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

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

DATA SHEET No. A 3
Cu-FRTP

1968 Edition

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		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
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	»
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/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 [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/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-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/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 (2) **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 (2) **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 (6) **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	**4 440**	—	—	**54.5**
Rod (2) **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-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 9.5 14	3.5 6 8.5	8 000 14 000 20 000	**2.50** **2.60** **0.17**	**2.6** **10.0** **29.8** (b)	**2.0** **7.6** —	0.15 1.2 39
		175	347	5.5 9.5	3.5 6	8 000 14 000	**2.00** **0.35**	**3.3** **15** (b)	**2.3** **8.0**	0.65 6.3
	Cold Worked 10 %	130	266	5.5 9.5 14	3.5 6 8.5	8 000 14 000 20 000	**8.25** **8.60** **1.750**	**0.20** **0.67** **2.4** (b)	**0.15** **0.26** **0.32**	0.01 0.042 0.45
		175	347	5.5 9.5	3.5 6	8 000 14 000	**6.85** **1.10**	**1.14** **2.0** (b)	**0.135** **0.22**	0.088 0.66
	Cold Worked 25 %	130	266	5.5 9.5 14	3.5 6 8.5	8 000 14 000 20 000	**7.20** **8.60** **4.68**	**0.235** **1.02** **3.4** (b)	**0.125** **0.25** **0.36**	0.01 0.054 0.27
		175	347	5.5	3.5	8 000	**1.05**	**3.3** (b)	—	0.6
	Cold Worked 50 %	130	266	5.5 9.5 14	3.5 6 8.5	8 000 14 000 20 000	**8.25** **8.70** **4.030**	**1.58** **7.31** **11** (b)	**0.08** **0.16** **0.24**	0.035 0.055 0.17
Rod (2) 3.2 mm diam. 0.125 in. diam.	Annealed (grain size 0.025 mm)	149	300	1.5 2 4 5.5	1 1.5 2.5 3.5	2 050 3 000 6 000 8 100	**6.40** **6.50** **6.50** **6.50**	**0.088** **0.257** **1.875** **3.475**	**0.048** **0.133** **1.120** **1.795**	**0.003 2** **0.013** **0.057 5** **0.088**
		204	400	1 1.5 2 2.5 4 5	0.7 1 1.5 2 2.5 3	1 550 2 050 3 050 4 000 6 100 7 050	**6.00** **6.50** **6.00** **6.50** **6.00** **4.50**	**0.168** **0.359** **1.050** **2.042** **2.485** **3.900**	**0.067** **0.168** **0.510** **1.232** **0.668** **2.750**	**0.014** **0.026** **0.083** **0.11** **0.204** **0.267**
		260	500	0.3 0.5 0.7 1.5	0.2 0.3 0.5 0.9	360 600 1 050 2 000	**6.00** **6.00** **6.50** **6.50**	**0.084** **0.195** **0.640** **2.877**	**0.016** **0.010** **0.113** **0.869**	**0.011** **0.030** **0.079 5** **0.306**
	Cold Worked 84 %	149	300	5 7 10 14 17.5	3 4.5 6.5 9 11	7 550 10 000 14 650 20 000 25 200	**6.40** **6.50** **6.40** **6.50** **1.78**	**0.118** **0.167** **0.540** **2.330** **2.565**	**0.041** **0.042** **— 0.170** **— 3.00** **— 4.98**	**0.004 9** **0.010** **0.097** (c) **0.80** (c) **4.14** (c)
		204	400	0.7 1.5 2.5 5	0.5 1 2 3	1 050 2 100 4 050 7 100	**6.50** **6.00** **6.50** **6.50**	**0.064** **0.203** **1.080** **5.418**	**0.045** **0.112** **0.409** **2.47**	**0.001 1** **0.011 5** **0.097** **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)
	10 % Cold Worked 37.1 % 84.4 %	121 121 121	250 250 250	17.5 17.5 17.5	11 11 11	25 000 25 000 25 000	**2.20** **4.80** **1.18**	**1.85** (d) **0.40** (d) **1.75** (d)	— — —	— (e) **0.056** — (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 10^4	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.**	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]
	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]
	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]
	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.

REFERENCES

PHYSICAL PROPERTIES (SECTION 2)

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

MECHANICAL PROPERTIES (SECTION 5)

(2) - 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).

(3) - Krupkowski, A. Propriétés Mécaniques du Cuivre. Rev. Metall., Vol. 28 (1931), pp. 641-652; Vol. 29 (1932), pp. 74-92.

(4) - Colbeck, E.W. and MacGillivray, W.E. The Mechanical Properties of Metals at Low Temperatures. (Part II - Non-Ferrous Materials). Trans. Inst. Chemical Engrs. (London), Vol. 11 (1933), pp. 107-122.

(5) - Pester, F. Festigkeitsprüfungen an Stangen und Drähten bei tiefen Temperaturen. Z. Metallk. Vol. 24 (1932), pp. 67-72, 115-120.

(6) - 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.

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

(8) - 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.

(9) - Greenall, C.H. and Gohn, G.R. Fatigue Properties of Non-ferrous Sheet Metals. Proc. A.S.T.M., Vol. 37 (1937), pp. 160-194.

(10) - 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.

(11) - Butts, A. ed. Copper. The Science and Technology of the Metal, its Alloys and Compounds. Reinhold Publishing Corp., New York, (1954), p. 369. (American Chemical Society, Monograph Series. No. 122).

(12) - Anderson, A.R., Swan, E.F. and Palmer, E.W. Fatigue Tests on Some Additional Copper Alloys. Proc. A.S.T.M., Vol. 46 (1946), pp. 678-692.

(13) - Burghoff, H.L. and Blank, A.I. Fatigue Characteristics of Some Copper Alloys. Proc. A.S.T.M., Vol. 47 (1947), pp. 695-712.

(14) - Metals Handbook, Vol. 1. 8th ed. American Society for Metals, Cleveland, Ohio, (1961), p. 1008.

PRINTED BY PEC - MILANO (ITALY)