
		204	400	0.7	0.5	1 050	6.50	0.059	0.042	0.001 1
				1.5	1	2 100	3.20	0.157	0.090	0.014
				2	1.5	3 050	6.00	0.422	0.185	0.034 5
				3	2	4 050	6.10	0.998	0.506	0.074
				4	2.5	5 600	6.00	2.077	1.190	0.14
				5	3	7 000	6.50	3.800	2.500	0.19
Square Wire (12) 6.5 mm 0.257 in.	Annealed (grain size 0.035 - 0.045 mm)	110	230	14	9	20 000	5.0	1.08 (d)	—	0.042
				17.5	11	25 000	5.0	1.33 (d)	—	0.067 (e)
		149	300	14	9	20 000	1.0	0.80 (d)	—	0.28
				17.5	11	25 000	0.9	1.4 (d)	—	0.48 (e)
	Cold Worked 5 %	300	572	5.5	3.5	8 000 (g)	0.029 8	0.25	—	3.2
				7.5	5	10 000 (g)	0.021 8	0.40	—	7.4
				10.5	6.5	15 000 (g)	0.024 3	1.36	—	25
				5.5	3.5	7 500	0.025 0	0.22	—	1.8
				7.5	5	10 750	0.024 3	0.35	—	4.0
				9	5.5	12 500	0.024 8	0.46	—	6.2
	Cold Worked 20 %	300	572	5.5	3.5	7 500	0.024 1	2.62	—	—
				9	5.5	12 500	0.020	2.73	—	—
	Cold Worked 30 %	300	572	9	5.5	12 500	0.012 1	8.94	—	—
	Cold Worked 40 %	300	572	5.5	3.5	7 500	0.003 25	2.74	—	—
	Cold Worked 84.4 %	110	230	14	9	20 000	5.00	0.046 (d)	—	0.006 5
				17.5	11	25 000	5.00	0.072 (d)	—	0.009 0
		149	300	10.5	6.5	15 000	1.00	0.4 (d)	—	0.029 (f)
				14	9	20 000	1.00	1.67 (d)	—	0.058 (f)
				17.5	11	25 000	0.68	1.67 (d)	—	0.068 (f)

(a) Total extension = Initial extension + Total creep = Initial extension + Intercept + (Minimum creep rate × Duration).
(b) Rupture test. - (c) Accelerating creep rate from third stage of creep. - (d) Total creep. - (e) Decreasing creep rate. - (f) Increasing creep rate (only approximate due to extremely short second stage). - (g) Compression test.

N.B.: — Original values are printed in **bold type**; other values are calculated.
— Further data can be obtained from the following papers:

- Jenkins, W.D., and Willard, W.A. Creep of Cold-Drawn Nickel, Copper, 70 per cent Nickel - 30 per cent Copper and 30 per cent Nickel - 70 per cent Copper Alloys. J. Res. Nat. Bureau of Standards Vol. 68 C (1962), pp. 59-76.
- Punched Card Code for High Temperature Strength Data of Metals and Alloys. American Society for Testing and Materials, Philadelphia, Pa. (1961).
- References (8) and (11) in the bibliography on page 10.

5.4 FATIGUE PROPERTIES

5.4.1 Fatigue Strength at Room Temperature

Form	Temper	Number of Cycles x 10^6	Metric Units kg/mm²		English Units ton/in²		American Units psi	
			Tensile Strength	Fatigue Strength	Tensile Strength	Fatigue Strength	Tensile Strength	Fatigue Strength
Rod [13]	Cold Worked 29.2 %	300	36	12 [a]	23	7.5 [a]	**51 000**	**17 000** [a]

[a] Rotating-beam test.

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

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(2) - Hodgman, C.D. ed. Handbook of Chemistry and Physics, 44th ed. The Chemical Rubber Publishing Company, Cleveland, Ohio. (1962).

(3) - Standards Handbook for Copper and Copper Alloy Wrought Mill Products. 5th ed. Copper Development Association, Inc. New York (1964). (CDA Pub. No. 101).

(4) - Hidnert, P. and Krider, H.S. Thermal Expansion of Some Copper Alloys, J. Res. Nat. Bureau of Standards, Vol. 39 (1947), p. 419.

(5) - Johnson, V.J. ed. A Compendium of the Properties of Materials at Low Temperature (Phase I). Part II - Properties of Solids. Pergamon Press. Oxford. (1961), p. 3.112-1.

(6) - Goldsmith, A. et al. Thermophysical Properties of Solid Materials, Vol. 1. MacMillan & Co, New York. (1961).

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(7) - McClintock, R.M., Van Gundy, D.A. and Kropschot, R.H. Low-Temperature Tensile Properties of Copper and Four Bronzes. A.S.T.M. Bulletin, September (1959), pp. 47-50.

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(9) - Warren, K.A., and Reed, R.P. Tensile and Impact Properties of Selected Materials from 20 to 300 °K. U.S. National Bureau of Standards Monograph 63 (1963).

(10) - Jenkins, W.D., Digges, T.G. and Johnson, C.R. Tensile Properties of Copper, Nickel, and 70 Per cent Copper - 30 Per cent Nickel and 30 Per cent Copper - 70 Per cent Nickel Alloys at High Temperatures. J. Res. Nat. Bureau of Standards Vol. 58 (1957), pp. 201-211.

(11) - Benson, N.D., McKeown, J. and Mends, N.D. The Creep and Softening Properties of Copper for Alternator Rotor Windings. J. of the Inst. of Metals, Vol. 80 (1951-52), pp. 131-142.

(12) - Schwope, A.D., Smith, K.F. and Jackson, L.R. The Comparative Creep Properties of Several Types of Commercial Coppers. Trans. A.I.M.E. Vol. 185 (1949) July, pp. 409-416.

(13) - Anderson, A.R. and Smith, C.S. Fatigue Tests on Some Copper Alloys. Proc. A.S.T.M. Vol. 41 (1941), pp. 849-858.