ELECTROLYTIC TOUGH-PITCH COPPER

Cu-ETP

Commercially-pure high-conductivity copper which has been refined by electrolytic deposition then melted and oxidised to the 'tough-pitch' condition with a controlled low oxygen content; it is subsequently cast into cakes, billets, wirebars, etc., for the fabrication of wrought forms by hot and cold working.

COMPOSITION (weight %)

Cu (+ Ag) . . . . . 99.90 min.

1 SOME TYPICAL USES

Electrical

All types of products, such as cables, overhead line conductors including railway electrification and telephone lines, motor, generator, transformer and instrument windings including enamelled wire, busbars, contacts, household and industrial wiring, radio and television parts, switches, terminals, earthing rods, commutator segments, co-axial lines; anodes for electroplating and electroforming.

Chemical

Plant equipment such as kettles, stills, vats and pans, food processing equipment, cooking utensils.

Mechanical

Heat exchange apparatus, numerous strip and wire products, automobile radiators and gaskets, pressings, nails, rivets.

Architectural and Building

Cladding and fascia work, rainwater pipes, roofing, gutters, flashings, decorative screens and trim, sections drawn on wood.

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)	3.10 cal cm/cm² s °C	750 Btu ft/ft² h °F
— 200 °C *— 328 °F* (5)	1.37 »	330 »
— 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 1
Cu-ETP
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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/ft) 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 [b]	200 - 650 °C	390 - 1 200 °F
Stress relieving temperature range [b]	150 - 200 °C	300 - 390 °F
3.3 Hot working temperature range [b]	750 - 950 °C	1 400 - 1 750 °F
3.4 Hot formability [b]	Good	
3.5 Cold formability	Excellent	
3.6 Cold reduction between anneals	90 % max.	
3.7 Machinability:	See General Data Sheet No. 2	
Machinability rating (free-cutting brass = 100)	20	
3.8 Joining methods [b]:	See General Data Sheet No. 3.1	
Soldering	Excellent	
Brazing	Good	
Oxy-acetylene welding	Not recommended	
Carbon-arc welding	Fair	
Gas-shielded arc welding	Fair	
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)*.

(b) Embrittlement will occur if this copper is heated in atmospheres containing an excess of hydrogen.

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	CuE	—	266.01 428	266.01 428	266.01 428	266.01 428	—	266.01 428
Canada	CSA	Cu-ETP 110	—	HC.4.1	HC.4.1 HC.5.10 HC.5.1	HC.5.25	—	HC.8.1	HC.5.1
Chile	INDITECNOR	Cu-ETP	244 p	196 ch	—	360 ch 361 ch 362 ch 364 ch	395 ch	—	—
France	NF	Cu/a1	A53-100	A53-601	A53-301	C31-111 C31-112 C31-211 C34-110 C34-800	A53-501	A53-301	A53-301
Germany	DIN	E-Cu (2.0060)	1787	17670 40500/1	17672 40500/3	17672 40500/4	17671 40500/2	17673	17674 40500/3
Italy	UNI	Cu-ETP	5649	3310 [b]	3310 [b]	3310 [b]	3310 [b]	—	3310 [b]
Netherlands	N or NEN [c]	Cu-ETP	NEN 6023	—	—	N 173 NEN 2354 NEN 3194	V2261 [d] V2262 [d] NEN 2263	—	NEN 2353
South Africa	SABS	Cu-ETPHC	804	—	—	98-1961 150-1957	—	—	—
Spain	UNE	Cu-e	37.103	—	—	—	—	—	—
Sweden	SIS	Cu-ETP	—	14 50 10	14 50 10	14 50 10	—	14 50 10	14 50 10
Switzerland	VSM	Cu-ETP	10826	11852	11852	11852	11852	—	11852
United Kingdom	BS	C101	1036	899 1432 2875 2870	1433 2874	4109 2873	1977 2871	—	1434 2874
United States [e]	ASTM	ETP	—	B48 B124 B133 B152 B187 B272	B49 B124 B133 B187	B1 B2 B3 B33 B47 B116 B189 B298	B111 B188 B395	B283	B124 B133 B187

(a) Applicable when the chemical composition is not given in the specifications for wrought forms.
(b) Under revision.
(c) Older specifications bear prefix N; for new specifications the NEN prefix is used.
(d) Draft specification.
(e) 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	$5.65\sqrt{S_0}$	50	10	—
	Typical Cold Worked Tempers	17	13	30	$5.65\sqrt{S_0}$	85	11	0.25 - 1 in. diam. or up to 1 in² area
		20	16	17	$5.65\sqrt{S_0}$	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	$5.65\sqrt{S_0}$	60	10	—
Sections (extruded)	Typical Cold Drawn Tempers [(b)]	16	11	27	$5.65\sqrt{S_0}$	80	10	—
		20	16	15	$5.65\sqrt{S_0}$	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] **3.2 mm 0.125 in.**	Annealed (grain size 0.040 mm)	+ 24	+ 75	22	14	**31 580**	**6.64** [a]	—	**10 170**	**57.5**	2 in.	**96.2**	—	—
		— 40	— 40	25	16	**35 330**	**7.45** [a]	—	**11 480**	**53.3**	2 in.	**59.5**	—	—
		— 68	— 90	26	16.5	**37 300**	**7.16** [a]	—	**11 100**	**55.0**	2 in.	**55.0**	—	—
		— 196	— 321	35.5	22.5	**50 400**	**7.06** [a]	—	**11 150**	**57.5**	2 in.	**51.5**	—	—
	Cold Worked 5 - 7 %	+ 24	+ 75	24.5	15.5	**34 520**	**22.0** [a]	—	**31 500**	**32.4**	2 in.	**63.3**	—	—
		— 40	— 40	28	17.5	**39 500**	**23.8** [a]	—	**34 050**	**34.0**	2 in.	**53.8**	—	—
		— 68	— 90	29.5	18.5	**41 800**	**24.5** [a]	—	**34 950**	**32.8**	2 in.	**50.5**	—	—
		— 196	— 321	39	25	**55 600**	**26.1** [a]	—	**37 250**	**45.0**	2 in.	**51.9**	—	—
Rod [8] **4.5 mm diam. 0.177 in. diam.**	Annealed	+ 18	+ 64	**24.1**	15.5	34 500	**3.9** [b]	—	—	**50.5**	45 mm	**71.4**	**10.0** [c]	36.2 [c]
		— 78	— 110	**29.2**	18.5	41 500	**10.0** [b]	—	—	**50.0**	45 mm	**73.6**	**9.5** [c]	34.4 [c]
		— 183	— 295	**36.5**	23	52 000	**8.7** [b]	—	—	**50.5**	45 mm	**83.3**	**9.1** [c]	32.9 [c]
	Cold Worked 50 %	+ 20	+ 68	**41.2**	26	58 500	**37.5** [b]	—	—	**8.4**	45 mm	**51.5**	**6.4** [c]	23.1 [c]
		— 78	— 110	**42.5**	27	60 500	**40.8** [b]	—	—	**12.0**	45 mm	**56.6**	**6.6** [c]	23.9 [c]
		— 183	— 295	**45.5**	29	65 000	**41.9** [b]	—	—	**11.2**	45 mm	**61.2**	**7.4** [c]	26.8 [c]
Rod [9] **6.35 mm diam. 0.25 in. diam.**	Annealed	+ 20	+ 68	22	**14.0**	31 500	—	**3.82**	—	**48.0**	2 in.	**76.5**	7.4 [d]	**43.0** [d]
		— 10	+ 14	22.5	**14.3**	32 000	—	**3.97**	—	**40.2**	2 in.	**78.0**	—	—
		— 40	— 40	24	**15.1**	34 000	—	**4.09**	—	**47.0**	2 in.	**77.0**	7.8 [d]	**45.0** [d]
		— 80	— 112	27	**17.2**	38 500	—	**4.50**	—	**47.0**	2 in.	**74.0**	7.6 [d]	**44.0** [d]
		— 120	— 184	29	**18.4**	41 000	—	**4.82**	—	**44.6**	2 in.	**70.0**	7.7 [d]	**44.5** [d]
		— 180	— 292	35.5	**22.7**	51 000	—	**5.12**	—	**57.6**	2 in.	**77.0**	8.6 [d]	**50.0** [d]
Square Rod [10] **40 mm 1.6 in.**	Hot Worked	+ 20	+ 68	**22.0**	14	31 500	**5.20**	—	—	**55** [e]	100 mm	**70**	—	—
		— 20	— 4	**23.8**	15	34 000	**5.20**	—	—	**56.2** [e]	100 mm	**70**	—	—
		— 60	— 76	**25.6**	16	36 500	**5.60**	—	—	**57.3** [e]	100 mm	**67**	—	—
		— 77	— 107	**26.4**	17	37 500	**5.20**	—	—	**57.2** [e]	100 mm	**68**	—	—

(a) This value was originally reported in psi; in this table it is given in kg/mm² to 3 significant figures.
(b) Quoted as yield point, but offset strain not defined.
(c) Charpy test, 10 x 8 x 100 mm specimen; 45° V-notch, 3 mm deep; cross-sectional area 0.5 cm².
(d) Izod specimen; cross-sectional area 0.8 cm².
(e) 20 mm diam. specimen.

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 (and vice versa) taking into account the actual cross-sectional area of the specimen at the notch.

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 (7) 3.2 - 6.35 mm 0.125 - 0.25 in.	Annealed (grain size 0.043 mm)	24	75	22	14	**31 000**	6.33 (a)	**9 930**	**57.8**
		100	212	19	12	**27 080**	6.48 (a)	**9 840**	**57.4**
		204	400	16	10	**22 750**	5.82 (a)	**8 690**	**56.8**
	Cold Worked 5 - 7 %	24	75	23	14.5	**32 630**	17.5 (a)	**25 380**	**41.3**
		100	212	20.5	13	**29 400**	16.6 (a)	**24 100**	**37.9**
		204	400	17.5	11	**24 700**	14.5 (a)	**21 000**	**34.1**
Rod (7) 3.2 mm diam. 0.125 in. diam.	Annealed (grain size 0.025 mm)	24	75	24.5	15.5	**35 100**	4.29 (a)	**7 200**	**50.0**
		149	300	—	—	—	—	**6 400**	—
		204	400	—	—	—	—	**5 800**	—
		260	500	—	—	—	—	**5 300**	—
	Cold Worked 84 %	24	75	39	24.5	**55 400**	34.8 (a)	**50 000**	**11.0**
		149	300	—	—	—	—	**43 000**	—
		204	400	—	—	—	—	**17 200**	—
		260	500	—	—	—	—	**7 700**	—
Rod (11) 19 mm diam. 0.75 in. diam.	Hot Worked	Room	Room	22.5	14.5	**32 350**	—	—	**60.0**
		65	150	21.5	13.5	**30 500**	—	—	**58.5**
		121	250	19	12	**27 200**	—	—	**61.5**
		177	350	18	11.5	**25 600**	—	—	**65.0**
		232	450	16	10	**22 850**	—	—	**68.5**
		288	550	14.5	9	**20 300**	—	—	**59.5**
		343	650	12.5	8	**17 750**	—	—	**56.0**
		426	800	9	6	**13 100**	—	—	**59.3**
		538	**1 000**	6	3.5	**8 250**	—	—	**74.3**
		620	**1 150**	4.5	3	**6 350**	—	—	**48.8**
		704	**1 300**	3	2	**4 400**	—	—	**54.5**
Rod (7) 19 mm diam. 0.75 in. diam.	Cold Worked 21 %	Room	Room	34	21.5	**48 100**	—	—	**17**
		260	500	26.5	17	**37 700**	—	—	**14**
		288	550	26	16.5	**37 200**	—	—	**14**
		315	600	24.5	15.5	**35 200**	—	—	**14**
		343	650	18.5	12	**26 600**	—	—	**25**
		371	700	12.5	8	**17 700**	—	—	**41**
		399	750	11.5	7	**16 100**	—	—	**39**
		426	800	11	6.5	**15 300**	—	—	**36**

(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 paper:
■ Crowe, C.H. Properties of Some Copper Alloys at Elevated Temperatures. A.S.T.M. Bull. No. 250 (1960), December, pp. 30-31.
— 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 (12) **2.54 mm** **0.1 in.**	Annealed (grain size 0.030 mm)	130	266	5.5	3.5	**8 000**	**2.50**	**2.6**	**2.0**	0.15
				9.5	6	**14 000**	**2.60**	**10.0**	**7.6**	1.2
				14	8.5	**20 000**	**0.17**	**29.8** (b)	—	39
		175	347	5.5	3.5	**8 000**	**2.00**	**3.3**	**2.3**	0.65
				9.5	6	**14 000**	**0.35**	**15** (b)	**8.0**	6.3
	Cold Worked 10 %	130	266	5.5	3.5	**8 000**	**8.25**	**0.20**	**0.15**	0.01
				9.5	6	**14 000**	**8.60**	**0.67**	**0.26**	0.042
				14	8.5	**20 000**	**1.750**	**2.4** (b)	**0.32**	0.45
		175	347	5.5	3.5	**8 000**	**6.85**	**1.14**	**0.135**	0.088
				9.5	6	**14 000**	**1.10**	**2.0** (b)	**0.22**	0.66
	Cold Worked 25 %	130	266	5.5	3.5	**8 000**	**7.20**	**0.235**	**0.125**	0.01
				9.5	6	**14 000**	**8.60**	**1.02**	**0.25**	0.054
				14	8.5	**20 000**	**4.68**	**3.4** (b)	**0.36**	0.27
		175	347	5.5	3.5	**8 000**	**1.05**	**3.3** (b)	—	0.6
	Cold Worked 50 %	130	266	5.5	3.5	**8 000**	**8.25**	**1.58**	**0.08**	0.035
				9.5	6	**14 000**	**8.70**	**7.31**	**0.16**	0.055
				14	8.5	**20 000**	**4.030**	**11** (b)	**0.24**	0.17
Rod (7) **3.2 mm diam.** **0.125 in. diam.**	Annealed (grain size 0.025 mm)	**149**	300	1.5	1	**2 050**	**6.40**	**0.088**	**0.048**	**0.003 2**
				2	1.5	**3 000**	**6.50**	**0.257**	**0.133**	**0.013**
				4	2.5	**6 000**	**6.50**	**1.875**	**1.120**	**0.057 5**
				5.5	3.5	**8 100**	**6.50**	**3.475**	**1.795**	**0.088**
		204	400	1	0.7	**1 550**	**6.00**	**0.168**	**0.067**	**0.014**
				1.5	1	**2 050**	**6.50**	**0.359**	**0.168**	**0.026**
				2	1.5	**3 050**	**6.00**	**1.050**	**0.510**	**0.083**
				2.5	2	**4 000**	**6.50**	**2.042**	**1.232**	**0.11**
				4	2.5	**6 100**	**6.00**	**2.485**	**0.668**	**0.204**
				5	3	**7 050**	**4.50**	**3.900**	**2.750**	**0.267**
		260	500	0.3	0.2	**360**	**6.00**	**0.084**	**0.016**	**0.011**
				0.5	0.3	**600**	**6.00**	**0.195**	**0.010**	**0.030**
				0.7	0.5	**1 050**	**6.50**	**0.640**	**0.113**	**0.079 5**
				1.5	0.9	**2 000**	**6.50**	**2.877**	**0.869**	**0.306**
	Cold Worked 84 %	149	300	5	3	**7 550**	**6.40**	**0.118**	**0.041**	**0.004 9**
				7	4.5	**10 000**	**6.50**	**0.167**	**0.042**	**0.010**
				10	6.5	**14 650**	**6.40**	**0.540**	**— 0.170**	**0.097** (c)
				14	9	**20 000**	**6.50**	**2.330**	**— 3.00**	**0.80** (c)
				17.5	11	**25 200**	**1.78**	**2.565**	**— 4.98**	**4.14** (c)
		204	400	0.7	0.5	**1 050**	**6.50**	**0.064**	**0.045**	**0.001 1**
				1.5	1	**2 100**	**6.00**	**0.203**	**0.112**	**0.011 5**
				2.5	2	**4 050**	**6.50**	**1.080**	**0.409**	**0.097**
				5	3	**7 100**	**6.50**	**5.418**	**2.47**	**0.44**
Square Wire (13) **6.5 mm** **0.257 in.**	Annealed	121	250	17.5	11	**25 000**	**1.44**	**1.75** (d)	—	— (e)
	Cold Worked 10 %	121	250	17.5	11	**25 000**	**2.20**	**1.85** (d)	—	— (e)
	Cold Worked 37.1 %	121	250	17.5	11	**25 000**	**4.80**	**0.40** (d)	—	**0.056**
	Cold Worked 84.4 %	121	250	17.5	11	**25 000**	**1.18**	**1.75** (d)	—	— (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 does not include the initial elastic elongation - (e) Decreasing creep rate - (f) Accelerating creep rate.

N.B.: — Original values are printed in **bold type**; other values are calculated.
— Further data can be obtained from references (7) and (12) 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
Strip (14) 0.5 mm 0.02 in.	Annealed	100	22	7.5 (a)	14	5 (a)	**31 400**	**11 000 (a)**
	Cold Worked 20 %	100	31	9 (a)	20	6 (a)	**44 400**	**13 000 (a)**
	Cold Worked 60 %	100	37	10 (a)	23.5	6.5 (a)	**52 600**	**14 000 (a)**
Strip (15) 0.8 mm 0.032 in.	Cold Worked 21 %	100	29	8.5 (a)	18.5	5.5 (a)	**41 000**	**12 000 (a)**
	Cold Worked 37 %	100	34.5	9 (a)	22	6 (a)	**49 300**	**13 000 (a)**
	Cold Worked 60 %	100	40.5	7.5 (a)	25.5	5 (a)	**57 700**	**11 000 (a)**
Flat Products (16) 1 mm 0.04 in.	Annealed (grain size 0.025 mm)	100	24	7.5 (a)	15	5 (a)	**34 000**	**11 000 (a)**
	Cold Worked 21 %	100	29.5	9 (a)	18.5	6 (a)	**42 000**	**13 000 (a)**
	Cold Worked 37 %	100	35	9 (a)	22.5	6 (a)	**50 000**	**13 000 (a)**
	Cold Worked 60 %	100	38.5	10 (a)	24.5	6.5 (a)	**55 000**	**14 000 (a)**
Rod (17) 7.6 mm diam. 0.3 in. diam.	Annealed (grain size 0.040 mm)	300	22	6.5 (b)	14	4 (b)	**31 100**	**9 000 (b)**
	Cold Worked 36 %	300	34.5	12 (b)	22	7.5 (b)	**48 800**	**17 000 (b)**
Rod (18) 16 mm diam. 0.625 in. diam.	Cold Worked 30 %	100	31	11.5 (b)	19.5	7.5 (b)	**44 000**	**16 500 (b)**
Rod (16) 25.4 mm diam. 1 in. diam.	Cold Worked 35 %	300	33.5	12 (b)	21.5	7.5 (b)	**48 000**	**17 000 (b)**
Wire (19) 2 mm diam. 0.08 in. diam.	Cold Worked 37 %	100	36 - 41	11 (a)	22.5 - 26	7 (a)	**51 000 - 58 000**	**15 500 (a)**

(a) Reversed-bending test. (b) Rotating-beam test.

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

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FIRE-REFINED TOUGH-PITCH HIGH-CONDUCTIVITY COPPER

Cu-FRHC

Commercially-pure high-conductivity copper which is furnace refined without at any stage having been electrolytically refined. It is melted and oxidised to the 'tough-pitch' condition with a controlled oxygen content, cast into cakes, billets, wirebars, etc., and finally hot and cold worked into wrought forms. The maximum impurity limits are slightly higher than in Cu-ETP (electrolytic 'tough-pitch' copper) but the same minimum conductivity requirements apply.

COMPOSITION (weight %)

Cu (+ Ag) . . . . . 99.90 min.

1 SOME TYPICAL USES

Electrical:

Numerous types of products, such as cables, overhead line conductors including railway electrification and telephone lines, motor, generator, transformer and instrument windings, busbars, contacts, household and industrial wiring, radio and television parts, switches, terminals, earthing rods, commutator segments, co-axial lines; anodes for electroplating and electroforming.

Chemical:

Plant equipment such as kettles, stills, vats and pans, food processing equipment, cooking utensils.

Mechanical:

Heat exchange apparatus, numerous strip and wire products, automobile radiators and gaskets, pressings, nails, rivets.

Architectural and Building:

Cladding and fascia work, rainwater pipes, roofing, gutters, flashings, decorative screens and trim, sections drawn on wood.

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]	3.10 cal cm/cm² s °C	750 Btu ft/ft² h °F
	— 200 °C *— 328 °F* [5]	1.37 »	330 »
	— 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 2
Cu-FRHC
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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/ft) 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 [b]	200 - 650 °C	390 - 1 200 °F
Stress relieving temperature range [b]	150 - 200 °C	300 - 390 °F
3.3 Hot working temperature range [b]	750 - 950 °C	1 400 - 1 750 °F
3.4 Hot formability [b]	Good	
3.5 Cold formability	Excellent	
3.6 Cold reduction between anneals	90 % max.	
3.7 Machinability:	See General Data Sheet No. 2	
Machinability rating (free-cutting brass = 100)	20	
3.8 Joining methods: [b]	See General Data Sheet No. 3.1	
Soldering	Excellent	
Brazing	Good	
Oxy-acetylene welding	Not recommended	
Carbon-arc welding	Fair	
Gas-shielded arc welding	Fair	
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)*.

[b] Embrittlement will occur if this copper is heated in atmospheres containing an excess of hydrogen.

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	—	—	—	—	—	—	—	—
Canada	CSA	Cu-FRHC	—	—	—	—	—	—	—
Chile	INDITECNOR	Cu-FRHC	244 p	146 ch	—	360 ch 361 ch 362 ch 364 ch	—	—	—
France	NF	Cu/a2	A53-100	A53-601	A53-301	C31-111 C31-112 C31-211 C34-110	A53-501	A53-301	A53-301
Germany	DIN	E-Cu(2.0060)	1787	17670 40500/1	17672 40500/3	17672 40500/4	17671 40500/2	17673	17674 40500/3
Italy	UNI	—	—	—	—	—	—	—	—
Netherlands	N or NEN [(b)]	Cu-FRHC	NEN 6023	—	—	N173	NEN 2263	—	—
South Africa	SABS	Cu-FRHC	805	—	—	—	—	—	—
Spain	UNE	—	—	—	—	—	—	—	—
Sweden	SIS	—	—	—	—	—	—	—	—
Switzerland	VSM	—	—	—	—	—	—	—	—
United Kingdom	BS	C102	1037	899 1432 2875 2870	1433 2874	2873 4109	1977 2871	—	1434 2874
United States [(c)]	ASTM	FRHC	—	B48 B124 B133 B272	B49 B124 B133	B1 B2 B3 B33 B47 B116 B189	—	B283	B124 B133

(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/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	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 mm^2 area
		34	28	10	$5.65\sqrt{S_o}$	95	105	19	6 - 20 mm diam. or up to 300 mm^2 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 17 23	9 14 20	45 30 10	2 in. 2 in. 2 in.	75 85 110	11 11 13	0.006 - 0.5 in. thick 0.006 - 0.25 in. thick 0.006 - 0.1 in. thick
Rod	Annealed	14	3	50	$5.65\sqrt{S_o}$	50	10	—
	Typical Cold Worked Tempers	17 20	13 16	30 17	$5.65\sqrt{S_o}$ $5.65\sqrt{S_o}$	85 105	11 12	0.25 - 1 in. diam. or up to 1 in² area »
Wire	Annealed	14 15 16 —	— — — —	35 30 25 20	10 in. 10 in. 10 in. 10 in.	— — — —	10 10 11 —	over 0.05 in. diam. over 0.036 up to 0.05 in. diam. over 0.02 up to 0.036 in. diam. over 0.005 up to 0.02 in. diam.
	Typical Cold Drawn Tempers	26 29 30	— — —	— — —	— — —	— — —	14 15 15	over 0.104 in. diam. over 0.064 up to 0.104 in. diam. up to 0.064 in. diam.
Tube	Annealed	15	5	50	2 in.	50	10	—
	Typical Cold Drawn Tempers	17 20 18 24	10 17 12 21	45 20 30 10	2 in. 2 in. 2 in. 2 in.	80 100 85 110	11 12 12 13	4-8 in. O.D. up to 0.5 in. wall » 0.5-4 in. O.D. up to 0.2 in. wall »
Forgings	Hot Worked	15	6	35	$5.65\sqrt{S_o}$	60	10	—
Sections (extruded)	Typical Cold Drawn Tempers (b)	16 20	11 16	27 15	$5.65\sqrt{S_o}$ $5.65\sqrt{S_o}$	80 105	10 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 %	Elongation gauge length	Rockwell Hardness F	Rockwell Hardness B	Rockwell Hardness 30 T	Shear Strength psi	Typical Size Related to Properties Shown [a]
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 °C	Testing Temperature °F	Tensile Strength kg/mm²	Tensile Strength ton/in²	Tensile Strength psi	Proof Stress 0.2 % offset kg/mm²	Proof Stress 0.1 % offset ton/in²	Proof Stress Yield Strength 0.5% ext. under load psi	Elongation %	Elongation gauge length	Reduction of Area %	Impact Strength kg m/cm²	Impact Strength ft lb
Sheet (7) 3.2 mm 0.125 in.	Annealed (grain size 0.040 mm)	+ 24	+ 75	22	14	**31 580**	**6.64** (a)	—	**10 170**	**57.5**	2 in.	**96.2**	—	—
		— 40	— 40	25	16	**35 330**	**7.45** (a)	—	**11 480**	**53.3**	2 in.	**59.5**	—	—
		— 68	— 90	26	16.5	**37 300**	**7.16** (a)	—	**11 100**	**55.0**	2 in.	**55.0**	—	—
		— 196	— 321	35.5	22.5	**50 400**	**7.06** (a)	—	**11 150**	**57.5**	2 in.	**51.5**	—	—
	Cold Worked 5 - 7 %	+ 24	+ 75	24.5	15.5	**34 520**	**22.0** (a)	—	**31 500**	**32.4**	2 in.	**63.3**	—	—
		— 40	— 40	28	17.5	**39 500**	**23.8** (a)	—	**34 050**	**34.0**	2 in.	**53.8**	—	—
		— 68	— 90	29.5	18.5	**41 800**	**24.5** (a)	—	**34 950**	**32.8**	2 in.	**50.5**	—	—
		— 196	— 321	39	25	**55 600**	**26.1** (a)	—	**37 250**	**45.0**	2 in.	**51.9**	—	—
Rod (8) 4.5 mm diam. 0.177 in. diam.	Annealed	+ 18	+ 64	**24.1**	15.5	34 500	**3.9** (b)	—	—	**50.5**	45 mm	**71.4**	**10.0** (c)	36.2 (c)
		— 78	— 110	**29.2**	18.5	41 500	**10.0** (b)	—	—	**50.0**	45 mm	**73.6**	**9.5** (c)	34.4 (c)
		— 183	— 295	**36.5**	23	52 000	**8.7** (b)	—	—	**50.5**	45 mm	**83.3**	**9.1** (c)	32.9 (c)
	Cold Worked 50 %	+ 20	+ 68	**41.2**	26	58 500	**37.5** (b)	—	—	**8.4**	45 mm	**51.5**	**6.4** (c)	23.1 (c)
		— 78	— 110	**42.5**	27	60 500	**40.8** (b)	—	—	**12.0**	45 mm	**56.6**	**6.6** (c)	23.9 (c)
		— 183	— 295	**45.5**	29	65 000	**41.9** (b)	—	—	**11.2**	45 mm	**61.2**	**7.4** (c)	26.8 (c)
Rod (9) 6.35 mm diam. 0.25 in. diam.	Annealed	+ 20	+ 68	22	**14.0**	31 500	—	**3.82**	—	**48.0**	2 in.	**76.5**	7.4 (d)	**43.0** (d)
		— 10	+ 14	22.5	**14.3**	32 000	—	**3.97**	—	**40.2**	2 in.	**78.0**	—	—
		— 40	— 40	24	**15.1**	34 000	—	**4.09**	—	**47.0**	2 in.	**77.0**	7.8 (d)	**45.0** (d)
		— 80	— 112	27	**17.2**	38 500	—	**4.50**	—	**47.0**	2 in.	**74.0**	7.6 (d)	**44.0** (d)
		— 120	— 184	29	**18.4**	41 000	—	**4.82**	—	**44.6**	2 in.	**70.0**	7.7 (d)	**44.5** (d)
		— 180	— 292	35.5	**22.7**	51 000	—	**5.12**	—	**57.6**	2 in.	**77.0**	8.6 (d)	**50.0** (d)
Square Rod (10) 40 mm 1.6 in.	Hot Worked	+ 20	+ 68	**22.0**	14	31 500	**5.20**	—	—	**55** (e)	100 mm	**70**	—	—
		— 20	— 4	**23.8**	15	34 000	**5.20**	—	—	**56.2** (e)	100 mm	**70**	—	—
		— 60	— 76	**25.6**	16	36 500	**5.60**	—	—	**57.3** (e)	100 mm	**67**	—	—
		— 77	— 107	**26.4**	17	37 500	**5.20**	—	—	**57.2** (e)	100 mm	**68**	—	—

(a) This value was originally reported in psi; in this table it is given in kg/mm² to 3 significant figures.
(b) Quoted as yield point, but offset strain not defined.
(c) Charpy test, 10 x 8 x 100 mm specimen; 45° V-notch, 3 mm deep; cross-sectional area 0.5 cm².
(d) Izod specimen; cross-sectional area 0.8 cm².
(e) 20 mm diam. specimen.

N.B.: — Values obtained using Cu-ETP (electrolytic ' tough-pitch ' copper) test specimens; it is assumed that Cu-FRHC exhibits the same mechanical properties at low temperatures.
— 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 (and vice versa) taking into account the actual cross-sectional area of the specimen at the notch.

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 (7) 3.2 - 6.35 mm 0.125 - 0.25 in.	Annealed (grain size 0.043 mm)	24	75	22	14	**31 000**	6.33 (a)	**9 930**	**57.8**
		100	212	19	12	**27 080**	6.48 (a)	**9 840**	**57.4**
		204	400	16	10	**22 750**	5.82 (a)	**8 690**	**56.8**
	Cold Worked 5 - 7 %	24	75	23	14.5	**32 630**	17.5 (a)	**25 380**	**41.3**
		100	212	20.5	13	**29 400**	16.6 (a)	**24 100**	**37.9**
		204	400	17.5	11	**24 700**	14.5 (a)	**21 000**	**34.1**
Rod (7) 3.2 mm diam. 0.125 in. diam.	Annealed (grain size 0.025 mm)	24	75	24.5	15.5	**35 100**	4.29 (a)	**7 200**	**50.0**
		149	300	—	—	—	—	**6 400**	—
		204	400	—	—	—	—	**5 800**	—
		260	500	—	—	—	—	**5 300**	—
	Cold Worked 84 %	24	75	39	24.5	**55 400**	34.8 (a)	**50 000**	**11.0**
		149	300	—	—	—	—	**43 000**	—
		204	400	—	—	—	—	**17 200**	—
		260	500	—	—	—	—	**7 700**	—
Rod (11) 19 mm diam. 0.75 in. diam.	Hot Worked	Room	Room	22.5	14.5	**32 350**	—	—	**60.0**
		65	150	21.5	13.5	**30 500**	—	—	**58.5**
		121	250	19	12	**27 200**	—	—	**61.5**
		177	350	18	11.5	**25 600**	—	—	**65.0**
		232	450	16	10	**22 850**	—	—	**68.5**
		288	550	14.5	9	**20 300**	—	—	**59.5**
		343	650	12.5	8	**17 750**	—	—	**56.0**
		426	800	9	6	**13 100**	—	—	**59.3**
		538	1 000	6	3.5	**8 250**	—	—	**74.3**
		620	1 150	4.5	3	**6 350**	—	—	**48.8**
		704	1 300	3	2	**4 400**	—	—	**54.5**
Rod (7) 19 mm diam. 0.75 in. diam.	Cold Worked 21 %	Room	Room	34	21.5	**48 100**	—	—	**17**
		260	500	26.5	17	**37 700**	—	—	**14**
		288	550	26	16.5	**37 200**	—	—	**14**
		315	600	24.5	15.5	**35 200**	—	—	**14**
		343	650	18.5	12	**26 600**	—	—	**25**
		371	700	12.5	8	**17 700**	—	—	**41**
		399	750	11.5	7	**16 100**	—	—	**39**
		426	800	11	6.5	**15 300**	—	—	**36**

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

N.B.: — Values obtained using Cu-ETP (electrolytic 'tough-pitch' copper) test specimens; it is assumed that Cu-FRHC exhibits the same short-time tensile properties at elevated temperatures.

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

— Further data can be obtained from the following paper:

■ Crowe, C.H. Properties of Some Copper Alloys at Elevated Temperatures. A.S.T.M. Bull. No. 250 (1960), December, pp. 30-31.

— 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 (12) 2.54 mm 0.1 in.	Annealed (grain size 0.030 mm)	130	266	5.5	3.5	**8 000**	**2.50**	**2.6**	**2.0**	0.15
				9.5	6	**14 000**	**2.60**	**10.0**	**7.6**	1.2
				14	8.5	**20 000**	**0.17**	**29.8** (b)	—	39
		175	347	5.5	3.5	**8 000**	**2.00**	**3.3**	**2.3**	0.65
				9.5	6	**14 000**	**0.35**	**15** (b)	**8.0**	6.3
	Cold Worked 10 %	130	266	5.5	3.5	**8 000**	**8.25**	**0.20**	**0.15**	0.01
				9.5	6	**14 000**	**8.60**	**0.67**	**0.26**	0.042
				14	8.5	**20 000**	**1.750**	**2.4** (b)	**0.32**	0.45
		175	347	5.5	3.5	**8 000**	**6.85**	**1.14**	**0.135**	0.088
				9.5	6	**14 000**	**1.10**	**2.0** (b)	**0.22**	0.66
	Cold Worked 25 %	130	266	5.5	3.5	**8 000**	**7.20**	**0.235**	**0.125**	0.01
				9.5	6	**14 000**	**8.60**	**1.02**	**0.25**	0.054
				14	8.5	**20 000**	**4.68**	**3.4** (b)	**0.36**	0.27
		175	347	5.5	3.5	**8 000**	**1.05**	**3.3** (b)	—	0.6
	Cold Worked 50 %	130	266	5.5	3.5	**8 000**	**8.25**	**1.58**	**0.08**	0.035
				9.5	6	**14 000**	**8.70**	**7.31**	**0.16**	0.055
				14	8.5	**20 000**	**4.030**	**11** (b)	**0.24**	0.17
Rod (7) 3.2 mm diam. 0.125 in. diam.	Annealed (grain size 0.025 mm)	149	300	1.5	1	**2 050**	**6.40**	**0.088**	**0.048**	**0.003 2**
				2	1.5	**3 000**	**6.50**	**0.257**	**0.133**	**0.013**
				4	2.5	**6 000**	**6.50**	**1.875**	**1.120**	**0.057 5**
				5.5	3.5	**8 100**	**6.50**	**3.475**	**1.795**	**0.088**
		204	400	1	0.7	**1 550**	**6.00**	**0.168**	**0.067**	**0.014**
				1.5	1	**2 050**	**6.50**	**0.359**	**0.168**	**0.026**
				2	1.5	**3 050**	**6.00**	**1.050**	**0.510**	**0.083**
				2.5	2	**4 000**	**6.50**	**2.042**	**1.232**	**0.11**
				4	2.5	**6 100**	**6.00**	**2.485**	**0.668**	**0.204**
				5	3	**7 050**	**4.50**	**3.900**	**2.750**	**0.267**
		260	500	0.3	0.2	**360**	**6.00**	**0.084**	**0.016**	**0.011**
				0.5	0.3	**600**	**6.00**	**0.195**	**0.010**	**0.030**
				0.7	0.5	**1 050**	**6.50**	**0.640**	**0.113**	**0.079 5**
				1.5	1	**2 000**	**6.50**	**2.877**	**0.869**	**0.306**
	Cold Worked 84 %	149	300	5	3	**7 550**	**6.40**	**0.118**	**0.041**	**0.004 9**
				7	4.5	**10 000**	**6.50**	**0.167**	**0.042**	**0.010**
				10	6.5	**14 650**	**6.40**	**0.540**	**—0.170**	**0.097** (c)
				14	9	**20 000**	**6.50**	**2.330**	**—3.00**	**0.80** (c)
				17.5	11	**25 200**	**1.78**	**2.565**	**—4.98**	**4.14** (c)
		204	400	0.7	0.5	**1 050**	**6.50**	**0.064**	**0.045**	**0.001 1**
				1.5	1	**2 100**	**6.00**	**0.203**	**0.112**	**0.011 5**
				2.5	2	**4 050**	**6.50**	**1.080**	**0.409**	**0.097**
				5	3	**7 100**	**6.50**	**5.418**	**2.47**	**0.44**
Square Wire (13) 6.5 mm 0.257 in.	Annealed	121	250	17.5	11	**25 000**	**1.44**	**1.75** (d)	—	— (e)
	Cold Worked 10 %	121	250	17.5	11	**25 000**	**2.20**	**1.85** (d)	—	— (e)
	Cold Worked 37.1 %	121	250	17.5	11	**25 000**	**4.80**	**0.40** (d)	—	**0.056**
	Cold Worked 84.4 %	121	250	17.5	11	**25 000**	**1.18**	**1.75** (d)	—	— (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 does not include the initial elastic elongation. - (e) Decreasing creep rate - (f) Accelerating creep rate.

N.B.: — Values obtained using Cu-ETP (electrolytic 'tough-pitch' copper) test specimens; it is assumed that Cu-FRHC exhibits the same creep properties at elevated temperatures.

— Original values are printed in **bold type;** other values are calculated.

— Further data can be obtained from references (7) and (12) 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 1000 psi	
			Tensile Strength	Fatigue Strength	Tensile Strength	Fatigue Strength	Tensile Strength	Fatigue Strength
Strip (14) **0.5 mm 0.02 in.**	Annealed	100	22	7.5 (a)	14	5 (a)	**31 400**	**11 000** (a)
	Cold Worked 20 %	100	31	9 (a)	20	6 (a)	**44 400**	**13 000** (a)
	Cold Worked 60 %	100	37	10 (a)	23.5	6.5 (a)	**52 600**	**14 000** (a)
Strip (15) **0.8 mm 0.032 in.**	Cold Worked 21 %	100	29	8.5 (a)	18.5	5.5 (a)	**41 000**	**12 000** (a)
	Cold Worked 37 %	100	34.5	9 (a)	22	6 (a)	**49 300**	**13 000** (a)
	Cold Worked 60 %	100	40.5	7.5 (a)	25.5	5 (a)	**57 700**	**11 000** (a)
Flat Products (16) **1 mm 0.04 in.**	Annealed (grain size 0.025 mm)	100	24	7.5 (a)	15	5 (a)	**34 000**	**11 000** (a)
	Cold Worked 21 %	100	29.5	9 (a)	18.5	6 (a)	**42 000**	**13 000** (a)
	Cold Worked 37 %	100	35	9 (a)	22.5	6 (a)	**50 000**	**13 000** (a)
	Cold Worked 60 %	100	38.5	10 (a)	24.5	6.5 (a)	**55 000**	**14 000** (a)
Rod (17) **7.6 mm diam. 0.3 in. diam.**	Annealed (grain size 0.040 mm)	300	22	6.5 (b)	14	4 (b)	**31 100**	**9 000** (b)
	Cold Worked 36 %	300	34.5	12 (b)	22	7.5 (b)	**48 800**	**17 000** (b)
Rod (18) **16 mm diam. 0.625 in. diam.**	Cold Worked 30 %	100	31	11.5 (b)	19.5	7.5 (b)	**44 000**	**16 500** (b)
Rod (16) **25.4 mm diam. 1 in. diam.**	Cold Worked 35 %	300	33.5	12 (b)	21.5	7.5 (b)	**48 000**	**17 000** (b)
Wire (19) **2 in. diam. 0.08 in. diam.**	Cold Worked 37 %	100	36 - 41	11 (a)	22.5 - 26	7 (a)	**51 000-58 000**	**15 500** (a)

(a) Reversed-bending test - (b) Rotating-beam test.

N.B.: — Values obtained using Cu-ETP (electrolytic 'tough-pitch' copper) test specimens; it is assumed that Cu-FRHC exhibits the same fatigue properties at room temperature.

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

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FIRE-REFINED TOUGH-PITCH COPPER

Cu-FRTP

Commercially-pure copper which is fire-refined without, at any stage, having been electrolytically refined. It is melted and oxidised to the 'tough-pitch' condition with a controlled oxygen content, then cast into cakes, slabs or billets to be hot and cold worked into wrought forms. The conductivity of this type of copper may be appreciably below that of the high-conductivity coppers (Cu-ETP, Cu-FRHC and Cu-OF), while the amounts of oxygen and impurities often reach the higher contents allowed by the relevant specifications.

COMPOSITION (weight %)

Cu (+ Ag) . . . . 99.85 min.

1 SOME TYPICAL USES

Architectural and Building:

Cladding and fascia work, rainwater pipes, roofing, gutters, flashings, decorative screens and trim, sections drawn on wood.

Chemical:

Plant equipment such as kettles, stills, vats and pans, food processing equipment, cooking utensils.

Mechanical:

Miscellaneous strip products including pressed, spun and cupped articles; printing cylinders; automobile gaskets.

Electrical:

Apparatus for general purposes when highest electrical conductivity is not required.

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: 25 to 100 °C *77 to 212 °F* (1)	0.000 016 8 per °C	0.000 009 33 per °F
2.4	Specific heat (thermal capacity) at: 20 °C *68 °F* (1)	0.092 1 cal/g °C	0.092 1 Btu/lb °F
2.5	Thermal conductivity at: 20 °C *68 °F*	0.80 - 0.90 cal cm/cm² s °C	194 - 218 Btu ft/ft² h °F
2.6	Electrical conductivity (volume) at: 20 °C *68 °F* (annealed or cold worked)	49 - 55 m/ohm mm²	85 - 95 % IACS
2.7	Electrical resistivity (volume) at: 20 °C *68 °F* (annealed or cold worked)	0.020 - 0.018 ohm mm²/m 2.0 - 1.8 microhm cm	12 - 11 ohm (circ mil/ft) 0.80 - 0.71 microhm in
2.8	Temperature coefficient of electrical resistance at: (a) 20 °C *68 °F* (annealed or cold worked) applicable over range from 0 to 100 °C *32 to 212 °F*	0.003 34 per °C (85 % IACS) 0.003 73 » » (95 % IACS)	0.001 86 per °F (85 % IACS) 0.002 07 » » (95 % IACS)
2.9	Modulus of elasticity (tension) at 20 °C *68 °F*: annealed cold worked	 12 000 kg/mm² 12 000 - 13 500 »	 17 000 000 lb/in² 17 000 000 - 19 000 000 »
2.10	Modulus of rigidity (torsion) at 20 °C *68 °F*: annealed cold worked	 4 500 kg/mm² 4 500 - 5 000 »	 6 400 000 lb/in² 6 400 000 - 7 000 000 »

(a) — 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)*.

— The temperature coefficient of resistance of copper can be assumed to be directly proportional to the conductivity value and the figures given above have been calculated on the basis that copper of 100 % IACS conductivity at 20 °C *(68 °F)* has a temperature coefficient of resistance of 0.003 93 per °C *(0.002 18 per °F)*. Temperature coefficients of resistance for copper with a conductivity value within the range shown above may be calculated in the same manner.

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 3
Cu-FRTP
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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.

	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 [(b)]	225 - 650 °C	435 - 1 200 °F
Stress relieving temperature range [(b)]	175 - 225 °C	345 - 435 °F
3.3 Hot working temperature range [(b)]	750 - 950 °C	1 400 - 1 750 °F
3.4 Hot formability [(b)]	Good	
3.5 Cold formability	Excellent	
3.6 Cold reduction between anneals	85 % max.	
3.7 Machinability	See General Data Sheet No. 2	
Machinability rating (free-cutting brass = 100)	20	
3.8 Joining methods: [(b)]	See General Data Sheet No. 3.1	
Soldering	Excellent	
Brazing	Good	
Oxy-acetylene welding	Not recommended	
Carbon-arc welding	Fair	
Gas-shielded arc welding	Fair	
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).*

(b) Embrittlement will occur if this copper is heated in atmospheres containing an excess of hydrogen.

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	—	—	—	—	—	—	—	—
Canada	CSA	Cu-FRTP 125	—	—	—	—	—	—	—
Chile	INDITECNOR	Cu-FRTP	244 p	196 ch	—	—	395 ch	—	—
France	NF	Cu/a3	A53-100	A53-601	A53-301	—	—	A53-301	A53-301
Germany	DIN	F-Cu(2.0080)	1787	17670	17672	17672	17671	17673	17674
Italy	UNI	Cu-FRTP	5649	3310 [b]	3310 [b]	3310 [b]	3310 [b]	—	3310 [b]
Netherlands	N or NEN [c]	Cu-FRTP	NEN 6023	—	—	—	NEN 2263	—	—
South Africa	SABS	—	—	—	—	—	—	—	—
Spain	UNE	Cu 99.75 Cu 99.85	37.103	37.105	—	—	37.119	37.109	—
Sweden	SIS	Cu-FRTP	—	14 50 13	—	—	—	—	—
Switzerland	VSM	—	—	—	—	—	—	—	—
United Kingdom	BS	C104	1038	899 1569 2027 2875 2870	—	—	—	—	—
United States	ASTM	FRTP	—	B48 B124 B133 B152 B272	B12 B49 B124 B133	B1 B2 B3 B33 B47 B116 B189	—	B283	B124 B133

(a) Applicable when the chemical composition is not given in the specifications for wrought forms.
(b) Under revision.
(c) 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
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
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/in^2	Proof Stress 0.1 % offset ton/in^2	Elongation %	Elongation gauge length	Vickers Hardness	Shear Strength ton/in^2	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 in^2 area
		20	16	17	$5.65\sqrt{S_o}$	105	12	»
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)	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.
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 Hard [b]	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/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
Sheet [2] 3.2 mm 0.125 in.	Annealed (grain size 0.040 mm)	+ 24	+ 75	22	14	**31 580**	**6.64** [a]	—	**10 170**	**57.5**	2 in.	**96.2**	—	—
		— 40	— 40	25	16	**35 330**	**7.45** [a]	—	**11 480**	**53.3**	2 in.	**59.2**	—	—
		— 68	— 90	26	16.5	**37 300**	**7.16** [a]	—	**11 100**	**55.0**	2 in.	**55.0**	—	—
		— 196	— 321	35.5	22.5	**50 400**	**7.06** [a]	—	**11 150**	**57.5**	2 in.	**51.5**	—	—
	Cold Worked 5 - 7 %	+ 24	+ 75	24.5	15.5	**34 520**	**22.0** [a]	—	**31 500**	**32.4**	2 in.	**63.3**	—	—
		— 40	— 40	28	17.5	**39 500**	**23.8** [a]	—	**34 050**	**34.0**	2 in.	**53.8**	—	—
		— 68	— 90	29.5	18.5	**41 800**	**24.5** [a]	—	**34 950**	**32.8**	2 in.	**50.5**	—	—
		— 196	— 321	39	25	**55 600**	**26.1** [a]	—	**37 250**	**45.0**	2 in.	**51.9**	—	—
Rod [3] 4.5 mm diam. 0.177 in. diam.	Annealed	+ 18	+ 64	**24.1**	15.5	34 500	**3.9** [b]	—	—	**50.5**	45 mm	**71.4**	**10.0** [c]	36.2 [c]
		— 78	— 110	**29.2**	18.5	41 500	**10.0** [b]	—	—	**50.0**	45 mm	**73.6**	**9.5** [c]	34.4 [c]
		— 183	— 295	**36.5**	23	52 000	**8.7** [b]	—	—	**50.5**	45 mm	**83.3**	**9.1** [c]	32.9 [c]
	Cold Worked 50 %	+ 20	+ 68	**41.2**	26	58 500	**37.5** [b]	—	—	**8.4**	45 mm	**51.5**	**6.4** [c]	23.1 [c]
		— 78	— 110	**42.5**	27	60 500	**40.8** [b]	—	—	**12.0**	45 mm	**56.6**	**6.6** [c]	23.9 [c]
		— 183	— 295	**45.5**	29	65 000	**41.9** [b]	—	—	**11.2**	45 mm	**61.2**	**7.4** [c]	26.8 [c]
Rod [4] 6.35 mm diam. 0.25 in. diam.	Annealed	+ 20	+ 68	22	**14.0**	31 500	—	**3.82**	—	**48.0**	2 in.	**76.5**	7.4 [d]	**43.0** [d]
		— 10	+ 14	22.5	**14.3**	32 000	—	**3.97**	—	**40.2**	2 in.	**78.0**	—	—
		— 40	— 40	24	**15.1**	34 000	—	**4.09**	—	**47.0**	2 in.	**77.0**	7.8 [d]	**45.0** [d]
		— 80	— 112	27	**17.2**	38 500	—	**4.50**	—	**47.0**	2 in.	**74.0**	7.6 [d]	**44.0** [d]
		— 120	— 184	29	**18.4**	41 000	—	**4.82**	—	**44.6**	2 in.	**70.0**	7.7 [d]	**44.5** [d]
		— 180	— 292	35.5	**22.7**	51 000	—	**5.12**	—	**57.6**	2 in.	**77.0**	8.6 [d]	**50.0** [d]
Square Rod [5] 40 mm 1.6 in.	Hot Worked	+ 20	+ 68	**22.0**	14	31 500	**5.20**	—	—	**55** [e]	100 mm	**70**	—	—
		— 20	— 4	**23.8**	15	34 000	**5.20**	—	—	**56.2** [e]	100 mm	**70**	—	—
		— 60	— 76	**25.6**	16	36 500	**5.60**	—	—	**57.3** [e]	100 mm	**67**	—	—
		— 77	— 107	**26.4**	17	37 500	**5.20**	—	—	**57.2** [e]	100 mm	**68**	—	—

(a) This value was originally reported in psi; in this table it is given in kg/mm^2 to 3 significant figures.
(b) Quoted as yield point, but offset strain not defined.
(c) Charpy test, 10 x 8 x 100 mm specimen; 45° V-notch, 3 mm deep; cross-sectional area 0.5 cm^2.
(d) Izod specimen; cross-sectional area 0.8 cm^2.
(e) 20 mm diam. specimen.

N.B.: — Values obtained using Cu-ETP (electrolytic ' tough-pitch ' copper) test specimens; it is assumed that Cu-FRTP exhibits the same mechanical properties at low temperatures.
— 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/cm^2 (and vice versa) taking into account the actual cross-sectional area of the specimen at the notch.

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 (2) 3.2 - 6.35 mm 0.125 - 0.25 in.	Annealed (grain size 0.043 mm)	24 100 204	75 212 400	22 19 16	14 12 10	**31 000** **27 080** **22 750**	**6.33** (a) **6.48** (a) **5.82** (a)	**9 930** **9 840** **8 690**	**57.8** **57.4** **56.8**
	Cold Worked 5 - 7 %	24 100 204	75 212 400	23 20.5 17.5	14.5 13 11	**32 630** **29 400** **24 700**	**17.5** (a) **16.6** (a) **14.5** (a)	**25 380** **24 100** **21 000**	**41.3** **37.9** **34.1**
Rod (2) 3.2 mm diam. 0.125 in. diam.	Annealed (grain size 0.025 mm)	24 149 204 260	75 300 400 500	24.5 — — —	15.5 — — —	**35 100** — — —	**4.29** (a) — — —	**7 200** **6 400** **5 800** **5 300**	**50.0** — — —
	Cold Worked 84 %	24 149 204 260	75 300 400 500	39 — — —	24.5 — — —	**55 400** — — —	**34.8** (a) — — —	**50 000** **43 000** **17 200** **7 700**	**11.0** — — —
Rod (6) 19 mm diam. 0.75 in. diam.	Hot Worked	Room 65 121 177 232 288 343 426 538 620 704	Room 150 250 350 450 550 650 800 1 000 1 150 1 300	22.5 21.5 19 18 16 14.5 12.5 9 6 4.5 3	14.5 13.5 12 11.5 10 9 8 6 3.5 3 2	**32 350** **30 500** **27 200** **25 600** **22 850** **20 300** **17 750** **13 100** **8 250** **6 350** **4 440**	— — — — — — — — — — —	— — — — — — — — — — —	**60.0** **58.5** **61.5** **65.0** **68.5** **59.5** **56.0** **59.3** **74.3** **48.8** **54.5**
Rod (2) 19 mm diam. 0.75 in. diam.	Cold Worked 21 %	Room 260 288 315 343 371 399 426	Room 500 550 600 650 700 750 800	34 26.5 26 24.5 18.5 12.5 11.5 11	21.5 17 16.5 15.5 12 8 7 6.5	**48 100** **37 700** **37 200** **35 200** **26 600** **17 700** **16 100** **15 300**	— — — — — — — —	— — — — — — — —	**17** **14** **14** **14** **25** **41** **39** **36**

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

N.B.: — Values obtained using Cu-ETP (electrolytic 'tough-pitch' copper) test specimens; it is assumed that Cu-FRTP exhibits the same short-time tensile properties at elevated temperatures.

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

— Further data can be obtained from the following paper:

■ Crowe, C.H. Properties of Some Copper Alloys at Elevated Temperatures. A.S.T.M. Bull. No. 250 (1960), December, pp. 30-31.

— The 0.1 % proof stress values are not available.

5.3.2 Creep Properties

Form	Temper	Testing Temperature		Stress			Duration 1 000 h	Total Extension % [a]	Intercept %	Min. Creep Rate in % per 1 000 h
		°C	°F	kg/mm²	ton/in²	psi				
Strip [7] 2.54 mm 0.1 in.	Annealed (grain size 0.030 mm)	130	266	5.5	3.5	8 000	2.50	2.6	2.0	0.15
				9.5	6	14 000	2.60	10.0	7.6	1.2
				14	8.5	20 000	0.17	29.8 [b]	—	39
		175	347	5.5	3.5	8 000	2.00	3.3	2.3	0.65
				9.5	6	14 000	0.35	15 [b]	8.0	6.3
	Cold Worked 10 %	130	266	5.5	3.5	8 000	8.25	0.20	0.15	0.01
				9.5	6	14 000	8.60	0.67	0.26	0.042
				14	8.5	20 000	1.750	2.4 [b]	0.32	0.45
		175	347	5.5	3.5	8 000	6.85	1.14	0.135	0.088
				9.5	6	14 000	1.10	2.0 [b]	0.22	0.66
	Cold Worked 25 %	130	266	5.5	3.5	8 000	7.20	0.235	0.125	0.01
				9.5	6	14 000	8.60	1.02	0.25	0.054
				14	8.5	20 000	4.68	3.4 [b]	0.36	0.27
		175	347	5.5	3.5	8 000	1.05	3.3 [b]	—	0.6
	Cold Worked 50 %	130	266	5.5	3.5	8 000	8.25	1.58	0.08	0.035
				9.5	6	14 000	8.70	7.31	0.16	0.055
				14	8.5	20 000	4.030	11 [b]	0.24	0.17
Rod [2] 3.2 mm diam. 0.125 in. diam.	Annealed (grain size 0.025 mm)	149	300	1.5	1	2 050	6.40	0.088	0.048	0.003 2
				2	1.5	3 000	6.50	0.257	0.133	0.013
				4	2.5	6 000	6.50	1.875	1.120	0.057 5
				5.5	3.5	8 100	6.50	3.475	1.795	0.088
		204	400	1	0.7	1 550	6.00	0.168	0.067	0.014
				1.5	1	2 050	6.50	0.359	0.168	0.026
				2	1.5	3 050	6.00	1.050	0.510	0.083
				2.5	2	4 000	6.50	2.042	1.232	0.11
				4	2.5	6 100	6.00	2.485	0.668	0.204
				5	3	7 050	4.50	3.900	2.750	0.267
		260	500	0.3	0.2	360	6.00	0.084	0.016	0.011
				0.5	0.3	600	6.00	0.195	0.010	0.030
				0.7	0.5	1 050	6.50	0.640	0.113	0.079 5
				1.5	0.9	2 000	6.50	2.877	0.869	0.306
	Cold Worked 84 %	149	300	5	3	7 550	6.40	0.118	0.041	0.004 9
				7	4.5	10 000	6.50	0.167	0.042	0.010
				10	6.5	14 650	6.40	0.540	— 0.170	0.097 [c]
				14	9	20 000	6.50	2.330	— 3.00	0.80 [c]
				17.5	11	25 200	1.78	2.565	— 4.98	4.14 [c]
		204	400	0.7	0.5	1 050	6.50	0.064	0.045	0.001 1
				1.5	1	2 100	6.00	0.203	0.112	0.011 5
				2.5	2	4 050	6.50	1.080	0.409	0.097
				5	3	7 100	6.50	5.418	2.47	0.44
Square Wire [8] 6.5 mm 0.257 in.	Annealed	121	250	17.5	11	25 000	1.44	1.75 [d]	—	— [e]
	Cold Worked 10 %	121	250	17.5	11	25 000	2.20	1.85 [d]	—	— [e]
	Cold Worked 37.1 %	121	250	17.5	11	25 000	4.80	0.40 [d]	—	0.056
	Cold Worked 84.4 %	121	250	17.5	11	25 000	1.18	1.75 [d]	—	— [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 does not include the initial elastic elongation. - [e] Decreasing creep rate. - [f] Accelerating creep rate.

N.B.: — Values obtained using Cu-ETP (electrolytic 'tough-pitch' copper) test specimens; it is assumed that Cu-FRTP exhibits the same creep properties at elevated temperatures.
— Original values are printed in **bold type**; other values are calculated.
— Further data can be obtained from reference (2) and (7) 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
Strip (9) **0.5 mm 0.02 in.**	Annealed	100	22	7.5 (a)	14	5 (a)	**31 400**	**11 000** (a)
	Cold Worked 20 %	100	31	9 (a)	20	6 (a)	**44 400**	**13 000** (a)
	Cold Worked 60 %	100	37	10 (a)	23.5	6.5 (a)	**52 600**	**14 000** (a)
Strip (10) **0.8 mm 0.032 in.**	Cold Worked 21 %	100	29	8.5 (a)	18.5	5.5 (a)	**41 000**	**12 000** (a)
	Cold Worked 37 %	100	34.5	9 (a)	22	6 (a)	**49 300**	**13 000** (a)
	Cold Worked 60 %	100	40.5	7.5 (a)	25.5	5 (a)	**57 700**	**11 000** (a)
Flat Products (11) **1 mm 0.04 in.**	Annealed (grain size 0.025 mm)	100	24	7.5 (a)	15	5 (a)	**34 000**	**11 000** (a)
	Cold Worked 21 %	100	29.5	9 (a)	18.5	6 (a)	**42 000**	**13 000** (a)
	Cold Worked 37 %	100	35	9 (a)	22.5	6 (a)	**50 000**	**13 000** (a)
	Cold Worked 60 %	100	38.5	10 (a)	24.5	6.5 (a)	**55 000**	**14 000** (a)
Rod (12) **7.6 mm diam. 0.3 in. diam.**	Annealed (grain size 0.040 mm)	300	22	6.5 (b)	14	4 (b)	**31 100**	**9 000** (b)
	Cold Worked 36 %	300	34.5	12 (b)	22	7.5 (b)	**48 800**	**17 000** (b)
Rod (13) **16 mm diam. 0.625 in. diam.**	Cold Worked 30 %	100	31	11.5 (b)	19.5	7.5 (b)	**44 000**	**16 500** (b)
Rod (11) **25.4 mm diam. 1 in. diam.**	Cold Worked 35 %	300	33.5	12 (b)	21.5	7.5 (b)	**48 000**	**17 000** (b)
Wire (14) **2 mm diam. 0.08 in. diam.**	Cold Worked 37 %	100	36 - 41	11 (a)	22.5 - 26	7 (a)	**51 000 - 58 000**	**15 500** (a)

(a) Reversed-bending test - (b) Rotating-beam test.

N.B.: — Values obtained using Cu-ETP (electrolytic ' tough-pitch ' copper) test specimens; it is assumed that Cu-FRTP exhibits the same fatigue properties at room temperature.

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

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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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CONSEIL INTERNATIONAL POUR LE DEVELOPPEMENT DU CUIVRE (CIDEC)
8, rue du Marché - GENEVE

DATA SHEET No. A 4
Cu-OF
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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/ft) 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		Hardness		Shear Strength kg/mm²	Typical Size Related to Properties Shown [b]
				%	gauge length	Brinell	Vickers		
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.

REFERENCES

PHYSICAL PROPERTIES (SECTION 2)

(1) - Corruccini, R.J. and Gniewek, J.J. Thermal Expansion of Technical Solids at Low Temperatures, U.S. National Bureau of Standards Monograph 29 (1961).

(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).

MECHANICAL PROPERTIES (SECTION 5)

(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.

(8) - Upthegrove, C. and Burghoff, H.L. Elevated-Temperature Properties of Coppers and Copper-base Alloys, American Society for Testing and Materials, Philadelphia, Pa. (1956). (A.S.T.M. Spec. Tech. Pub. No. 181).

(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.

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PHOSPHORUS-DEOXIDISED COPPER (LOW RESIDUAL PHOSPHORUS)

Cu-DLP

Commercially-pure copper which has been deoxidised with phosphorus to leave only a small residual content. It is not readily susceptible to hydrogen embrittlement. Generally the residual phosphorus lowers the conductivity to some extent as compared with high-conductivity and oxygen-free coppers (Cu-ETP, Cu-FRHC and Cu-OF). The raw material is normally available as cakes, slabs and billets which are hot and cold worked into wrought forms.

COMPOSITION (weight %)

Cu (+ Ag)	99.90 min.
P	0.005 - 0.012

1 SOME TYPICAL USES

Architectural and Building:

Tubes for hot and cold water services, gas and heating installations, both buried and above ground; soil and waste pipes; storage tanks, cisterns and cylinders; air conditioners.

Mechanical:

Suitable for any equipment involving heating in reducing gases either during joining processes or in service; evaporator and heat exchanger tubes; steam, air, water and oil lines; automobile radiators.

Chemical:

Stills, vats, autoclaves and general coppersmithing involving welding; tubes for relatively non-corrosive liquids and gases and for refrigeration.

Electrical:

Bus-bars (in U.S.A. only).

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:		
20 °C *68 °F*	0.80 - 0.93 cal cm/cm² s °C	194 - 225 Btu ft/ft² h °F
2.6 Electrical conductivity (volume) at: (a)		
20 °C *68 °F* (annealed)	49 - 57 m/ohm mm²	85 - 98 % IACS
20 °C *68 °F* (fully cold worked)	49 - 56 »	85 - 96 » »

continued overleaf

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

Prepared by
CONSEIL INTERNATIONAL POUR LE DEVELOPPEMENT DU CUIVRE (CIDEC)
8, rue du Marché - GENEVE

DATA SHEET No. A 5
Cu-DLP

1968 Edition

2 PHYSICAL PROPERTIES (continued)

	Metric Units	English Units
2.7 Electrical resistivity (volume) at:		
20 °C *68 °F* (annealed)	0.020 - 0.017 6 ohm mm²/m 2.0 - 1.76 microhm cm	12 - 10.6 ohms (circ mil/ft) 0.80 - 0.693 microhm in
20 °C *68 °F* (fully cold worked)	0.020 - 0.018 0 ohm mm²/m 2.0 - 1.80 microhm cm	12 - 10.8 ohms (circ mil/ft) 0.80 - 0.707 microhm in
2.8 Temperature coefficient of electrical resistance at: [b]		
20 °C *68 °F* (annealed) applicable over range from 0 to 100 °C *32 to 212 °F*	0.003 34 per °C (85 % IACS) 0.003 85 » » (98 % IACS)	0.001 86 per °F (85 % IACS) 0.002 14 » » (98 % IACS)
20 °C *68 °F* (fully cold worked) applicable over range from 0 to 100 °C *32 to 212 °F*	0.003 34 per °C (85 % IACS) 0.003 77 » » (96 % IACS)	0.001 86 per °F (85 % IACS) 0.002 10 » » (96 % 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) In the U.S.A., Cu-DLP may by special agreement, be supplied with a conductivity of 100 % IACS (58.00 m/ohm mm²) in the annealed condition; the corresponding resistivity figures are: 1.724 1 microhm cm, 0.017 241 ohm mm²/m, 0.678 8 microhm in, 10.371 ohms (circ mil/ft).

(b) — 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)*.
— The temperature coefficient of resistance of copper can be assumed to be directly proportional to the conductivity value and the figures given above have been calculated on the basis that copper of 100 % IACS conductivity at 20 °C *(68 °F)* has a temperature coefficient of resistance of 0.003 93 per °C *(0.002 18 per °F)*. Temperature coefficients of resistance for copper with a conductivity value within the range shown above may be calculated in the same manner.

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	1 140 - 1 200 °C	2 085 - 2 190 °F
3.2 Annealing temperature range	225 - 650 °C	435 - 1 200 °F
Stress relieving temperature range	175 - 225 °C	345 - 435 °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	

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	—	—	—	—	—	—	—	—
Belgium . . .	NBN	—	—	—	—	—	—	—	—
Canada . . .	CSA	Cu-DLP 120	—	—	—	—	HC. 7.1 HC. 7.6 HC. 7.7 HC. 7.8	—	—
Chile	INDITECNOR	Cu-DLP	244 p	196 ch	—	—	395 ch	—	—
France . . .	NF	—	—	—	—	—	—	—	—
Germany . . .	DIN	—	—	—	—	—	—	—	—
Italy	UNI	Cu-DLP	5649	—	—	—	—	—	—
Netherlands . .	N or NEN [b]	—	—	—	—	—	—	—	—
South Africa .	SABS	—	—	—	—	—	—	—	—
Spain	UNE	Cu P	37.103	—	—	—	—	—	—
Sweden . . .	SIS	—	—	—	—	—	—	—	—
Switzerland . .	VSM	Cu-DLP	10826	11852	11852	—	11852	—	—
United Kingdom	BS	—	—	—	—	—	—	—	—
United States [c]	ASTM	DLP	—	B48 B124 B133 B187 B272	B12 B49 B124 B133 B187	—	B42 B68 B75 B88 B111 B188 B280 B302 B306 B395	—	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/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	Annealed	22	5	48	$5.65\sqrt{S_0}$	45	50	16	—
	Hot Rolled	23	8	40	$5.65\sqrt{S_0}$	55	60	16	—
	Typical Cold Worked Tempers	27	18	25	$5.65\sqrt{S_0}$	75	80	18	0.2 - 10 mm thick
		32	27	12	$5.65\sqrt{S_0}$	90	100	19	0.2 - 6 mm thick
		38	34	6	$5.65\sqrt{S_0}$	105	115	20	0.2 - 1.5 mm thick
Rod	Annealed	22	5	45	$5.65\sqrt{S_0}$	45	50	16	—
	Typical Cold Worked Tempers	28	19	20	$5.65\sqrt{S_0}$	75	80	18	6 - 40 mm diam. or up to 1 250 mm^2 area
		34	28	10	$5.65\sqrt{S_0}$	95	105	19	6 - 20 mm diam. or up to 300 mm^2 area
Tube	Annealed	24	6	45	$5.65\sqrt{S_0}$	45	50	16	—
	Typical Cold Drawn Tempers	27	18	30	$5.65\sqrt{S_0}$	75	80	18	10 - 200 mm O.D. up to 10 mm wall
		32	27	15	$5.65\sqrt{S_0}$	90	100	19	10 - 100 mm O.D. up to 6 mm wall
		35	30	8	$5.65\sqrt{S_0}$	100	110	20	10 - 50 mm O.D. up to 2 mm wall
		38	35	6	$5.65\sqrt{S_0}$	105	115	20	up to 25 mm O.D. up to 1 mm wall

(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.

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		Vickers Hardness	Shear Strength ton/in²	Typical Size Related to Properties Shown [a]
				%	gauge length			
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	»
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	»

[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.

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)	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									
	Hard	50 000	45 000	6	2 in.	90	50	57	28 000	0.040 in. thick
	Hard	50 000	45 000	12	2 in.	90	50	—	28 000	0.250 in. thick
	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.
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	»

(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.

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	Yield Strength 0.5 % ext. under load psi	%	gauge length		kg m/cm²	ft lb
Sheet (5) 3.2 mm 0.125 in.	Annealed (grain size 0.045 mm)	+ 24	+ 75	21.5	13.5	**30 250**	**6.31** (a)	**9 750**	**51.2**	2 in.	**89.8**	—	—
		— 40	— 40	25	16	**35 580**	**7.20** (a)	**11 350**	**56.5**	2 in.	**74.3**	—	—
		— 68	— 90	26.5	17	**37 580**	**8.02** (a)	**11 830**	**55.8**	2 in.	**77.8**	—	—
		— 196	— 321	35.5	23	**50 800**	**7.40** (a)	**11 400**	**55.8**	2 in.	**64.1**	—	—
	Cold Worked 5 - 7 %	+ 24	+ 75	23	14.5	**32 600**	**17.1** (a)	**24 700**	**39.0**	2 in.	**91.8**	—	—
		— 40	— 40	26	16.5	**37 250**	**18.5** (a)	**26 450**	**41.0**	2 in.	**78.8**	—	—
		— 68	— 90	28	17.5	**39 600**	**18.6** (a)	**27 100**	**38.8**	2 in.	**68.7**	—	—
		— 196	— 321	37.5	23.5	**53 100**	**20.2** (a)	**28 980**	**49.0**	2 in.	**62.0**	—	—
Sheet (5) 6.4 mm 6.35 mm	Annealed (grain size 0.043 mm)	+ 24	+ 75	21.5	13.5	**30 750**	**5.94** (a)	**9 140**	**57.1**	2 in.	**63.3**	—	—
		— 40	— 40	24.5	15.5	**34 600**	**6.00** (a)	**9 490**	**55.3**	2 in.	**61.6**	—	—
		— 68	— 90	26.5	17	**37 900**	**5.86** (a)	**9 450**	**55.8**	2 in.	**58.3**	—	—
		— 196	— 321	35	22.5	**49 900**	**5.69** (a)	**9 240**	**58.8**	2 in.	**54.8**	—	—
	Cold Worked 5 - 7 %	+ 24	+ 75	23.5	15	**33 160**	**17.8** (a)	**25 450**	**52.0**	2 in.	**84.6**	—	—
		— 40	— 40	26.5	17	**37 900**	**18.1** (a)	**26 030**	**51.0**	2 in.	**78.1**	—	—
		— 68	— 90	27.5	17.5	**39 050**	**18.4** (a)	**26 400**	**50.5**	2 in.	**77.6**	—	—
		— 196	— 321	37	23.5	**52 300**	**18.6** (a)	**26 700**	**61.8**	2 in.	**70.1**	—	—
Rod (6) 19 mm diam. 0.75 in. diam.	Annealed	+ 20	+ 68	23	14.5	**32 600**	—	**8 290**	**57.5**	2 in.	—	12.9 (b)	**46.8** (b)
		+ 3	+ 37	—	—	—	—	—	—	—	—	12.9 (b)	**46.6** (b)
		— 18	— 0.4	—	—	—	—	—	—	—	—	12.1 (b)	**43.9** (b)
		— 30	— 22	—	—	—	—	—	—	—	—	12.4 (b)	**44.7** (b)
		— 50	— 58	—	—	—	—	—	—	—	—	12.1 (b)	**43.7** (b)
		— 80	— 112	—	—	—	—	—	—	—	—	12.8 (b)	**46.3** (b)
		— 115	— 175	—	—	—	—	—	—	—	—	13.3 (b)	**48.2** (b)

(a) This value was originally reported in psi; in this table it is given in kg/mm² to 3 significant figures.
(b) Charpy, keyhole notch, standard specimen; cross-sectional area 0.5 cm².

N.B.: — Values obtained using Cu-DHP (phosphorus-deoxidised copper, high residual phosphorus) test specimens; it is assumed that Cu-DLP exhibits the same mechanical properties at low temperatures.

— 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:

■ Reed, R.P. and Mikesell, R.P. Low-temperature (295 to 4 K) Mechanical Properties of Selected Copper Alloys. J. of Materials, Vol. 2, No. 2, June (1967), pp. 370-392.

— The 0.1 % proof stress values are not available.

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	
Rod (5) 3.2 mm diam. 0.125 in. diam.	Annealed (grain size 0.013 mm)	24	75	25	16	**36 500**	—	**12 000**	**48.0**
		149	300	—	—	—	—	**10 800**	—
		204	400	—	—	—	—	**9 200**	—
		260	500	—	—	—	—	**7 800**	—
	Cold Worked 84 %	24	75	40.5	25.5	**57 500**	37.3 [a]	**54 000**	**8.0**
		149	300	—	—	—	—	**46 000**	—
		204	400	—	—	—	—	**39 000**	—
		260	500	—	—	—	—	**13 800**	—
Rod (7) 19 mm diam. 0.75 in. diam.	Hot Worked	Room	Room	23	14.5	**32 500**	—	—	**59.0**
		65	150	21.5	13.5	**30 750**	—	—	**63.0**
		121	250	19.5	12.5	**27 850**	—	—	**62.3**
		177	350	17.5	11	**25 100**	—	—	**64.0**
		232	450	16.5	10	**23 250**	—	—	**57.5**
		288	550	14	9	**20 200**	—	—	**53.0**
		343	650	12	8	**17 400**	—	—	**51.8**
		426	800	9.5	6	**13 750**	—	—	**36.8**
		538	1 000	6.5	4	**9 100**	—	—	**85.3**
		620	1 150	4	2.5	**5 900**	—	—	**85.3**
		704	1 300	2.5	1.5	**3 800**	—	—	**66.5**

(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.
— 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
Rod (5) **3.2 mm diam.** **0.125 in. diam.**	Annealed (grain size 0.013 mm)	149	300	1.5	1	**2 100**	**5.90**	**0.026**	**0.015**	**0.000 5**
				4.5	3	**6 450**	**6.05**	**0.126**	**0.041**	**0.007 4**
				5.5	3.5	**7 750**	**5.05**	**0.202**	**0.093**	**0.011**
				6	4	**8 450**	**5.30**	**0.408**	**0.187**	**0.030**
				7	4.5	**10 400**	**0.90**	**2.110**	**0.180**	**0.135**
		204	400	0.7	0.5	**1 000**	**5.40**	**0.026**	**0.006**	**0.003 0**
				1.5	1	**2 050**	**6.60**	**0.128**	**0.047**	**0.011**
				2.5	1.5	**3 600**	**5.40**	**0.250**	**0.083**	**0.027**
				3.5	2	**5 100**	**6.60**	**1.482**	**0.786**	**0.10**
				5	3	**7 300**	**2.35**	**2.050**	**1.320**	**0.26**
		260	500	0.4	0.2	**500**	**6.60**	**0.039**	**0.006**	**0.004 7**
				0.7	0.5	**1 000**	**5.00**	**0.180**	**0.054**	**0.024**
				1.5	0.9	**2 000**	**5.00**	**0.670**	**0.150**	**0.10**
				2	1.5	**3 100**	**5.75**	**2.330**	**0.602**	**0.30**
	Cold Worked 84 %	149	300	5	3	**7 250**	**5.35**	**0.053**	**0.014**	**0.000 8**
				7	4.5	**10 400**	**5.28**	**0.080**	**0.027**	**0.001 9**
				12.5	8	**17 500**	**5.90**	**0.158**	**0.028**	**0.006 0**
				18	11.5	**25 800**	**5.40**	**0.338**	**0.077**	**0.020**
				22	14	**30 900**	**5.28**	**0.619**	**0.072**	**0.050**
		204	400	0.7	0.5	**1 000**	**5.20**	**0.027**	**0.015**	**0.001 4**
				1.5	1	**2 050**	**5.40**	**0.051**	**0.026**	**0.002 3**
				2	1.5	**3 050**	**5.20**	**0.074**	**0.035**	**0.003 6**
				3.5	2	**5 100**	**5.40**	**0.145**	**0.050**	**0.011**
				5.5	3.5	**8 100**	**5.30**	**0.334**	**0.075**	**0.037**
		260	500	0.4	0.2	**500**	**5.30**	**0.057**	**0.014**	**0.007 1**
				0.7	0.5	**1 000**	**5.55**	**0.151**	**0.029**	**0.020**
				1.5	1	**2 050**	**6.35**	**0.632**	**0.033**	**0.091**
				2	1.5	**3 050**	**6.60**	**1.612**	**0.246**	**0.20**

(a) Total extension = Initial extension + Total creep = Initial extension + Intercept + (Minimum creep rate × Duration).

N.B.: — Original values are printed in **bold type**; other values are converted.
— Further data can be obtained from the following paper:
■ Burghoff, H.L., and Blank, A.I. The Creep Characteristics of Copper and Copper Alloys at 300, 400 and 500 °F. Proc. A.S.T.M. Vol. 47 (1947), pp. 725-753.

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 1 000 psi	
			Tensile Strength	Fatigue Strength	Tensile Strength	Fatigue Strength	Tensile Strength	Fatigue Strength
Strip [8] **0.8 mm 0.032 in.**	Cold Worked 21 %	100	29	9 [a]	18.5	5.5 [a]	**41 400**	**13 000** [a]
	Cold Worked 37 %	100	32	11 [a]	20	7.9 [a]	**45 300**	**15 500** [a]
	Cold Worked 60 %	100	36	10 [a]	23	6 [a]	**51 600**	**14 000** [a]

(a) Reversed-bending 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.

MECHANICAL PROPERTIES (SECTION 5)

(5) - Upthegrove, C. and Burghoff, H.L. Elevated-temperature Properties of Coppers and Copper-base Alloys, American Society for Testing and Materials, Philadelphia, Pa. (1956). (A.S.T.M. Spec. Tech. Pub. No. 181).

(6) - Smith, C.S. Mechanical Properties of Copper and Its Alloys at Low Temperatures: a Review. Proc. A.S.T.M. Vol. 39 (1939), pp. 642-648.

(7) - 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, pp. 63-67, 72.

(8) - Burghoff, H.L. and Blank, A.I. Fatigue Properties of Some Coppers and Copper Alloys in Strip Form. Proc. A.S.T.M., Vol. 48 (1948), pp. 709-736.

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PHOSPHORUS-DEOXIDISED COPPER (HIGH RESIDUAL PHOSPHORUS)

Cu-DHP

Commercially-pure copper which has been deoxidised with phosphorus to leave a relatively high residual content. It is not susceptible to hydrogen embrittlement. The conductivity of this type of copper is relatively low on account of the high phosphorus content. The raw material is normally available as cakes, slabs and billets which are hot and cold worked into wrought forms.

COMPOSITION (weight %)

Cu (+ Ag)	99.85 min.
P	0.013 - 0.050

1 SOME TYPICAL USES

Architectural and Building:
Tubes for hot and cold water services, gas and heating installations, both buried and above ground; soil and waste pipes; storage tanks, cisterns and cylinders; air conditioners.

Mechanical:
Suitable for any equipment involving heating in reducing gases either during joining processes or in service; evaporator and heat exchanger tubes; steam, air, water and oil lines; automobile radiators.

Chemical:
Stills, vats, autoclaves and general coppersmithing involving welding; tubes for relatively non-corrosive liquids and gases and for refrigeration.

Electrical:
Anodes for electroplating and electroforming from acid sulphate baths.

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:		
20 °C *68 °F*	0.70 - 0.87 cal cm/cm² s °C	169 - 211 Btu ft/ft² h °F

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 6
Cu-DHP
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2 PHYSICAL PROPERTIES (continued)

	Metric Units		English Units	
2.6 Electrical conductivity (volume) at:				
20 °C *68 °F* (annealed or cold worked)	41 - 52	m/ohm mm²	70 - 90 % IACS	
2.7 Electrical resistivity (volume) at:				
20 °C *68 °F* (annealed or cold worked)	0.025 - 0.019 2.5 - 1.9	ohm mm²/m microhm cm	15 - 12 0.97 - 0.75	ohms (circ mil/ft) microhm in
2.8 Temperature coefficient of electrical resistance at: [a]				
20 °C *68 °F* (annealed or cold worked)	0.002 75 per °C (70 % IACS) 0.003 54 » » (90 % IACS)		0.001 53 per °F (70 % IACS) 0.001 96 » » (90 % IACS)	
applicable over range from 0 to 100 °C *32 to 212 °F*				
2.9 Modulus of elasticity (tension) at 20 °C *68 °F*:				
annealed	117 684 12 000	N/mm² kg/mm²	17 000 000	lb/in²
cold worked	12 000 - 13 500 117684 - 132400	» N/mm²	17 000 000 - 19 000 000	»
2.10 Modulus of rigidity (torsion) at 20 °C *68 °F*:				
annealed	44 132 4 500	N/mm² kg/mm²	6 400 000	lb/in²
cold worked	4 500 - 5 000 44132 - 49035	» N/mm²	6 400 000 - 7 000 000	»

(a) — 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)*.

— The temperature coefficient of resistance of copper can be assumed to be directly proportional to the conductivity value and the figures given above have been calculated on the basis that copper of 100 % IACS conductivity at 20 °C *(68 °F)* has a temperature coefficient of resistance of 0.003 93 per °C *(0.002 18 per °F)*. Temperature coefficients of resistance for copper with a conductivity value within the range shown above may be calculated in the same manner.

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	1 140 - 1 200 °C	2 085 - 2 190 °F
3.2 Annealing temperature range	250 - 650 °C	480 - 1 200 °F
Stress relieving temperature range	200 - 250 °C	390 - 480 °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	Good	
Carbon-arc welding	Good	
Gas-shielded arc welding	Excellent	
Coated metal-arc welding	Not recommended	
Resistance welding: spot and seam	Fair	
butt	Good	

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	—	—	B158 B159 B160	—	—
Belgium	NBN	CuP	—	266.01	266.01	—	266.01	—	266.01
Canada	CSA	Cu-DHP 122	—	HC.4.1	HC.4.1	—	HC.7.1 HC.7.3 HC.7.5 HC.7.6 HC.7.7 HC.7.8	—	—
Chile	INDITECNOR	Cu-DHP	244 p	196 ch	—	—	395 ch	—	—
France	NF	Cu/b	A53-100	A53-601	A53-301	—	A53-501	A53-301	A53-301
Germany	DIN	SF-Cu(2.0090)	1787	17670	17672	17672	17671	17673	17674
Italy	UNI	Cu-DHP	5649	—	—	—	—	—	—
Netherlands . . .	N or NEN [b]	Cu-DHP	NEN 6023	—	—	—	NEN 2263	—	—
South Africa . .	SABS	—	—	—	—	—	460/465	—	—
Spain	UNE	CuP	37.103	—	—	—	—	—	—
Sweden	SIS	Cu-DHP	—	14 50 15	—	—	14 50 15	—	—
Switzerland . . .	VSM	Cu-DHP	10826	11852	11852	—	11852	—	—
United Kingdom .	BS	C106	1172	899 1541 1569 2027 2875 2870	2874	2873	61 (Part 1) 378 659 1306 (Part 2) 1386 1401 2017 2871	—	2874
United States . .	ASTM	DHP 122	—	B124 B133 B152	B12 B124 B133	—	B42 B68 B75 B88 B111 B280 B302 B306 B359 B395	—	B124 B133

[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
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
Tube	Annealed	24	6	45	$5.65\sqrt{S_o}$	45	50	16	—
	Typical Cold Drawn Tempers [c]	**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 [d]	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] Tubes for condensers and heat exchangers are generally supplied only to the tempers whose representative mechanical properties are printed in **bold type.**

[d] 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	»
Tube	Annealed	15	5	50	2 in.	50	10	—
	Typical Cold Drawn Tempers [b]	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 [c]	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) Tubes for condensers and heat exchangers are generally supplied only to the tempers whose representative mechanical properties are printed in **bold type.**

(c) 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 %	Elongation gauge length	Rockwell Hardness F	Rockwell Hardness B	Rockwell Hardness 30 T	Shear Strength psi	Typical Size Related to Properties Shown [a]
Flat Products (Plate, Sheet, Strip)	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									
	Hard	50 000	45 000	6	2 in.	90	50	57	28 000	0.040 in. thick
	Hard	50 000	45 000	12	2 in.	90	50	—	28 000	0.250 in. thick
	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.
Tube	Annealed	32 000	10 000	45	2 in.	40	—	—	22 000	1.0 in. O.D. x 0.065 in. wall
	Cold Worked [b]									
	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**	»
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 [c]									
	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) Tubes for condensers and heat exchangers are generally supplied only to the tempers whose representative mechanical properties are printed in **bold type.**

(c) 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	Yield Strength 0.5 % ext. under load psi	%	gauge length		kg m/cm²	ft lb
Sheet (5) 3.2 mm 0.125 in.	Annealed (grain size 0.045 mm)	+ 24	+ 75	21.5	13.5	**30 250**	6.31 (a)	**9 750**	**51.2**	2 in	**89.8**	—	—
		— 40	— 40	25	16	**35 580**	7.20 (a)	**11 350**	**56.5**	2 in	**74.3**	—	—
		— 68	— 90	26.5	17	**37 580**	8.02 (a)	**11 830**	**55.8**	2 in	**77.8**	—	—
		— 196	— 321	35.5	23	**50 800**	7.40 (a)	**11 400**	**55.8**	2 in	**64.1**	—	—
	Cold Worked 5 - 7 %	+ 24	+ 75	23	14.5	**32 600**	17.1 (a)	**24 700**	**39.0**	2 in	**91.8**	—	—
		— 40	— 40	26	16.5	**37 250**	18.5 (a)	**26 450**	**41.0**	2 in	**78.8**	—	—
		— 68	— 90	28	17.5	**39 600**	18.6 (a)	**27 100**	**38.8**	2 in	**68.7**	—	—
		— 196	— 321	37.5	23.5	**53 100**	20.2 (a)	**28 980**	**49.0**	2 in	**62.0**	—	—
Sheet (5) 6.4 mm 6.35 mm	Annealed (grain size 0.043 mm)	+ 24	+ 75	21.5	13.5	**30 750**	5.94 (a)	**9 140**	**57.1**	2 in	**63.3**	—	—
		— 40	— 40	24.5	15.5	**34 600**	6.00 (a)	**9 490**	**55.3**	2 in	**61.6**	—	—
		— 68	— 90	26.5	17	**37 900**	5.86 (a)	**9 450**	**55.8**	2 in	**58.3**	—	—
		— 196	— 321	35	22.5	**49 900**	5.69 (a)	**9 240**	**58.8**	2 in	**54.8**	—	—
	Cold Worked 5 - 7 %	+ 24	+ 75	23.5	15	**33 160**	17.8 (a)	**25 450**	**52.0**	2 in	**84.6**	—	—
		— 40	— 40	26.5	17	**37 900**	18.1 (a)	**26 030**	**51.0**	2 in	**78.1**	—	—
		— 68	— 90	27.5	17.5	**39 050**	18.4 (a)	**26 400**	**50.5**	2 in	**77.6**	—	—
		— 196	— 321	37	23.5	**52 300**	18.6 (a)	**26 700**	**61.8**	2 in	**70.1**	—	—
Rod (6) 19 mm diam. 0.75 in. diam.	Annealed	+ 20	+ 68	23	14.5	**32 600**	—	**8 290**	**57.5**	2 in	—	12.9 (b)	**46.8 (b)**
		+ 3	+ 37	—	—	—	—	—	—	—	—	12.9 (b)	**46.6 (b)**
		— 18	— 0.4	—	—	—	—	—	—	—	—	12.1 (b)	**43.9 (b)**
		— 30	— 22	—	—	—	—	—	—	—	—	12.4 (b)	**44.7 (b)**
		— 50	— 58	—	—	—	—	—	—	—	—	12.1 (b)	**43.7 (b)**
		— 80	— 112	—	—	—	—	—	—	—	—	12.8 (b)	**46.3 (b)**
		— 115	— 175	—	—	—	—	—	—	—	—	13.3 (b)	**48.2 (b)**

(a) This value was originally reported in psi; in this table it is given in kg/mm² to 3 significant figures.
(b) Charpy, keyhole notch, standard specimen; cross-sectional area 0.5 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:
■ Reed, R.P. and Mikesell, R.P. Low-temperature (295 to 4 K) Mechanical Properties of Selected Copper Alloys. J. of Materials, Vol. 2, No. 2, June (1967), pp. 370-392.
— The 0.1 % proof stress values are not available.

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 [5] **3.2 - 6.35 mm 0.125 - 0.25 in.**	Annealed (grain size 0.044 mm)	24	75	21.5	13.5	**30 430**	**6.01** [a]	**9 370**	**53.4**
		100	212	18.5	12	**26 600**	**6.30** [a]	**9 550**	**52.5**
		204	400	16	10	**22 520**	**5.46** [a]	**8 320**	**52.1**
Sheet [5] **6.35 mm 0.25 in.**	Cold Worked 5 - 7 %	24	75	23.5	15	**33 160**	**17.8** [a]	**25 450**	**52.0**
		60	140	22	14	**31 530**	**16.5** [a]	**23 570**	**50.9**
		100	212	20.5	13	**29 480**	**17.4** [a]	**24 850**	**45.4**
		149	300	19.5	12.5	**27 430**	**15.4** [a]	**22 000**	**46.8**
		204	400	17.5	12	**25 180**	**15.5** [a]	**22 120**	**46.5**
		288	550	14	9.5	**21 650**	**11.9** [a]	**17 340**	**49.6**
		371	700	11.5	8	**17 550**	**9.93** [a]	**14 330**	**57.8**
		454	850	9.5	6.5	**13 180**	**7.26** [a]	**10 480**	**68.0**
		496	925	8	5	**11 090**	—	—	**88.0**
		538	1 000	6	3.5	**8 180**	—	—	**94.8**
		593	1 100	4.5	3	**6 260**	—	—	**98.0**
		648	1 200	3.5	2	**4 800**	—	—	**98.0**
Rod [5] **3.2 mm diam. 0.125 in. diam.**	Annealed (grain size 0.032 mm)	24	75	23.5	15	**33 300**	**3.48** [a]	**5 850**	**49.0**
		149	300	—	—	—	**3.13** [a]	**5 250**	—
		204	400	—	—	—	**2.99** [a]	**5 050**	—
		260	500	—	—	—	**2.67** [a]	**4 500**	—
	Cold Worked 21 %	24	75	30	19	**42 700**	**27.3** [a]	**40 100**	**14.0**
		149	300	—	—	—	**24.3** [a]	**35 100**	—
		204	400	—	—	—	**20.5** [a]	**30 300**	—
		260	500	—	—	—	**17.3** [a]	**26 000**	—
	Cold Worked 84 %	24	75	39.5	25	**56 400**	**35.6** [a]	**52 000**	**10.0**
		149	300	—	—	—	**30.9** [a]	**44 300**	—
		204	400	—	—	—	**27.0** [a]	**39 200**	—
		260	500	—	—	—	**8.86** [a]	**14 300**	—

(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:

■ Ashbolt, D. and Bowers, J.E. The Properties of Copper and Copper Alloys at Elevated Temperatures. B.N.F.M.R.A. Report A1550, July 1965.

■ Reference (5) 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
Rod (5) 3.2 mm diam. 0.125 in. diam.	Annealed (grain size 0.015 mm)	204	400	0.7	0.5	**1 000**	**7.08**	**0.030**	**0.013**	**0.001 4**
				1.5	1	**2 050**	**6.00**	**0.068**	**0.023**	**0.005 3**
				2	1.5	**3 050**	**6.00**	**0.147**	**0.054**	**0.011**
				3.5	2	**5 000**	**7.08**	**0.875**	**0.325**	**0.067**
				5.5	3.5	**8 000**	**6.00**	**3.090**	**1.640**	**0.148**
	Annealed (grain size 0.032 mm)	204	400	0.7	0.5	**1 050**	**7.08**	**0.019 5**	**0.005 5**	**0.001 0**
				1.5	1	**2 050**	**6.00**	**0.078**	**0.037**	**0.003 9**
				2	1.5	**3 050**	**7.08**	**0.355**	**0.164**	**0.018 5**
				3.5	2.5	**5 080**	**7.08**	**1.378**	**0.660**	**0.051**
				5.5	3.5	**8 050**	**6.00**	**3.340**	**1.120**	**0.120**
	Annealed (grain size 0.070 mm)	204	400	1.5	1	**2 050**	**6.00**	**0.069**	**0.029**	**0.001 2**
				2	1.5	**3 050**	**6.00**	**0.415**	**0.194**	**0.006 0**
				3	2	**4 500**	**7.08**	**1.098**	**0.359**	**0.013**
				4	2.5	**6 000**	**6.00**	**1.862**	**0.647**	**0.029**
				5.5	3.5	**8 000**	**7.08**	**3.460**	**1.040**	**0.084**
	Cold Worked 21 %	204	400	3.5	2.5	**4 050**	**7.08**	**0.065**	**0.027 5**	**0.001 3**
				4	2.5	**6 000**	**7.08**	**0.099**	**0.039**	**0.002 4**
				6.5	4	**9 100**	**7.08**	**0.156**	**0.051**	**0.006**
				10.5	6.5	**15 000**	**6.00**	**0.400**	**0.148**	**0.023**
				17.5	11	**25 000**	**0.90**	**4.412**	**— 0.485**	**5.18** (b)
	Cold Worked 37 %	204	400	3.5	2.5	**4 050**	**7.08**	**0.063**	**0.024**	**0.001 6**
				4	2.5	**6 000**	**7.08**	**0.100**	**0.034**	**0.003 5**
				6.5	4	**9 100**	**7.08**	**0.191**	**0.074**	**0.007 8**
				10.5	6.5	**15 000**	**6.00**	**0.408**	**0.147**	**0.026**
				17.5	11	**25 150**	**1.45**	**1.586**	**0.324**	**0.735**
				17.5	11	**25 150**	**6.00**	**7.276**	**— 5.760**	**2.14** (b)
				21	13.5	**30 000**	**0.24**	**2.89**	**—**	**—** (b)
	Cold Worked 84 %	204	400	2.5	1.5	**3 550**	**7.70**	**0.126**	**— 0.015 1**	**0.015 2**
				3.5	2	**5 050**	**7.08**	**0.119**	**— 0.085**	**0.038** (b)
				6.4	4	**9 050**	**7.08**	**0.534**	**— 1.110**	**0.224** (b)
				10.5	6.5	**15 000**	**0.58**	**0.169**	**0.034**	**0.055**
				10.5	6.5	**15 000**	**4.20**	**2.813**	**— 8.630**	**2.70** (b)
				21	13.5	**30 000**	**0.74**	**3.920**	**—**	**—** (b)

(a) Total extension = Initial extension + Total creep = Initial extension + Intercept + (Minimum creep rate × Duration).
(b) Accelerating creep rate.

N.B.: — Original values are printed in **bold type;** other values are converted.
— Further data can be obtained from reference (5) 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
Strip [7] 0.8 mm 0.032 in.	Cold Worked 21 %	100	30	10 [a]	19	6 [a]	**42 800**	**14 000** [a]
	Cold Worked 37 %	100	36	13.5 [a]	23	8.5 [a]	**51 600**	**19 000** [a]
	Cold Worked 60 %	100	41.5	13 [a]	26.5	8.5 [a]	**59 300**	**18 500** [a]
Tube [8]	Annealed (grain size 0.050 mm)	20	22.5	7.5 [b]	14	5 [b]	**32 000**	**11 000** [b]
	Cold Worked 15 %	20	28	10 [b]	18	6 [b]	**40 000**	**14 000** [b]
	Cold Worked 40 %	20	38.5	13.5 [b]	24.5	8.5 [b]	**55 000**	**19 000** [b]

(a) Reversed-bending test.
(b) Rotating-beam test on rod.
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.

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