COPPER - CADMIUM

Cu Cd1

Common names: Cadmium Copper
Cadmium Bronze

A copper alloy with an alpha phase structure. Addition of cadmium improves mechanical properties, especially in the cold-worked condition, with a relatively small reduction in conductivity. Cadmium copper has good fatigue properties and retains its hardness and strength at temperatures higher than those at which unalloyed copper would soften. It is also resistant to wear and arcing. The alloy is, therefore, used for applications requiring a combination of high strength and conductivity, even at relatively elevated temperatures, and is mainly supplied as round or shaped hard-drawn wire.

COMPOSITION (weight %)

Cd	0.7–1.3
Cu	rem.

1 SOME TYPICAL USES

Electrical
Catenary and contact (trolley) wires for electric traction; telephone and telegraph wires; spring contacts for automotive and signal relays; tinsel for flexible cords of telephone instruments and switchboards; plugs and sockets; jointing sleeves; reinforcing strip for pressurised electric cables; overhead lines with exceptionally large span lengths.

Mechanical
Spot and seam resistance-welding electrodes and wheels; electrode holders for resistance-welding machines and arc-furnaces; flash-butt-welding dies.

2 PHYSICAL PROPERTIES

		Metric Units	English Units
2.1	Density at 20 °C *68 °F*	8.9 g/cm³	0.320 lb/in³
2.2	Melting range	1 010–1 080 °C	1 850–1 975 °F
2.3	Coefficient of thermal expansion (linear) at:		
	20 to 100 °C *68 to 212 °F*	0.000 017 per °C	0.000 009 per °F
	20 „ 300 °C *68 „ 572 °F*	0.000 018 „ „	0.000 010 „ „
2.4	Specific heat (thermal capacity) at:		
	20 °C *68 °F*	0.09 cal/g °C	0.09 Btu/lb °F
2.5	Thermal conductivity at:		
	20 °C *68 °F*	0.75–0.85 cal cm/cm² s °C	180–205 Btu ft/ft² h °F
	200 °C *392 °F*	0.80–0.90 „	195–220 „
2.6	Electrical conductivity (volume) at:		
	20 °C *68 °F* (annealed)	46–53 m/ohm mm²	80–92 % IACS
	200 °C *392 °F* (annealed)	~31 „	~54 „ „
	20 °C *68 °F* (fully cold worked)	44–50 „	75–87 „ „
2.7	Electrical resistivity (volume) at:		
	20 °C *68 °F* (annealed)	0.022–0.019 ohm mm²/m 2.2–1.9 microhm cm	13–11 ohms (circ mil/ft) 0.85–0.74 microhm in
	200 °C *392 °F* (annealed)	~0.032 ohm mm²/m ~3.2 microhm cm	~19 ohms (circ mil/ft) ~1.3 microhm in
	20 °C *68 °F* (fully cold worked)	0.023–0.020 ohm mm²/m 2.3–2.0 microhm cm	14–12 ohms (circ mil/ft) 0.91–0.78 microhm in
2.8	Temperature coefficient of electrical resistance at:		
	20 °C *68 °F* (annealed)	0.003 1 per °C (80% IACS)	0.001 7 per °F (80% IACS)
	applicable over range from 0 to 100 °C *32 to 212 °F*	0.003 6 „ „ (92 „ „)	0.002 0 „ „ (92 „ „)
	20 °C *68 °F* (fully cold worked)	0.003 0 „ „ (75 „ „)	0.001 6 „ „ (75 „ „)
	applicable over range from 0 to 100 °C *32 to 212 °F*	0.003 4 „ „ (87 „ „)	0.001 9 „ „ (87 „ „)
2.9	Modulus of elasticity (tension) at 20 °C *68 °F*:		
	annealed	132400 N/mm² 13 500 kg/mm²	19 200 000 lb/in²
	cold worked	12 700 kg/mm² 114550 N/mm²	18 100 000 lb/in²
2.10	Modulus of rigidity (torsion) at 20° C *68 °F*:		
	annealed	49035 N/mm² 5 000 kg/mm²	7 100 000 lb/in²
	cold worked	4 700 kg/mm² 46091 N/mm²	6 700 000 lb/in²

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

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

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3 FABRICATION PROPERTIES

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

		Metric Units	English Units
3.1	Casting temperature range [(a)]	1 130–1 220 °C	2 065–2 230 °F
3.2	Annealing temperature range	500– 700 °C	930–1 290 °F
	Stress relieving temperature range	250– 350 °C	480– 660 °F
3.3	Hot working temperature range	750– 870 °C	1 380–1 600 °F
3.4	Hot formability	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)	25%	
3.8	Joining methods: [(a)]	See General Data Sheet No. 3.3	
	Soldering	Excellent	
	Brazing	Good	
	Oxy-acetylene welding	Fair	
	Carbon-arc welding	Not recommended	
	Gas-shielded arc welding	Fair	
	Coated metal-arc welding	Not recommended	
	Resistance welding: spot and seam	Fair	
	butt	Fair	

(a) Adequate fume extraction must be ensured during melting, casting and welding to avoid risk of toxicity from cadmium oxide.

4 NATIONAL SPECIFICATIONS FOR MANUFACTURED FORMS

and ISO Recommendation

Country	Designation of Standards	Designation of Material in Standards	Specification for Chemical Composition [a]	Plate Sheet Strip	Rod	Wire	Tube	Sections Shapes	Forgings
Australia . . .	SAA	—	—	—	—	—	—	—	—
Belgium . . .	NBN	—	—	—	266.02	266.02	—	—	—
Canada . . .	CSA	—	—	—	—	—	—	—	—
Chile	NCh (INDITECNOR)	Cu Cd	245 of. 68	—	—	—	259 of. 70	—	—
France	NF	—	—	—	—	—	—	—	—
Germany . . .	DIN	CuCd1	17 666	—	17 672	17 677	—	17 674	17 673 17 678
India	IS	—	—	—	—	—	—	—	—
Italy	UNI	CU CD1	—	—	—	2528	—	—	—
Japan	JIS	—	—	—	—	—	—	—	—
Netherlands . .	N or NEN [b]	—	—	—	—	—	—	—	—
South Africa . .	SABS	—	—	—	—	—	—	—	—
Spain	UNE	—	—	—	—	—	—	—	—
Sweden . . .	SIS	50 55	—	—	—	—	—	MNC 50 E 14 50 55	—
Switzerland . .	VSM	—	—	—	—	—	—	—	—
United Kingdom	BS	C108 A1/3	—	2875	4577	23 125 174 177 2755 2873	—	—	4577
United States	ASTM	No. 162	—	—	—	B 105	—	—	—
International Organisation for Standardization	ISO	Cu Cd1	R 1336	—	—	—	—	—	—

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

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

5 MECHANICAL PROPERTIES

5.1 Mechanical properties at room temperature

Tensile properties	see tables 5.1.1/2/3
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	no data
Impact properties	,, ,,

5.3 Mechanical properties at elevated temperature

Short-time tensile properties	see table 5.3.1
Creep properties	see tables 5.3.2.1/2

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

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

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

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

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	25	8	45	$5.65\sqrt{S_o}$	55	58	18	—
	Hot Rolled [c]	27	9	40	$5.65\sqrt{S_o}$	65	68	20	—
	Typical Cold Worked Tempers	34 42	27 38	20 7	$5.65\sqrt{S_o}$ 50 mm	100 120	105 125	23 27	0.2–5 mm thick 0.2–1 mm thick
Rod [c]	Annealed	24	7	45	$5.65\sqrt{S_o}$	50	53	18	—
	Hot Worked	27	9	40	$5.65\sqrt{S_o}$	60	63	20	—
	Typical Cold Worked Tempers	40 48	35 45	10 5	$5.65\sqrt{S_o}$ $5.65\sqrt{S_o}$	110 130	115 135	26 31	5–30 mm diam. or equivalent area 5–10 mm diam. or equivalent area
Wire	Annealed	26	8	35	200 mm	—	—	19	—
	Typical Cold Drawn Tempers	52 62 70	48 59 69	3 — —	200 mm — —	— — —	— — —	28 31 35	2–5 mm diam. 0.8–2 mm diam. up to 0.8 mm diam.
Sections [c] [d] / Shapes	Hot Worked	27	9	35	$5.65\sqrt{S_o}$	60	63	20	—
	Typical Cold Worked Tempers	35 42 **47**	27 38 **44**	15 5 **3**	$5.65\sqrt{S_o}$ $5.65\sqrt{S_o}$ 200 mm	100 120 **130**	105 125 **135**	23 27 **30**	— — —
Forgings [c]	Hot Worked	28	10	35	$5.65\sqrt{S_o}$	70	74	21	—

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

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

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

(d) Contact (trolley) wire is generally supplied only to the temper whose representative mechanical properties are printed in **bold type.**

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

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

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

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

Form	Temper [(a)]	Tensile Strength		Proof Stress 0.1% offset		Elongation		Vickers Hardness	Shear Strength		Typical Size Related to Properties Shown [(b)]
		hbar	ton/in²	hbar	ton/in²	%	gauge length		hbar	ton/in²	
Plate	Cold Rolled Hard	29	19	22	14	30	$5.65\sqrt{S_o}$	95	20	13	16–25 mm (0.625–1 in.) thick
		32	21	25	16	22	$5.65\sqrt{S_o}$	105	23	15	10–16 mm (0.375–0.625 in.) thick
Strip	Annealed	25	16	6	4	50	50 mm (2 in.)	60	17	11	—
	Typical Cold Worked Tempers	32	21	25	16	25	50 mm (2 in.)	105	23	15	0.2–3 mm (0.008–0.125 in.) thick
		39	25	34	22	12	50 mm (2 in.)	120	26	17	"
Rod [(c)]	Hot Worked	26	17	8	5	40	$5.65\sqrt{S_o}$	65	19	12	12–50 mm (0.5–2 in.) diam. or equivalent area
	Typical Cold Worked Temper	43	28	37	24	8	$5.65\sqrt{S_o}$	130	29	19	6–25 mm (0.25–1 in.) diam. or equivalent area
Wire	Cold Drawn Hard	62	40	—	—	3	200 mm (8 in.)	—	34	22	3–4 mm (0.12–0.16 in.) diam.
		70	45	—	—	—	—	—	36	23	1–2.5 mm (0.04–0.10 in.) diam.
Sections [(c)] (Extruded)	Hot Worked	26	17	8	5	35	$5.65\sqrt{S_o}$	65	19	12	—
	Typical Cold Drawn Temper	34	22	25	16	15	$5.65\sqrt{S_o}$	110	23	15	—
Sections [(d)] (Contact Wire)	Typical Cold Drawn Tempers	40	26	34	22	5	200 mm (8 in.)	120	26	17	~195 mm² (~0.30 in.²) cross-sectional area
		43	28	37	24	4	200 mm (8 in.)	130	28	18	~160 mm² (~0.25 in.²) cross-sectional area
		46	30	40	26	3	200 mm (8 in.)	135	29	19	~105 mm² (~0.16 in.²) cross-sectional area
Forgings [(c)]	Hot Worked	28	18	9	6	35	$5.65\sqrt{S_o}$	75	19	12	—
	Hot/Cold Worked	~37	~24	~31	~20	~12	$5.65\sqrt{S_o}$	~120	~25	~16	—

(a) The recognised temper designations used in the relevant British Standards are also given.

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

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

(d) Trolley and contact wire sections for electric traction; cold drawn from hot-rolled rod.

5.1.3 Typical Tensile Properties and Hardness Values—American Units

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

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

For a given temper, individual elongation values may show some variation above or below 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	39 000	13 000	40	2 in.	47	—	—	25 000	—
	Annealed	37 000	12 000	50	2 in.	47	—	—	24 000	0.040 in. thick
	Cold Worked									
	Half Hard	48 000	46 000	15	2 in.	93	62	58	27 000	0.040 in. thick
	Hard	55 000	53 000	6	2 in.	95	66	60	28 000	"
	Extra Hard	60 000	59 000	6	2 in.	96	68	62	30 000	"
	Spring	63 000	60 000	5	2 in.	97	70	63	31 000	"
	Extra Spring	66 000	63 000	4	2 in.	98	72	65	33 000	"
Rod [(b)]	As Hot Rolled	39 000	13 000	40	2 in.	47	—	—	25 000	—
	Annealed—Soft	35 000	12 000	45	2 in.	42	—	—	24 000	—
	Cold Worked									
	Extra Hard	94 000	85 000	1	2 in.	103	82	72	61 000	0.25 in. diam.
	Half Hard	50 000	36 000	7	2 in.	87	46	55	33 000	0.50 in. diam.
	Hard	71 000	65 000	1	2 in.	97	70	63	47 000	"
	Hard	53 000	50 000	8	2 in.	97	70	63	34 000	1 in. diam.
Wire	Cold Worked									
	Hard	95 000	91 000	1	10 in.	—	—	—	63 000	0.035 in. diam.
	Hard	91 000	87 000	1.5	10 in.	—	—	—	60 000	0.050 in. diam.
	Hard	88 000	84 000	2	10 in.	—	—	—	57 000	0.070 in. diam.
	Hard	85 000	81 000	2	10 in.	—	—	—	55 000	0.090 in. diam.
	Hard	83 000	78 000	3	10 in.	—	—	—	54 000	0.100 in. diam.
Shapes [(b)]	As Hot Rolled	38 000	12 000	45	2 in.	47	—	—	24 000	—
	Annealed	37 000	12 000	50	2 in.	45	—	—	24 000	—
	Cold Worked									
	Hard	60 000	54 000	5	2 in.	98	73	65	38 000	—
Forgings [(b)]	Cold Worked									
	Hard	60 000	54 000	5	2 in.	98	73	65	38 000	—

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

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

5.2 MECHANICAL PROPERTIES AT LOW TEMPERATURE

5.2.1 Tensile Properties—Impact Properties

At the date of publication of this sheet, no data relating to this material have been traced.

5.3 MECHANICAL PROPERTIES AT ELEVATED TEMPERATURE

5.3.1 Short-Time Tensile Properties

Form	Temper	Testing Temperature		Tensile Strength			Proof Stress			Elongation	
		°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
Rod (1) **14 mm diam. 0.56 in. diam.**	Annealed	20	68	27	**17.0**	38 000	—	**4.7** (a)	—	**63**	$4\sqrt{S_o}$
		400	752	17	**10.7**	24 000	—	**3.3** (a)	—	**112**	$4\sqrt{S_o}$
Rod (2) **15 mm diam. 0.59 in. diam.**	Cold Worked 44%	20	68	**39.4**	25	56 000	**39.0**	**22.7** (b)	—	**16.9**	$5.65\sqrt{S_o}$
		200	392	**36.7**	23.5	52 000	**35.1**	**21.8** (b)	—	**14.8**	$5.65\sqrt{S_o}$
		300	572	**31.0**	19.5	44 000	**27.5**	**16.4** (b)	—	**17.5**	$5.65\sqrt{S_o}$
Rod (3)	Cold Worked 37%	200	392	39	24.5	**55 200**	—	—	**55 100**	**14.0**	2 in.
		300	572	36.5	23	**51 800**	—	—	**51 200**	**11.5**	2 in.
		400	752	23	14.5	**32 400**	—	—	**20 200**	**37.5**	2 in.
		500	932	12	7.5	**17 100**	—	—	**6 400**	**111.2**	2 in.
		600	1 112	7	4.5	**10 000**	—	—	**4 200**	**107.5**	2 in.
		700	1 292	4.5	3	**6 400**	—	—	**3 900**	**139.5**	2 in.
Rod (4)	Cold Worked ~45%	20	68	**40**	25.5	57 000	**38**	—	—	**15**	$5.65\sqrt{S_o}$
		100	212	**40**	25.5	57 000	**36**	—	—	**10**	$5.65\sqrt{S_o}$
		200	392	**38**	24	54 000	**35**	—	—	**12**	$5.65\sqrt{S_o}$
		300	572	**33**	21	47 000	**28**	—	—	**17**	$5.65\sqrt{S_o}$
		350	662	**32**	20.5	45 500	**23**	—	—	**28**	$5.65\sqrt{S_o}$
Rod (5)	Cold Worked ~60%	20	68	**65**	41.5	92 500	**62**	—	—	**1**	(c)
		100	212	**60**	38	85 500	**58**	—	—	**2**	(c)
		200	392	**47**	30	67 000	**44**	—	—	**5**	(c)
		300	572	**37**	23.5	52 500	**30**	—	—	**10**	(c)
		350	662	**33**	21	47 000	**29**	—	—	**15**	(c)

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

(b) This value was originally reported in kg/mm²; in this table it is given in ton/in² to 3 significant figures.

(c) Gauge length not stated.

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

5.3.2 Creep Properties

5.3.2.1 Original Creep Data

Form	Temper	Testing Temperature		Stress			Duration h	Total Extension % (a)	Intercept %	Min. Creep Rate % per 1 000 h
		°C	°F	kg/mm²	ton/in²	psi				
Strip (6) 2.5 mm 0.1 in.	Cold Worked 20%	130	266	14.1	8.9	**20 000**	**2 400**	**0.155**	**0.142**	**0.006**
		225	437	5.6	3.6	**8 000**	**2 400**	**0.128**	**0.102**	**0.011**
				11.2	7.1	**16 000**	**2 400**	**0.325**	**0.246**	**0.065**
				14.1	8.9	**20 000**	**2 000**	**0.485**	**0.332**	**0.127**
Rod (2) 15 mm diam. 0.59 in. diam.	Cold Worked 44%	200	392	**14.0**	8.9	19 900	**3 018**	**0.19** (b)	—	—
				16.0	10.2	22 800	**2 512**	**0.22** (b)	—	—
				18.0	11.4	25 600	**3 018**	**0.29** (b)	—	—
				20.0	12.7	28 400	**2 655**	**0.35** (b)	—	—
		250	482	**12.2**	7.7	17 400	**4 276**	**0.29** (b)	—	—
				13.8	8.8	19 600	**4 276**	**0.41** (b)	—	—
				14.0	8.9	19 900	**5 010**	**0.51** (b)	—	—
				16.0	10.2	22 800	**1 747**	**0.56** (b)	—	—
				20.0	12.7	28 400	**1 747**	**1.42** (b)	—	—

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

(b) Total creep = Total extension — Initial extension.

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

5.3.2.2 Stress for Designated Extension

Form	Temper	Testing Temperature		Stress for Designated Extension											
		°C	°F	0.1% in 1 000 h			0.2% in 1 000 h			0.1% in 2 000 h			0.2% in 2 000 h		
				kg/mm²	ton/in²	psi	kg/mm²	ton/in²	psi	kg/mm²	ton/in²	psi	kg/mm²	ton/in²	psi
Rod (2) 15 mm diam. 0.59 in. diam.	Cold Worked 44%	200	392	**12.2**	7.7	17 400	**16.5**	10.5	23 500	**11.0**	7.0	15 600	**15.5**	9.8	22 000
		250	482	**10.1**	6.4	14 400	**12.5**	7.9	17 800	**9.4**	6.0	13 400	**11.4**	7.2	16 200

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

5.4 FATIGUE PROPERTIES

5.4.1 Fatigue Strength at Room Temperature

Form	Temper	Number of Cycles $\times 10^6$	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] **1 mm 0.040 in.**	Cold Worked 21%	100	33.5	20.5 [a]	21.5	13 [a]	**48 000**	**29 000** [a]
Rod [8] **13 mm diam. 0.5 in. diam.**	Annealed (grain size 0.050 mm)	300	24.5	10 [b]	15.5	6.5 [b]	**35 200**	**14 500** [b]
	Cold Worked 29.1%	300	51.5	21 [b]	32.5	13.5 [b]	**73 100**	**30 000** [b]
Rod [4] **20 mm diam. 0.8 in. diam.**	Forged 50%	30	**52**	**16** [c]	33	10 [c]	74 000	23 000 [c]
Wire [9] **2.5 mm diam. 0.1 in. diam.**	Cold Drawn [g]	10	—	~14 [d]	—	**~9** [d]	—	~20 000 [d]
Wire [10] **10 mm diam. 0.4 in. diam.**	Cold Drawn	10	45	13.5 [e] 20.5 [f]	**28.7**	**8.5** [e] **13.0** [f]	64 500	19 000 [e] 29 000 [f]
		10	46	14 [e] 19 [f]	**29.1**	**9.0** [e] **12.0** [f]	65 000	20 000 [e] 27 000 [f]
		10	55	12 [e] 25 [f]	**35.0**	**7.5** [e] **16.0** [f]	78 500	17 000 [e] 36 000 [f]
		10	55.5	10 [e] 25 [f]	**35.2**	**6.5** [e] **16.0** [f]	79 000	14 500 [e] 36 000 [f]
Wire [11] **10 mm diam. 0.4 in. diam.**	Cold Drawn	10	45	11.5 [e]	**28.7**	**7.2** [e]	64 500	16 000 [e]
		10	46	12 [e]	**29.2**	**7.5** [e]	65 500	17 000 [e]
		10	46	12 [e] 18.5 [f]	**29.1**	**7.6** [e] **11.9** [f]	65 000	17 000 [e] 26 500 [f]
		10	46.5	10 [e] 21.5 [f]	**29.5**	**6.2** [e] **13.6** [f]	66 000	14 000 [e] 30 500 [f]
		10	48	12 [e] 21.5 [f]	**30.4**	**7.7** [e] **13.6** [f]	68 000	17 000 [e] 30 500 [f]
		10	50.5	11.5 [e] 22.5 [f]	**32.1**	**7.3** [e] **14.2** [f]	72 000	16 500 [e] 32 000 [f]
		10	51	11.5 [e] 20 [f]	**32.3**	**7.2** [e] **12.8** [f]	72 500	16 000 [e] 28 500 [f]
		10	53	13 [e] 23 [f]	**33.7**	**8.4** [e] **14.5** [f]	75 500	19 000 [e] 32 500 [f]

(a) Reversed-bending test.
(b) Rotating-beam test.
(c) Rotating-cantilever test.
(d) Rotating-bending test.
(e) Rotating-bending test on "full-diameter" as-drawn wire.
(f) Rotating-bending test on specimen machined from as-drawn wire.
(g) Quoted as "hard drawn" in original document, but amount of cold work not defined.

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

—Further data can be obtained from the following paper:

■Fatigue of Cadmium Copper Trolley Wires. Third Report-Grooved Wires. Electrical Research Association, Leatherhead, England. Tech. Rept. No. O/T1 (1947). 13 pp.

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SILVER-BEARING TOUGH-PITCH COPPER

(Low Silver)

Cu-LSTP

Common name: Silver Copper

A high-conductivity oxygen-bearing copper containing silver either naturally or as an added alloying element. The material has greater resistance to softening and creep than unalloyed high-conductivity copper at moderately elevated temperatures.

COMPOSITION (weight %)

Cu (+ Ag) . . .	99.90 min.
Ag	0.02–0.12

1 SOME TYPICAL USES

Electrical

Windings, including hollow conductors for large generators and other heavy-duty rotating machines; commutator segments; busbars; contacts and switches; induction coils; integrated circuit lead frames.

Mechanical

Strip for automobile radiators and other heat exchangers; photogravure printing plates.

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	1 082 (a) °C	1 980 (a) °F
2.3 Coefficient of thermal expansion (linear) at:		
− 183 °C *− 297 °F*	0.000 009 5 per °C	0.000 005 28 per °F
− 191 to 16 °C *− 312 to 61 °F*	0.000 014 1 „ „	0.000 007 83 „ „
20 to 100 °C *68 to 212 °F*	0.000 016 8 „ „	0.000 009 33 „ „
20 to 300 °C *68 to 572 °F*	0.000 017 7 „ „	0.000 009 83 „ „
2.4 Specific heat (thermal capacity) at:		
− 150 °C *− 238 °F*	0.069 cal/g °C	0.069 Btu/lb °F
− 50 °C *− 58 °F*	0.087 „	0.087 „
20 °C *68 °F*	0.092 „	0.092 „
100 °C *212 °F*	0.094 „	0.094 „
200 °C *392 °F*	0.097 „	0.097 „
2.5 Thermal conductivity at:		
− 200 °C *− 328 °F*	1.37 cal cm/cm² s °C	330 Btu ft/ft² h °F
− 183 °C *− 297 °F*	1.13 „	270 „
− 100 °C *− 148 °F*	1.04 „	252 „
20 °C *68 °F*	0.94 „	227 „
100 °C *212 °F*	0.92 „	223 „
200 °C *392 °F*	0.91 „	220 „
300 °C *572 °F*	0.90 „	217 „
2.6 Electrical conductivity (volume) at:		
− 200 °C *− 328 °F* (annealed) (b)	460 (a) m/ohm mm²	800 (a) % IACS
− 100 °C *− 148 °F* („) (b)	110 (a) „	190 (a) „ „
20 °C *68 °F* („)	57.4–58.6 „	99–101 „ „
100 °C *212 °F* („) (b)	44 „	76 „ „
200 °C *392 °F* („) (b)	34 „	58 „ „
20 °C *68 °F* (fully cold worked) (b)	56.3 „	97 „ „

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)
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DATA SHEET No. B 2
Cu-LSTP

PHYSICAL PROPERTIES (continued)	Metric Units	English Units
2.7 Electrical resistivity (volume) at:		
− 200 °C *− 328 °F* (annealed) [b]	0.002 2 [a] ohm mm²/m 0.22 [a] microhm cm	1.3 [a] ohms (circ mil/ft) 0.085 [a] microhm in
− 100 °C *− 148 °F* („) [b]	0.009 1 [a] ohm mm²/m 0.91 [a] microhm cm	5.5 [a] ohms (circ mil/ft) 0.36 [a] microhm in
20 °C *68 °F* („)	0.017 4–0.017 1 ohm mm²/m 1.74–1.71 microhm cm	10.5–10.3 ohms (circ mil/ft) 0.686–0.672 microhm in
100 °C *212 °F* („) [b]	0.022 7 ohm mm²/m 2.27 microhm cm	13.6 ohms (circ mil/ft) 0.89 microhm in
200 °C *392 °F* („) [b]	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) [b]	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) Approximate value.

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

(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.

N.B.: The values shown in Section 2, which have been appropriately rounded in view of the composition range involved, are based partially on selected literature references and also upon values for Cu-ETP (electrolytic 'tough-pitch' copper).

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)]	350– 650 °C	660–1 200 °F
Stress relieving temperature range [(b)]	225– 275 °C	440– 530 °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. 3.2	
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 material 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	Sections / Shapes	Forgings
Australia . .	SAA	—	—	—	—	—	—	—	—
Belgium . .	NBN	Cu Ag	—	266.02	266.02	266.02	—	266.02	—
Canada . .	CSA	Cu-STP 114	—	HC.4.1	—	—	—	—	—
Chile . .	INDITECNOR	CuAg $\overline{TP}$	245 n.68	—	—	—	—	—	—
France . .	NF	—	—	—	—	—	—	—	—
Germany . .	DIN	E-CuAg (2.1202)	17 666	40 500, Bl.1	40 500, Bl.3	40 500, Bl.4	—	—	—
Italy . . .	UNI	Cu-STP	5649	—	—	—	—	—	—
Netherlands .	N or NEN [b]	—	—	—	—	—	—	—	—
South Africa .	SABS	—	—	—	—	—	—	—	—
Spain . .	UNE	—	—	—	—	—	—	—	—
Sweden . .	SIS	14 50 30	—	—	—	—	—	—	—
Switzerland .	VSM	Cu-LSTP	10826	11852	11852	11852	—	11852	—
United Kingdom	BS	—	—	—	—	—	—	—	—
United States [c]	ASTM	Nos. 113, 114 115, 116 or STP	—	B48 B124 B133 B152 B187 B272	B49 B124 B133 B152 B187	B1 B2 B3 B33 B47 B48	B188	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	no data traced
Impact properties	„ „ „

5.3 Mechanical properties at elevated temperature

Short-time tensile properties	see table 5.3.1
Creep properties	see tables 5.3.2.1/2

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 above or below 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 [(c)]	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 equivalent area
		34	28	10	$5.65\sqrt{S_o}$	95	105	19	6–20 mm diam. or equivalent area
Wire	Annealed	23	—	37	200 mm	—	—	16	over 3 mm diam.
		24	—	35	200 mm	—	—	16	1–3 mm diam.
		26	—	28	200 mm	—	—	17	0.5–1 mm diam.
		—	—	26	200 mm	—	—	—	0.2–0.5 mm diam.
	Typical Cold Drawn Tempers	38	—	—	—	—	—	20	over 6 mm diam.
		42	—	—	—	—	—	22	3–6 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
Sections / Shapes	Hot Worked [(c)]	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 manufacturers.

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

5.1.2 Typical Tensile Properties and Hardness Values - 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 above or below 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 [(b)]	15	6	45	2 in.	65	10	—
	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 equivalent 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 "
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 manufacturers.

(b) The mechanical properties will be largely dependent upon the size and cross-sectional area or complexity 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 above or below the typical values indicated.

Form	Temper [(a)]	Tensile Strength psi	Yield Strength 0.5 % extension under load psi	Elongation		Rockwell Hardness			Shear Strength psi	Typical Size Related to Properties Shown [(b)]
				%	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. × 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. × 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 Hard	40 000	32 000	30	2 in.	—	35	—	26 000	0.50 in. thick
Forgings	As Forged [(c)]	33 000	11 000	45	2 in.	37	—	—	23 000	—

(a) The tempers listed are those referred to in ASTM and other American Standards.

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

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

5.2 MECHANICAL PROPERTIES AT LOW TEMPERATURE

5.2.1 Tensile Properties - Impact Properties

At the date of publication of this sheet, no data relating to this material have been traced.

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	0.1 % offset ton/in²	Yield Strength 0.5 % ext. under load psi	
Sheet (1) 2 mm 0.08 in.	Annealed (grain size 0.030 mm)	20	68	23	**14.7**	33 000	—	**3.1**	—	**53**
		100	212	21	**13.4**	30 000	—	**3.0**	—	**49**
		200	392	18.5	**11.8**	26 500	—	**2.9**	—	**47**
		300	572	16.5	**10.5**	23 500	—	**2.9**	—	**45**
		400	752	15	**9.5**	21 500	—	**2.4**	—	**44**
		500	932	11	**6.9**	15 500	—	**2.1**	—	**42**
Strip (2)	Cold Worked (a)	20	68	35	22.5	**50 000**	**33.0** (b)	—	—	**8.5**
		288	550	24.5	15.5	**35 000**	**19.7** (b)	—	—	**12.1**
Rod (3) 3.2 mm diam. 0.125 in. diam.	Cold Worked 84 %	24	75	41.5	26.5	**59 300**	—	—	**54 100**	**8.5**
		149	300	—	—	—	—	—	**47 000**	—

(a) Quoted as 'cold rolled to RB 61' hardness, in original document, but amount of cold work not defined.
(b) 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.

5.3.2 Creep Properties

5.3.2.1 Original Creep Data

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 % per 1 000 h
Strip (4) 2.5 mm 0.1 in.	Annealed (grain size 0.030 mm)	130	266	14	8.5	20 000	2.40	15.8	14.7	1.05
		175	347	9.5	6	14 000	2.60	7.0	6.7	0.35
				14	8.5	20 000	2.40	27.4	23.2	1.85
		225	437	4	2.5	6 000	3.00	0.9	0.6	0.02
				9.5	6	14 000	2.50	10.6	8.0	1.1
	Cold Worked 10 %	130	266	5.5	3.5	8 000	4.75	0.09	0.08	0.000 4
				9.5	6	14 000	9.80	0.17	0.145	0.002 4
				14	8.5	20 000	7.20	0.325	0.29	0.007
		175	347	5.5	3.5	8 000	4.85	0.13	0.11	0.006 5
				9.5	6	14 000	12.90	0.28	0.22	0.008 2
				14	8.5	20 000	4.90	0.565	0.43	0.03
		225	437	5.5	3.5	8 000	8.90	0.26	0.175	0.009 8
				9.5	6	14 000	12.90	0.865	0.34	0.037
	Cold Worked 25 %	130	266	5.5	3.5	8 000	4.75	0.08	0.075	0.002
				9.5	6	14 000	10.20	0.18	0.16	0.004
				14	8.5	20 000	7.20	0.26	0.24	0.005
		175	347	5.5	3.5	8 000	4.90	0.16	0.14	0.003
				9.5	6	14 000	12.90	0.25	0.18	0.005
				14	8.5	20 000	10.30	0.43	0.33	0.011
		225	437	5.5	3.5	8 000	8.90	0.21	0.14	0.006 4
				9.5	6	14 000	11.50	0.56	0.38	0.017
				14	8.5	20 000	9.87	1.7 (b)	0.43	0.105
	Cold Worked 50 %	130	266	5.5	3.5	8 000	4.55	0.09	0.08	0.001 5
				9.5	6	14 000	11.40	0.20	0.185	0.001 5
				14	8.5	20 000	7.25	0.29	0.265	0.004
		175	347	5.5	3.5	8 000	6.90	0.135	0.115	0.004
				9.5	6	14 000	12.90	0.285	0.25	0.006
				14	8.5	20 000	3.70	0.39	0.315	0.021
		225	437	5.5	3.5	8 000	8.90	0.26	0.15	0.011
				9.5	6	14 000	12.90	0.795	0.335	0.029
				14	8.5	20 000	3.00	0.825	0.525	0.10
Strip (2)	Cold Worked (c)	288	550	21	13	30 000	0.001 05 (b)	—	—	—
				17.5	11	25 000	0.020 (b)	—	—	—
				15	9.5	22 000	0.040 (b)	—	—	—
				10.5	6.5	15 000	0.170 (b)	—	—	—
Rod (3) 3.2 mm diam. 0.125 in. diam.	Cold Worked 84 %	149	300	6.5	4	9 900	7.25	0.079 9	0.016 9	<0.000 1
				10.5	6.5	15 000	7.25	0.112	0.013 8	0.000 3
				14	8.5	19 950	7.08	0.181	0.043 6	0.001
				17.5	11	24 950	7.08	0.224	0.051 5	0.001 6
				21	13	30 000	6.00	0.305	0.089 8	0.002 9
				28	17.5	40 000	6.00	0.870	0.268	0.055

continued overleaf

5.3.2.1 Original Creep Data (continued)

Form	Temper	Testing Temperature		Stress			Duration 1 000 h	Total Extension % (a)	Intercept %	Min. Creep Rate % per 1 000 h
		°C	°F	kg/mm²	ton/in²	psi				
Square Wire (5) 6.5 mm 0.257 in.	Cold Worked 5 %	300	572	5	3	7 500	**1.440** (d)	**0.345**	—	**6.3** (f)
				8.5	5.5	**12 500**	**1.440** (d)	**0.755**	—	**19.2** (f)
				5	3	**7 500**	**1.240** (d)	**0.35**	—	**4.7** (g)
				7	4	**10 000**	**1.275** (d)	**0.48**	—	**7.8** (g)
				5	3	**7 500** (e)	**1.410** (d)	**0.43**	—	**5.4** (g)
				7	4	**10 000** (e)	**1.340** (d)	**0.45**	—	**7.8** (g)
				5	3	**7 500**	**1.400** (d)	**0.40**	—	**5.7** (g)
				7	4	**10 000**	**1.250** (d)	**0.465**	—	**9.6** (g)
				5	3	**7 500** (e)	**1.200** (d)	**0.39**	—	**6.0** (g)
				7	4	**10 000** (e)	**1.340** (d)	**0.625**	—	**10.2** (g)
	Cold Worked 20 %	300	572	5	3	**7 500**	**1.395** (d)	**0.420**	—	**10.0** (f)
				8.5	5.5	**12 500**	**1.415** (d)	**0.870**	—	**24.6** (f)
				12	7.5	**17 500**	**0.315** (d)	**1.060**	—	— (f)
				8.5	5.5	**12 500**	**1.440** (d)	**1.075**	—	**30.0** (g)
	Cold Worked 30 %	300	572	5	3	**7 500**	**1.370** (d)	**0.370**	—	**9.4** (f)
				8.5	5.5	**12 500**	**1.380** (d)	**0.940**	—	**22.0** (f)
	Cold Worked 40 %	300	572	5	3	**7 500**	**1.400** (d)	**0.405**	—	**12.5** (f)
				8.5	5.5	**12 500**	**1.400** (d)	**0.970**	—	**27.2** (f)
				8.5	5.5	**12 500**	**1.340** (d)	**1.050**	—	**31.0** (g)

(a) Total extension = Initial extension + Total Creep = Initial extension + Intercept + (Minimum creep rate × Duration).
(b) Rupture test. (c) Quoted as 'cold rolled to RB 61' hardness in original document, but amount of cold work not defined.
(d) Duration in 1 000 minutes. (e) Compression test. (f) Creep tests performed on material containing 0.063% Ag. (g) Creep tests performed on material containing 0.072% Ag.
N.B.: Original values are printed in **bold type**; other values are calculated.

5.3.2.2 Stress for Designated Creep Rate

Form	Temper	Testing Temperature		Stress for Designated Creep Rate								
				0.001 % per 1 000 h			0.01 % per 1 000 h			0.1 % per 1 000 h		
		°C	°F	kg/mm²	ton/in²	psi	kg/mm²	ton/in²	psi	kg/mm²	ton/in²	psi
Rod (3) 3.2 mm diam. 0.125 in. diam.	Cold Worked 84 %	149	300	15	9.5	**22 000**	25	16	**36 000**	28.5	18	**41 000**

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

5.4 FATIGUE PROPERTIES

5.4.1 Fatigue Strength at Room Temperature

At the date of publication of this sheet, no data relating to this material have been traced.

REFERENCES

MECHANICAL PROPERTIES (SECTION 5)

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SILVER-BEARING OXYGEN-FREE COPPER

Cu-OFS

Common name: Silver Copper

A high-conductivity copper made by remelting of cathodes and containing silver as an added alloying element. Melting and casting take place under conditions which ensure freedom from oxide and deoxidants. The material has greater resistance to softening and creep than unalloyed high-conductivity copper at moderately elevated temperatures and is not embrittled when heated in a reducing atmosphere.

COMPOSITION (weight %)

Cu (+ Ag) . .	99.95 min.
Ag . . .	0.02–0.12

1 SOME TYPICAL USES

Electrical

Glass-to-metal seals in electronic equipment; transistor and rectifier bases; windings, including hollow conductors, for large generators and other heavy-duty rotating machines; commutator segments; busbars; contacts and switches.

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	1 082[(a)] °C	1 980[(a)] °F
2.3 Coefficient of thermal expansion (linear) at:		
−183 °C *−297 °F*	0.000 009 5 per °C	0.000 005 28 per °F
−191 to 16 °C *−312 to 61 °F*	0.000 014 1 „ „	0.000 007 83 „ „
20 to 100 °C *68 to 212 °F*	0.000 016 8 „ „	0.000 009 33 „ „
20 to 300 °C *68 to 572 °F*	0.000 017 7 „ „	0.000 009 83 „ „
2.4 Specific heat (thermal capacity) at:		
−150 °C *−238 °F*	0.069 cal/g °C	0.069 Btu/lb °F
− 50 °C *− 58 °F*	0.087 „	0.087 „
20 °C *68 °F*	0.092 „	0.092 „
100 °C *212 °F*	0.094 „	0.094 „
200 °C *392 °F*	0.097 „	0.097 „
2.5 Thermal conductivity at:		
−200 °C *−328 °F*	1.25 cal cm/cm² s °C	300 Btu ft/ft² h °F
−183 °C *−297 °F*	1.13 „	270 „
−100 °C *−148 °F*	1.04 „	252 „
20 °C *68 °F*	0.94 „	227 „
100 °C *212 °F*	0.92 „	223 „
200 °C *392 °F*	0.91 „	220 „
300 °C *572 °F*	0.90 „	217 „
2.6 Electrical conductivity (volume) at:		
−200 °C *−328 °F* (annealed) [(b)]	460 [(a)] m/ohm mm²	800 [(a)] % IACS
−100 °C *−148 °F* („) [(b)]	110 [(a)] „	190 [(a)] „ „
20 °C *68 °F* („)	57.4–58.6 „	99–101 „ „
100 °C *212 °F* („) [(b)]	44 „	76 „ „
200 °C *392 °F* („) [(b)]	34 „	58 „ „
20 °C *68 °F* (fully cold worked) [(b)]	56.3 „	97 „ „

continued overleaf

INDEX NUMBERS RELATE TO LITERATURE REFERENCES (see page 8): INDEX LETTERS RELATE TO FOOTNOTES AT END OF TABLE

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DATA SHEET No. B 3
Cu-OFS
1968 Edition

2 PHYSICAL PROPERTIES (continued)

	Metric Units		English Units	
2.7 Electrical resistivity (volume) at:				
−200 °C *−328 °F* (annealed) [b]	0.002 2 [a] 0.22 [a]	ohm mm²/m microhm cm	1.3 [a] 0.085 [a]	ohms (circ mil/ft) microhm in
−100 °C *−148 °F* („) [b]	0.009 1 [a] 0.91 [a]	ohm mm²/m microhm cm	5.5 [a] 0.36 [a]	ohms (circ mil/ft) microhm in
20 °C *68 °F* („)	0.017 4–0.017 1 1.74–1.71	ohm mm²/m microhm cm	10.5–10.3 0.686–0.672	ohms (circ mil/ft) microhm in
100 °C *212 °F* („) [b]	0.022 7 2.27	ohm mm²/m microhm cm	13.6 0.89	ohms (circ mil/ft) microhm in
200 °C *392 °F* („) [b]	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) [b]	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) Approximate value.

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

(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.

N.B.: The values shown in Section 2, which have been appropriately rounded in view of the composition range involved, are based partially on selected literature references and also upon values for Cu-OF (oxygen-free copper).

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	350– 650 °C	660–1 200 °F
Stress relieving temperature range	225– 275 °C	440– 530 °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. 3.2	
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	Sections / Shapes	Forgings
Australia	SAA	—	—	—	—	—	—	—	—
Belgium	NBN	Cu Ag	—	266.02	266.02	266.02	—	266.02	—
Canada	CSA	—	—	—	—	—	—	—	—
Chile	INDITECNOR	CuAg $\overline{\text{OF}}$	245 n.68	—	—	—	—	—	—
France	NF	—	—	—	—	—	—	—	—
Germany	DIN	SE–CuAg	40 500	40 500, Bl.1	40 500, Bl.3	40 500, Bl.4	—	—	—
Italy	UNI	—	—	—	—	—	—	—	—
Netherlands	N or NEN [b]	—	—	—	—	—	—	—	—
South Africa	SABS	—	—	—	—	—	—	—	—
Spain	UNE	—	—	—	—	—	—	—	—
Sweden	SIS	—	—	—	—	—	—	—	—
Switzerland	VSM	—	—	—	—	—	—	—	—
United Kingdom	BS	—	—	—	—	—	—	—	—
United States [c]	ASTM	Nos. 104, 105, and 107 or OFS	—	B152 B187	B187	—	B188	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	No data traced
Impact properties	,, ,, ,,

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 above or below 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 [(c)]	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 equivalent area
		34	28	10	$5.65\sqrt{S_o}$	95	105	19	6–20 mm diam. or equivalent area
Wire	Annealed	23	—	37	200 mm	—	—	16	over 3 mm diam.
		24	—	35	200 mm	—	—	16	1–3 mm diam.
		26	—	28	200 mm	—	—	17	0.5–1 mm diam.
		—	—	26	200 mm	—	—	—	0.2–0.5 mm diam.
	Typical Cold Drawn Tempers	38	—	—	—	—	—	20	over 6 mm diam.
		42	—	—	—	—	—	22	3–6 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
Sections / Shapes	Hot Worked [(c)]	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 manufacturers.

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

5.1.2 Typical Tensile Properties and Hardness Values - 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 above or below 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 [b]	15	6	45	2 in.	65	10	—
	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 equivalent 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	"
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 manufacturers.

(b) The mechanical properties will be largely dependent upon the size and cross-sectional area or complexity 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 above or below the typical values indicated.

Form	Temper [(a)]	Tensile Strength psi	Yield Strength 0.5 % extension under load psi	Elongation		Rockwell Hardness			Shear Strength psi	Typical Size Related to Properties Shown [(b)]
				%	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.
	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.
Wire	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. × 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. × 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									
	Hard	40 000	32 000	30	2 in.	—	35	—	26 000	0.50 in. thick

(a) The tempers listed are those referred to in ASTM and other American Standards.

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

5.2 MECHANICAL PROPERTIES AT LOW TEMPERATURE

5.2.1 Tensile Properties - Impact Properties

At the date of publication of this sheet, no data relating to this material have been traced.

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	0.1 % offset ton/in²	Yield Strength 0.5 % ext. under load psi	
Sheet [1] 2 mm 0.08 in.	Annealed (grain size 0.030 mm)	20	68	23	**14.7**	33 000	—	**3.1**	—	**53**
		100	212	21	**13.4**	30 000	—	**3.0**	—	**49**
		200	392	18.5	**11.8**	26 500	—	**2.9**	—	**47**
		300	572	16.5	**10.5**	23 500	—	**2.9**	—	**45**
		400	752	15	**9.5**	21 500	—	**2.4**	—	**44**
		500	932	11	**6.9**	15 500	—	**2.1**	—	**42**
Strip [2]	Cold Worked [a]	20	68	35	22.5	**50 000**	**33.0** [b]	—	—	**8.5**
		288	550	24.5	15.5	**35 000**	**19.7** [b]	—	—	**12.1**
Rod [3] 3.2 mm diam. 0.125 in. diam.	Cold Worked 84 %	24	75	41.5	26.5	**59 300**	—	—	**54 100**	**8.5**
		149	300	—	—	—	—	—	**47 000**	—

(a) Quoted as 'cold rolled to RB 61' hardness in original document, but amount of cold work not defined.
(b) This value was originally reported in psi; in this table it is given in kg/mm² to 3 significant figures.

N.B.:— The values shown in this table were obtained using Cu-LSTP (silver-bearing 'tough-pitch' copper) test specimens; it is assumed that Cu-OFS exhibits the same short-time tensile properties at elevated temperature.
— Original values are printed in **bold type**; other values are converted.

5.3.2 Creep Properties

Form	Temper	Testing Temperature		Stress			Duration 1 000 h	Total Extension % [a]	Intercept %	Min.Creep Rate % per 1 000 h
		°C	°F	kg/mm²	ton/in²	psi				
Strip [4] 2.5 mm 0.1 in.	Cold Worked 10 %	130	266	14	8.5	**20 000**	**0.75**	**0.215**	**0.201**	0.001 5
		225	437	9.5	6	**14 000**	**1.05**	**0.253**	**0.143**	0.041
	Cold Worked 25 %	130	266	9.5	6	**14 000**	**1.55**	**0.15**	**0.138**	0.02
				14	8.5	**20 000**	**1.05**	**0.22**	**0.195**	0.06
		225	437	5.5	3.5	**8 000**	**3.15**	**0.16**	**0.108**	0.016
				9.5	6	**14 000**	**3.10**	**0.40**	**0.228**	0.048
				14	8.5	**20 000**	**5.00**	**2.56**	**0.426**	0.31
	Cold Worked 50 %	130	266	14	8.5	**20 000**	**0.75**	**0.175**	**0.155**	0.003
		225	437	9.5	6	**14 000**	**3.25**	**0.283**	**0.193**	0.019
Rod [5] [6] 4 mm diam. 0.16 in. diam.	Annealed (water quenched)	250	482	**13.1**	8	18 500	**0.050** [b]	—	—	—
				14.0	8.5	19 500	**0.023** [b]	—	—	—
				16.1	10	22 500	**0.002** [b]	—	—	—
				20.4	12.5	29 000	**0.000 1** [b]	—	—	—
	Annealed (furnace cooled)	250	482	**14.9**	9	21 000	**0.065** [b]	—	—	—
				16.1	10.5	22 500	**0.013 5** [b]	—	—	—
				17.1	10.5	24 000	**0.002** [b]	—	—	—
				18.0	11	25 500	**0.001 3** [b]	—	—	—
				22.3	14	31 500	**0.000 1** [b]	—	—	—

Continued overleaf

5.3.2 Creep Properties—Continued

Form	Temper	Testing Temperature		Stress			Duration 1 000 h	Total Extension % [a]	Intercept %	Min.Creep Rate % per 1 000 h
		°C	°F	kg/mm²	ton/in²	psi				
Wire [7] 2 mm diam. 0.08 in. diam.	Annealed	110	230	17.5	11	**25 000**	**5.00**	**0.38** [c]	—	**0.025**
		121	250	17.5	11	**25 000**	**4.20**	**1.00** [c]	—	**0.090** [d]
		149	300	14 17.5	8.5 11	**20 000** **25 000**	**1.10** **1.10**	**0.750** [c] **0.880** [c]	— —	**0.21** **0.25**
	Cold Worked 10 %	121	250	17.5	11	**25 000**	**5.00**	**0.170** [c]	—	**0.013**
	Cold Worked 37 %	121	250	17.5	11	**25 000**	**4.80**	**0.10** [c]	—	**0.004 0**
	Cold Worked 84 %	115	240	17.5	11	**25 000**	**4.80**	**0.033** [c]	—	**0.003 2**
		149	300	17.5	11	**25 000**	**1.00**	**0.066** [c]	—	**0.045**
Square Wire [7] 6.5 mm 0.257 in.	Cold Worked 5 %	300	572	5 8.5	3 5.5	**7 500** **12 500**	**1.440** [e] **1.440** [e]	**0.215** **0.340**	— —	**1.4** [g] **4.5** [g]
				5 7 8.5	3 4 5.5	**7 500** **10 000** **12 500**	**1.400** [e] **1.415** [e] **1.205** [e]	**0.22** **0.25** **0.36**	— — —	**1.0** [h] **1.6** [h] **7.9** [h]
				5.5 7 8.5	3.5 4.5 5.5	**7 870** [f] **10 600** [f] **12 500** [f]	**1.505** [e] **1.455** [e] **1.540** [e]	**0.31** **0.36** **0.56**	— — —	**2.1** [h] **5.1** [h] **8.9** [h]
	Cold Worked 20 %	300	572	5 8.5 12	3 5.5 7.5	**7 500** **12 500** **17 500**	**1.360** [e] **1.440** [e] **1.430** [e]	**0.25** **0.45** **0.945**	— — —	**5.2** [g] **10.0** [g] **23.0** [g]
	Cold Worked 30 %	300	572	5 8.5	3 5.5	**7 500** **12 500**	**1.375** [e] **1.355** [e]	**0.20** **0.48**	— —	**4.9** [g] **11.0** [g]
	Cold Worked 40 %	300	572	5 8.5	3 5.5	**7 500** **12 500**	**1.440** [e] **1.440** [e]	**0.20** **0.48**	— —	**5.2** [g] **7.4** [g]

[a] Total extension = Initial extension + Total creep = Initial extension + Intercept + (Minimum creep rate × Duration). [b] Rupture test.
[c] Total creep strain = Total extension — Initial extension. [d] Decreasing creep rate. [e] Duration in 1 000 minutes. [f] Compression test.
[g] Creep tests performed on material containing 0.054% Ag. [h] Creep tests performed on material containing 0.076% Ag.

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

5.4 FATIGUE PROPERTIES

5.4.1 Fatigue Strength at Room Temperature

Form	Temper	Number of Cycles × 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 [8] **1 mm** **0.04 in.**	Cold Worked 50 %	—	36.5–41	10.5 [a]	23–26	6.5 [a]	**52 000–58 000**	**15 000** [a]

[a] Reversed-bending test.

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

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 Printed in England by Impress (Worcester) Ltd.

COPPER-SULPHUR

Cu S

Common name: Sulphur Copper

A free-machining copper with a small sulphur addition. The material is oxygen-free or deoxidised, has relatively high conductivity and is free from risk of hydrogen embrittlement.

COMPOSITION (weight %)

Cu (+ Ag) + S	99.90 min.
S	0.20–0.50

1 SOME TYPICAL USES

Electrical

Transformer and circuit-breaker terminals; contacts, connectors (including crimped types), clamps and other high-conductivity current-carrying components requiring free-machining properties.

Mechanical

Bolts, nuts, studs and a wide variety of other components requiring free-machinability and in most cases good conductivity, often for production on automatic screw machines.

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 range	1 067–1 079 °C	1 953–1 975 °F
2.3 Coefficient of thermal expansion (linear) at:		
20 to 100 °C *68 to 212 °F*	0.000 017 per °C	0.000 009 3 per °F
20 to 300 °C *68 to 572 °F*	0.000 018 „ „	0.000 009 8 „ „
2.4 Specific heat (thermal capacity) at:		
20 °C *68 °F*	0.092 cal/g °C	0.092 Btu/lb °F
2.5 Thermal conductivity at:		
20 °C *68 °F* [a]	0.89 cal cm/cm² s °C	215 Btu ft/ft² h °F
2.6 Electrical conductivity (volume) at:		
20 °C *68 °F* (annealed)	55.1 m/ohm mm²	95 % IACS
20 °C *68 °F* (fully cold worked)	53.9 „	93 „ „
2.7 Electrical resistivity (volume) at:		
20 °C *68 °F* (annealed)	0.018 1 ohm mm²/m 1.81 microhm cm	10.9 ohms (circ mil/ft) 0.714 microhm in
20 °C *68 °F* (fully cold worked)	0.018 5 ohm mm²/m 1.85 microhm cm	11.2 ohms (circ mil/ft) 0.730 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 7 per °C (95 % IACS)	0.002 1 per °F (95 % IACS)
20 °C *68 °F* (fully cold worked) applicable over range from 0 to 100 °C *32 to 212 °F*	0.003 6 „ „ (93 % IACS)	0.002 0 „ „ (93 % 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) Deduced from electrical conductivity value for annealed material.

(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 this low-alloyed 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*).

N.B.: The values shown in Section 2, which have been appropriately rounded in view of the composition range involved, are based on selected literature references.

INDEX NUMBERS RELATE TO LITERATURE REFERENCES (see page 6); INDEX LETTERS RELATE TO FOOTNOTES AT END OF TABLE

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DATA SHEET No. B 4
Cu S

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	2 080–2 190 °F
3.2 Annealing temperature range	400– 650 °C	750–1 200 °F
Stress relieving temperature range	225– 275 °C	440– 530 °F
3.3 Hot working temperature range	750– 870 °C	1 400–1 600 °F
3.4 Hot formability	Good	
3.5 Cold formability	Good	
3.6 Cold reduction between anneals	70 % max.	
3.7 Machinability:	See General Data Sheet No. 2	
Machinability rating (free-cutting brass = 100)	75	
3.8 Joining methods:	See General Data Sheet No. 3.2	
Soldering	Excellent	
Brazing	Good	
Oxy-acetylene welding	Not recommended	
Carbon-arc welding	Not recommended	
Gas-shielded arc welding	Not recommended	
Coated metal-arc welding	Not recommended	
Resistance welding: spot and seam	Not recommended	
butt	Fair	

4 NATIONAL SPECIFICATIONS FOR MANUFACTURED FORMS

At the date of publication of this sheet, the only known national specification is British Standard 2874 in which copper-sulphur rod material is designated as C111.

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	no data traced
Impact properties	„ „ „

5.3 Mechanical properties at elevated temperature

Short-time tensile properties	see table 5.3.1
Creep properties	no data traced

5.4 Fatigue properties

Fatigue strength at room temperature	no data traced

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 above or below 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		
Rod	Annealed	23	6	40	$5.65\sqrt{S_o}$	50	55	14	—
	Typical Cold Worked Tempers	27	23	15	$5.65\sqrt{S_o}$	80	85	17	6–40 mm diam. or equivalent area
		32	29	8	$5.65\sqrt{S_o}$	90	100	18	6–20 mm diam. or equivalent area
		35	32	5	$5.65\sqrt{S_o}$	100	110	19	up to 6 mm diam. or equivalent area

(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 manufacturers.

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 above or below 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			
Rod	Annealed	14	3	45	$5.65\sqrt{S_o}$	50	9	—
	Typical Cold Worked Tempers	18	15	20	$5.65\sqrt{S_o}$	85	11	0.25–1 in. diam. or equivalent area
		20	17	10	$5.65\sqrt{S_o}$	100	12	"
Forgings	Hot Worked [b]	15	6	30	$5.65\sqrt{S_o}$	60	10	—

(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 manufacturers.

(b) The mechanical properties will be largely dependent upon the size and cross-sectional area or complexity 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 above or below the typical values indicated.

Form	Temper [a]	Tensile Strength psi	Yield Strength 0.5 % extension under load psi	Elongation		Rockwell Hardness			Shear Strength psi	Typical Size Related to Properties Shown [b]
				%	gauge length	F	B	30 T		
Flat Products (Bar)	As Hot Rolled [c]	34 000	10 000	40	2 in.	50	—	—	23 000	—
	Annealed	34 000	10 000	42	2 in.	52	—	—	23 000	—
	Cold Worked									
	Half Hard	42 000	40 000	15	2 in.	77	35	50	25 000	0.125–0.250 in. thick
	Hard	50 000	48 000	10	2 in.	83	45	54	29 000	"
	Quarter Hard	35 000	31 000	30	2 in.	72	25	45	24 000	0.250–0.50 in. thick
	Half Hard	42 000	40 000	15	2 in.	77	35	50	26 000	"
	Hard	50 000	48 000	10	2 in.	83	45	54	29 000	"
	Half Hard	40 000	35 000	20	2 in.	75	32	48	25 000	over 0.50 in. thick
	Hard	46 000	43 000	15	2 in.	81	42	53	27 000	"
Rod	As Hot Rolled [c]	34 000	10 000	40	2 in.	50	—	—	23 000	—
	Annealed	34 000	10 000	42	2 in.	52	—	—	23 000	—
	Cold Worked									
	Hard	52 000	50 000	10	2 in.	85	50	57	30 000	0.125 in. diam.
	Quarter Hard	35 000	31 000	30	2 in.	72	25	45	24 000	0.250 in. diam.
	Half Hard	42 000	40 000	15	2 in.	77	35	50	26 000	"
	Hard	50 000	48 000	10	2 in.	83	45	54	29 000	"
	Quarter Hard	35 000	31 000	30	2 in.	72	25	45	24 000	0.50 in. diam.
	Half Hard	42 000	40 000	15	2 in.	77	35	50	26 000	"
	Hard	50 000	48 000	10	2 in.	83	45	54	29 000	"
	Half Hard	41 000	38 000	20	2 in.	76	33	49	25 000	1.0 in. diam.
	Hard	48 000	46 000	15	2 in.	82	43	53	28 000	"
	Half Hard	40 000	37 000	20	2 in.	75	32	48	25 000	2.0 in. diam.
	Hard	46 000	43 000	15	2 in.	81	42	52	27 000	"
Shapes	As Hot Rolled [c]	34 000	10 000	40	2 in.	50	—	—	23 000	—
	Annealed [c]	34 000	10 000	42	2 in.	52	—	—	23 000	—
	Cold Worked [c]									
	Half Hard	42 000	38 000	20	2 in.	77	35	50	26 000	—
	Hard	50 000	48 000	15	2 in.	83	45	54	29 000	—
Forgings	As Forged [c]	30 000	10 000	40	2 in.	52	—	—	21 000	—

(a) The tempers listed are those referred to in ASTM and other American Standards.

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

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

5.2 MECHANICAL PROPERTIES AT LOW TEMPERATURE

5.2.1 Tensile Properties - Impact Properties

At the date of publication of this sheet, no data relating to this material have been traced.

5.3 MECHANICAL PROPERTIES AT ELEVATED TEMPERATURE

5.3.1 Short-Time Tensile Properties

Form	Temper	Testing Temperature		Tensile Strength			Proof Stress 0.1 % offset ton/in²	Elongation % on 2 in.
		°C	°F	kg/mm²	ton/in²	psi		
Rod (1) **25.4 mm diam. 1 in. diam.**	Cold Worked	20	68	30.5	**19.5**	43 500	**16.0**	**20.0**
		100	212	27.5	**17.5**	39 000	—	**19.5**
		200	392	24	**15.0**	34 000	—	**18.5**
		300	572	18	**11.5**	25 500	—	**23.0**
		400	752	11	**7.0**	16 000	—	**53.0**
		500	932	9.5	**6.0**	13 500	—	**50.0**

N.B.: — Original values are printed in **bold type**; other values are converted.
— Data not available:
Proof Stress 0.2 % offset.
Yield Strength 0.5 % extension under load.

5.3.2 Creep Properties

At the date of publication of this sheet, no data relating to this material have been traced.

5.4 FATIGUE PROPERTIES

5.4.1 Fatigue Strength at Room Temperature

At the date of publication of this sheet, no data relating to this material have been traced.

REFERENCE

MECHANICAL PROPERTIES (SECTION 5)

(1) Copper-Sulphur — Boltomet 917. Thomas Bolton & Sons Ltd., England. TBS 127. August, 1965.

Printed in England by Impress (Worcester) Ltd.

COPPER-TELLURIUM

Cu Te

Common name: Tellurium Copper

A free-machining copper with a small tellurium addition. The material has relatively high conductivity and is available in both phosphorus-bearing and 'tough-pitch' varieties, the first being free from risk of hydrogen embrittlement.

COMPOSITION (weight %)

Cu (+ Ag) + Te	99.90 min.
Te	0.30–0.80

1 SOME TYPICAL USES

Electrical

Transformer and circuit-breaker terminals; contacts, connectors, clamps and other high-conductivity current-carrying components requiring free-machining properties.

Mechanical

Bolts, nuts, studs and a wide variety of other components requiring free-machinability and in most cases good conductivity, often for production on automatic screw machines.

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 range	870–1 081 °C [a] 1 051–1 081 °C [b]	1 600–1 978 °F [a] 1 924–1 978 °F [b]
2.3 Coefficient of thermal expansion (linear) at:		
20 to 100 °C *68 to 212 °F*	0.000 017 per °C	0.000 009 3 per °F
20 to 300 °C *68 to 572 °F*	0.000 018 ,, ,,	0.000 009 8 ,, ,,
2.4 Specific heat (thermal capacity) at:		
20 °C *68 °F*	0.092 cal/g °C	0.092 Btu/lb °F
2.5 Thermal conductivity at:		
−240 °C *−400 °F*	1.9 [b] cal cm/cm² s °C	462 [b] Btu ft/ft² h °F
−173 °C *−280 °F*	0.98 [b] ,,	237 [b] ,,
20 °C *68 °F* [c]	0.91 [a] ,, 0.88 [b] ,,	220 [a] ,, 214 [b] ,,
2.6 Electrical conductivity (volume) at:		
20 °C *68 °F* (annealed)	56.8 [a] m/ohm mm² 54.5 [b] ,,	98 [a] % IACS 94 [b] ,, ,,
20 °C *68 °F* (fully cold worked)	55.7 [a] ,, 53.4 [b] ,,	96 [a] ,, ,, 92 [b] ,, ,,
2.7 Electrical resistivity (volume) at:		
20 °C *68 °F* (annealed)	0.017 6 [a] ohm mm²/m 1.76 [a] microhm cm 0.018 3 [b] ohm mm²/m 1.83 [b] microhm cm	10.6 [a] ohms (circ mil/ft) 0.693 [a] microhm in 11.0 [b] ohms (circ mil/ft) 0.722 [b] microhm in
20 °C *68 °F* (fully cold worked)	0.018 0 [a] ohm mm²/m 1.80 [a] microhm cm 0.018 7 [b] ohm mm²/m 1.87 [b] microhm cm	10.8 [a] ohms (circ mil/ft) 0.707 [a] microhm in 11.3 [b] ohms (circ mil/ft) 0.738 [b] microhm in

continued overleaf

INDEX NUMBERS RELATE TO LITERATURE REFERENCES (see page 8); INDEX LETTERS RELATE TO FOOTNOTES AT END OF TABLE

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Cu Te
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2 PHYSICAL PROPERTIES (continued)

	Metric Units	English Units
2.8 Temperature coefficient of electrical resistance at: [d]		
20 °C *68 °F* (annealed) applicable over range from 0 to 100 °C *32 to 212 °F*	0.003 9 [a] per °C (98 % IACS) 0.003 7 [b] „ „ (94 % IACS)	0.002 1 [a] per °F (98 % IACS) 0.002 0 [b] „ „ (94 % IACS)
20 °C *68 °F* (fully cold worked) applicable over range from 0 to 100 °C *32 to 212 °F*	0.003 8 [a] „ „ (96 % IACS) 0.003 6 [b] „ „ (92 % IACS)	0.002 1 [a] „ „ (96 % IACS) 0.002 0 [b] „ „ (92 % 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) Oxygen-bearing ('tough-pitch') tellurium copper.
(b) Phosphorus-deoxidised tellurium copper.
(c) Deduced from electrical conductivity values for annealed material.
(d)—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 this low-alloyed 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)*.

N.B.: The values shown in Section 2, which have been appropriately rounded in view of the composition range involved, are based on selected literature references.

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]	425– 650 °C	800–1 200 °F
Stress relieving temperature range [b]	225– 275 °C	440– 530 °F
3.3 Hot working temperature range [b]	725– 825 °C	1 340–1 520 °F
3.4 Hot formability [b]	Good	
3.5 Cold formability	Good	
3.6 Cold reduction between anneals	70 % max.	
3.7 Machinability:	See General Data Sheet No. 2	
Machinability rating (free-cutting brass = 100)	85	
3.8 Joining methods [b]	See General Data Sheet No. 3.2	
Soldering	Excellent	
Brazing [c]	Good	
Oxy-acetylene welding	Not recommended	
Carbon-arc welding	Not recommended	
Gas-shielded arc welding	Fair	
Coated metal-arc welding	Not recommended	
Resistance welding: spot and seam	Not recommended	
butt	Fair	

(a) Optimum casting temperature range for 'tough-pitch' variety 1 120–1 150 °C *(2 050–2 100 °F)*.
(b) Embrittlement will occur if the 'tough-pitch' variety is heated in atmospheres containing an excess of hydrogen.
(c) For 'tough-pitch' variety, care should be taken to avoid melting of ternary eutectic which occurs at 870 °C *(1 600 °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	Sections / Shapes	Forgings
Australia	SAA	—	—	—	—	—	—	—	—
Belgium	NBN	Cu Te	—	—	266.02	—	—	—	—
Canada	CSA	—	—	—	—	—	—	—	—
Chile	INDITECNOR	Cu-Te	245 n.68	—	—	—	—	—	—
France	NF	—	—	—	—	—	—	—	—
Germany	DIN	E-CuTe (2.1545)	17 666	—	17 672	17 672	17 671	17 674	—
		SE-CuTe (2.1546)	17 666	—	17 672	17 672	17 671	—	—
Italy	UNI	—	—	—	—	—	—	—	—
Netherlands	N or NEN [b]	—	—	—	—	—	—	—	—
South Africa	SABS	—	—	—	—	—	—	—	—
Spain	UNE	—	—	—	—	—	—	—	—
Sweden	SIS	—	—	—	—	—	—	—	—
Switzerland	VSM	Cu-OFTE	10826	—	11852	—	—	—	—
United Kingdom	BS	C109	—	—	2874	—	—	2874	—
United States	ASTM	No. 145 or DPTE or OFTE or OFPTE	—	—	B301	—	—	—	—

(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	no data traced
Impact properties	„ „ „

5.3 Mechanical properties at elevated temperature

Short-time tensile properties	see table 5.3.1
Creep properties	see tables 5.3.2.1/2

5.4 Fatigue properties

Fatigue strength at room temperature	see table 5.4.1

5.1 MECHANICAL PROPERTIES AT ROOM TEMPERATURE *

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 above or below 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 (a)
				%	gauge length	Brinell	Vickers		
Rod	Annealed	23	6	40	$5.65\sqrt{S_o}$	50	55	14	—
	Typical Cold Worked Tempers	27	23	15	$5.65\sqrt{S_o}$	80	85	17	6–40 mm diam. or equivalent area
		32	29	8	$5.65\sqrt{S_o}$	90	100	18	6–20 mm diam. or equivalent area
		35	32	4	$5.65\sqrt{S_o}$	100	110	19	up to 6 mm diam. or equivalent area
Tube	Annealed	23	6	40	$5.65\sqrt{S_o}$	50	55	14	—
	Typical Cold Drawn Tempers	27	23	15	$5.65\sqrt{S_o}$	80	85	17	10–50 mm O.D. up to 6 mm wall
		32	29	8	$5.65\sqrt{S_o}$	90	100	18	10–25 mm O.D. up to 2 mm wall
Sections / Shapes	Hot Worked (b)	23	6	40	$5.65\sqrt{S_o}$	55	60	15	—
	Typical Cold Worked Temper (b)	30	26	12	$5.65\sqrt{S_o}$	85	95	18	—

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

5.1.2 Typical Tensile Properties and Hardness Values - 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 above or below 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			
Rod	Annealed	15	3	45	$5.65\sqrt{S_o}$	50	9	—
	Typical Cold Worked Tempers	18	15	20	$5.65\sqrt{S_o}$	85	11	0.25–1 in. diam. or equivalent area
		20	17	10	$5.65\sqrt{S_o}$	100	12	"
Sections (extruded)	Typical Cold Drawn Temper (b)	18	15	20	$5.65\sqrt{S_o}$	85	11	—
Forgings	Hot Worked (b)	15	6	30	$5.65\sqrt{S_o}$	60	10	—

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

* 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.

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 above or below the typical values indicated.

Form	Temper [a]	Tensile Strength psi	Yield Strength, 0.5 % extension under load psi	Elongation		Rockwell Hardness			Shear Strength psi	Typical Size Related to Properties Shown [b]
				%	gauge length	F	B	30 T		
Flat Products (Bar)	As Hot Rolled [c]	33 000	8 000	45	2 in.	40	—	—	23 000	—
	Annealed	33 000	8 000	47	2 in.	32	—	—	23 000	—
	Cold Worked									
	Half Hard	42 000	38 000	20	2 in.	80	40	24	26 000	0.125–0.250 in. thick
	Hard	54 000	51 000	11	2 in.	85	50	31	29 000	"
	Quarter Hard	37 000	32 000	30	2 in.	72	25	13	24 000	0.250–0.50 in. thick
	Half Hard	42 000	38 000	20	2 in.	77	35	20	26 000	"
	Hard	50 000	47 000	15	2 in.	83	45	28	28 000	"
	Half Hard	42 000	36 000	25	2 in.	79	38	23	26 000	over 0.50 in. thick
	Hard	48 000	43 000	15	2 in.	85	50	32	27 000	"
Rod	As Hot Rolled [c]	33 000	8 000	45	2 in.	40	—	—	23 000	—
	Annealed-Soft	33 000	8 000	47	2 in.	32	—	—	23 000	—
	Cold Worked									
	Hard	54 000	50 000	9	2 in.	85	50	32	29 000	0.125 in. diam.
	Quarter Hard	37 000	32 000	30	2 in.	69	20	10	24 000	0.250 in. diam.
	Half Hard	43 000	38 000	20	2 in.	79	38	23	26 000	"
	Hard	53 000	49 000	10	2 in.	87	52	33	28 000	"
	Quarter Hard	37 000	32 000	30	2 in.	75	30	16	24 000	0.50 in. diam.
	Half Hard	42 000	38 000	20	2 in.	80	40	24	26 000	"
	Hard	48 000	45 000	15	2 in.	83	45	28	27 000	"
	Half Hard	42 000	36 000	25	2 in.	75	35	22	26 000	1.0 in. diam.
	Hard	48 000	42 000	15	2 in.	80	42	27	27 000	"
	Half Hard	41 000	35 000	30	2 in.	75	35	22	25 000	2.0 in. diam.
	Hard	46 000	40 000	20	2 in.	80	42	27	27 000	"
Shapes	As Hot Rolled [c]	33 000	8 000	45	2 in.	40	—	—	23 000	—
	Annealed [c]	33 000	8 000	47	2 in.	32	—	—	23 000	—
	Cold Worked [c]									
	Half Hard	42 000	36 000	25	2 in.	75	35	22	26 000	—
	Hard	48 000	42 000	15	2 in.	80	42	27	27 000	—
Forgings	As Forged [c]	33 000	8 000	40	2 in.	40	—	—	23 000	—

(a) The tempers listed are those referred to in ASTM and other American Standards.
(b) It is possible to obtain sizes different from those given in this column, but information on their mechanical properties should be obtained from the metal manufacturers.
(c) The mechanical properties will be largely dependent upon the size and cross-sectional area or complexity of the product.

5.2 MECHANICAL PROPERTIES AT LOW TEMPERATURE

5.2.1 Tensile Properties - Impact Properties

At the date of publication of this sheet, no data relating to this material have been traced.

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 (1) 3.2 mm diam. 0.125 in. diam.	Annealed (grain size 0.025 mm)	24	75	24.5	15.5	**34 800**	**5.35** (a)	**8 400**	**48**
		149	300	—	—	—	**4.50** (a)	**7 300**	—
		204	400	—	—	—	**4.22** (a)	**6 800**	—
		260	500	—	—	—	**4.07** (a)	**6 600**	—
	Cold Worked 37 %	24	75	34.5	22	**49 200**	**31.4** (a)	**45 000**	**8.5**
		149	300	—	—	—	**27.7** (a)	**40 000**	—
		204	400	—	—	—	**24.8** (a)	**36 000**	—
		260	500	—	—	—	**22.6** (a)	**32 800**	—
Rod (1) 19 mm diam. 0.75 in. diam.	Cold Worked 21 %	20	68	35.5	22.5	**50 400**	—	—	**12.5**
		260	500	28.5	18.5	**40 900**	—	—	**9**
		288	550	27	17	**38 600**	—	—	**9**
		315	600	25	16	**35 400**	—	—	**7**
		343	650	23	14.5	**32 700**	—	—	**8**
		371	700	22.5	14.5	**32 200**	—	—	**8**
		399	750	18	11.5	**25 600**	—	—	**8**
		426	800	15.5	10	**22 100**	—	—	**11**
	Cold Worked (b)	27	80	37	23.5	**52 400**	**35.6** (a)	—	**12.8**
		260	500	27	17	**38 600**	**27.1** (a)	—	**4.7**

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

(b) Quoted as 'Rockwell hardness 56B' in original document, but amount of cold work not defined.

N.B.: — Original values are printed in **bold type**; other values are converted.
— The 0.1% offset proof stress values are not available.

5.3.2 Creep Properties

5.3.2.1 Original Creep Data

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 % per 1 000 h
Rod [1] 3.2 mm diam. 0.125 in. diam.	Annealed (grain size 0.025 mm)	149	300	2 3.5 6	1 2 3.5	**3 050** **5 200** **8 550**	**6.00** **6.00** **6.00**	**0.134 4** **0.251 5** **1.553**	**0.077** **0.121** **0.737**	**0.001 4** **0.007 8** **0.022 3**
	Cold Worked 37 %	149	300	4.5 7 10.5 14 20.5	3 4 6.5 8.5 13	**6 900** **10 000** **15 000** **19 950** **29 200**	**6.00** **6.00** **6.00** **6.00** **6.00**	**0.089 5** **0.149 4** **0.223 4** **0.390 5** **1.133**	**0.034 4** **0.068 1** **0.088** **0.155 5** **0.479**	**0.000 85** **0.001 9** **0.005 23** **0.011 5** **0.080**
Rod [1] 19 mm diam. 0.75 in. diam.	Cold Worked [b]	260 315	500 600	5.5 2	3.5 1	**8 000** **3 000**	**>4.368** **>3.60**	**0.420** **0.084**	**0.219** **0.065**	**0.046** **0.005**

(a) Total extension = Initial extension + Total creep = Initial extension + Intercept + (Minimum creep rate × Duration).
(b) Quoted as 'Rockwell hardness 56B' in original document, but amount of cold work not defined.
N.B.: Original values are printed in **bold type**; other values are converted.

5.3.2.2 Stress for Designated Creep Rate

Form	Temper	Testing Temperature °C	Testing Temperature °F	0.001 % per 1 000 h kg/mm²	0.001 % per 1 000 h ton/in²	0.001 % per 1 000 h psi	0.01 % per 1 000 h kg/mm²	0.01 % per 1 000 h ton/in²	0.01 % per 1 000 h psi	0.1 % per 1 000 h kg/mm²	0.1 % per 1 000 h ton/in²	0.1 % per 1 000 h psi
Rod [1] 3.2 mm diam. 0.125 in. diam.	Cold Worked 37 %	149	300	5	3	**7 400**	13	8	**19 000**	21.5	13.5	**31 000**

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

5.4 FATIGUE PROPERTIES

5.4.1 Fatigue Strength at Room Temperature

Form	Temper	Number of Cycles $\times 10^6$	Metric Units kg/mm^2		English Units ton/in^2		American Units psi	
			Tensile Strength	Fatigue Strength	Tensile Strength	Fatigue Strength	Tensile Strength	Fatigue Strength
Rod [2] **7.6 mm diam. 0.3 in. diam.**	Cold Worked 17 %	100	28	11.5 [a]	17.5	7.5 [a]	**39 500**	**16 500** [a]
Rod [3]	Hot Worked	10	25	8.5 [a]	**16**	**5.5** [a]	36 000	12 500 [a]
Rod [3]	Cold Worked 25 %	10	31.5	11 [a]	**20**	**7** [a]	45 000	15 500 [a]

[a] Rotating-beam test.
N.B.: Original values are printed in **bold type**; other values are converted.

REFERENCES

MECHANICAL PROPERTIES (SECTION 5)

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