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

2 PHYSICAL PROPERTIES (continued)

	Metric Units	English Units
2.7 Electrical resistivity (volume) at:		
— 200 °C — *328 °F* (annealed) [a]	0.002 2 [b] ohm mm²/m 0.22 [b] microhm cm	1.3 [b] ohms (circ mil/ft) 0.085 [b] microhm in
— 100 °C — *148 °F* (») [a]	0.009 1 [b] ohm mm²/m 0.91 [b] microhm cm	5.5 [b] ohms (circ mil/ft) 0.36 [b] microhm in
20 °C *68 °F* (»)	0.017 241 - 0.017 0 ohm mm²/m 1.724 1 - 1.70 microhm cm	10.371 - 10.2 ohms (circ mil/ft) 0.678 8 - 0.669 microhm in
100 °C *212 °F* (») [a]	0.022 7 ohm mm²/m 2.27 microhm cm	13.6 ohms (circ mil/ft) 0.89 microhm in
200 °C *392 °F* (») [a]	0.029 5 ohm mm²/m 2.95 microhm cm	17.7 ohms (circ mil/ft) 1.16 microhm in
20 °C *68 °F* (fully cold worked) [a]	0.017 8 ohm mm²/m 1.78 microhm cm	10.7 ohms (circ mil/ft) 0.700 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		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		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	»
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) **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**	—	—	**38**

(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		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 (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)
	10 % Cold Worked	121	250	17.5	11	**25 000**	**2.20**	**1.85** (d)	—	— (e)
	37.1 % Cold Worked	121	250	17.5	11	**25 000**	**4.80**	**0.40** (d)	—	**0.056**
	84.4 % Cold Worked	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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