

APPLICATION DATA SHEET

COPPER • BRASS • BRONZE

mechanical properties of copper and copper alloys at low temperatures

■ Copper alloys become stronger and more ductile as temperature goes down. They also retain excellent impact resistance to 20 K. These general characteristics have been revealed in tests on 15 copper alloys, including brasses, bronzes and commercially pure coppers. They were tested by the Cryogenics Div., National Bureau of Standards, for the copper and brass industry to check tensile strength, notch tensile strength, Young's modulus, and impact properties at temperatures down to 4 K (-454 F). The information presented here is based on a report by R. P. Reed and R. P. Mikesell "Low Temperature Mechanical Properties Of Copper and Selected Copper Alloys," NBS Monograph 101, Institute for Materials Research, National Bureau of Standards, Boulder, Colorado 80302.

Tests — The compositions and condition of these alloys — that is, for standard, commercially available mill stock — are listed in Table 1. Tensile specimens with 1.5 inch gauge lengths provided the data on elastic modulus. Notch tension (also 1.5 inch gauge lengths) and tension tests were conducted using the cryostat and related equipment. Tests were conducted at 295 (ambient), 195, 76, 20, and 4 K. An Instron testing machine was used with a crosshead speed of 0.02 in. per min. Test procedures are described by R.A. Warren and R.P. Reed in NBS Monograph 63.

Results — The figures on the following pages present stress-strain behavior. In

Table 2 the average data for each alloy are tabulated for all tests and temperatures. Data spread in most instances was less than $\pm 1\%$.

Considerable spread in the impact strength occurred for Copper 102 in the 60% cold-drawn condition. This was related to grain size. Metallographic examination revealed that the specimens with high impact strengths (113 to 115 ft-lb) had small grains while those with low impact strength (57 to 84 ft-lb) had large grains.

Aged Copper Alloy No. 647, although containing only about 2.5 wt. % alloying elements, proved to be considerably stronger than any other alloy tested. Its impact strength remains high, and the notch tensile strength, although falling off at 4 K, is good when compared to the tensile strength. In addition, elongation increases at low temperatures.

Except for the sand cast nickel-aluminum-bronze alloy, all alloys had notched-to-unnotched tensile ratios above one, and good or very good impact properties. Only the sand cast alloy was brittle at low temperature. For most alloys the tensile strength, yield strength, elongation and notch tensile strength increased in the temperature range from 295 to 20 K. Ultimate and yield strengths of most alloys are less at 4 K than at 20 K. Discontinuous yielding is evident in all stress-strain curves at 4 K.

TABLE 1. Condition and Composition of Alloys

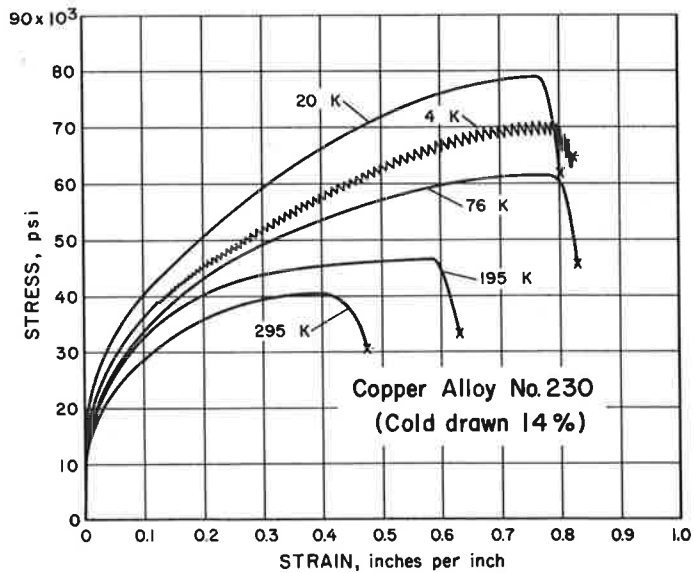
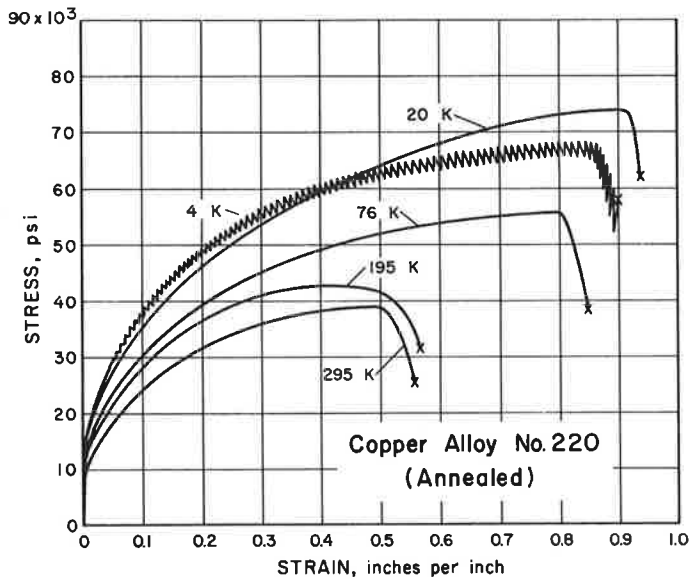
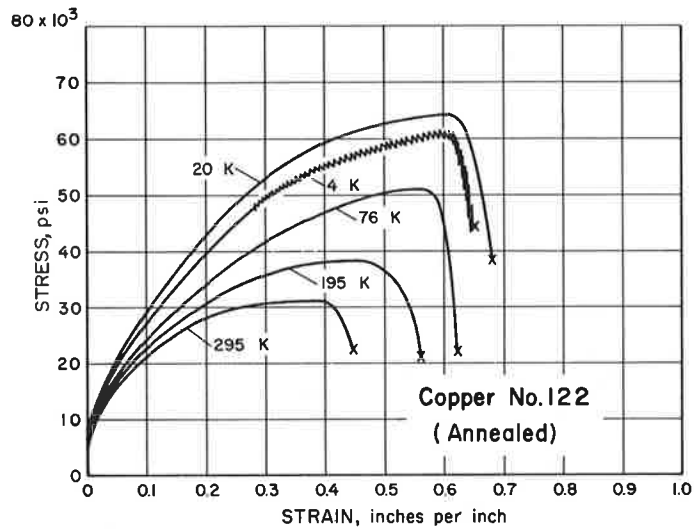
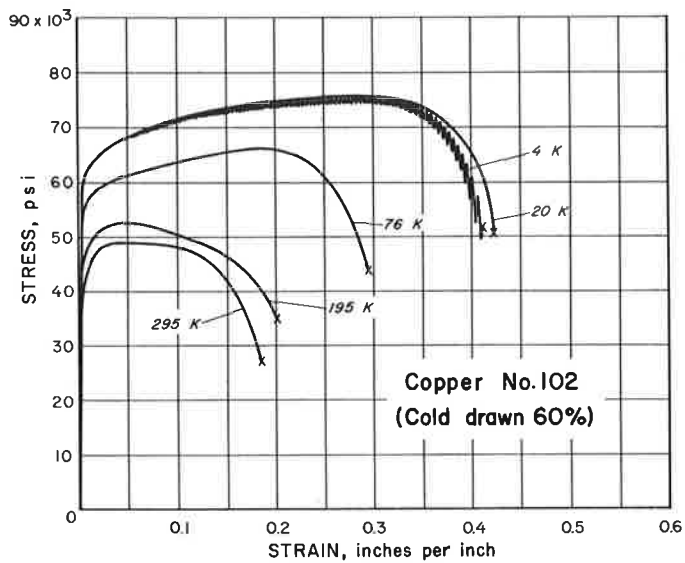
Copper and Copper Alloy *		Condition	Composition, %						Others	Hardness	Average Grain Diameter, mm
No.	Name		Pb	Fe	Sn	Zn	Ni	P			
102	Oxygen Free	Cold drawn 60%	4 ppm	4 ppm	1 ppm		4 ppm	1 ppm	**	Rb 45 to 53	0.287 to 2.00
122	Phosphorus Deoxidized, High Residual Phosphorus	Annealed	0.0002	0.003	0.00035	0.001		0.028	Ag, Bi, Sb, Mn, As, Ni (trace)	Rf 35	0.051
		Cold drawn 26%	Same as annealed samples							Rb 50	0.101
150	Zirconium Copper	Annealed, 950 C; cold drawn 85 to 90%; aged, 450 C, 1 hr	Similar to that of Oxygen Free with Zr added						Zr, 0.18	Rb 68	0.203
220	Commercial Bronze, 90%	Annealed, 575 C, 3 hr	0.005	0.01		10.01				Rf 49	0.051
230	Red Brass, 85%	Cold drawn 14%		0.02		15.33			Ag, Mg (trace)	Rf 64	0.025
443	Admiralty Arsenical	Annealed, 575 C, 1 hr	0.04	0.03	0.97	27.56			As, 0.041	Rf 55	0.144
464	Naval Brass	Annealed, 593 C, 1 hr	0.09	0.02	0.63	39.71				Rb 57	0.036
510	Phosphor Bronze, 5% A	Spring cold drawn 85%	0.02	0.02	4.85	0.05		0.18		Rb 94	0.101
614	Aluminum Bronze D	Commercial anneal		2.13					Al, 6.57	Rb 97	0.036
647	Copper-nickel silicon	Aged, 450 C, 2 hr		0.01			1.97			Rb 98	0.025
655	High Silicon Bronze A	Commercial anneal (soft)	0.01	0.09			0.04		Mn, 0.88; Si, 2.90	Rb 54	0.025
706	Copper Nickel 10%	Annealed, 677 C, 40 min	0.02	1.16		0.07	9.98			Rb 33	0.051
715	Copper Nickel 30%	Commercial anneal	<0.01	0.59	<0.01	0.04	30.05		Mn, 0.71 to 0.73 Al, <0.01; As, <0.01	Rb 47	0.036
	Nickel-aluminum bronze	Sand cast		3.35			5.20		Al, 9.95; Mn, 0.3	Rb 93	0.036

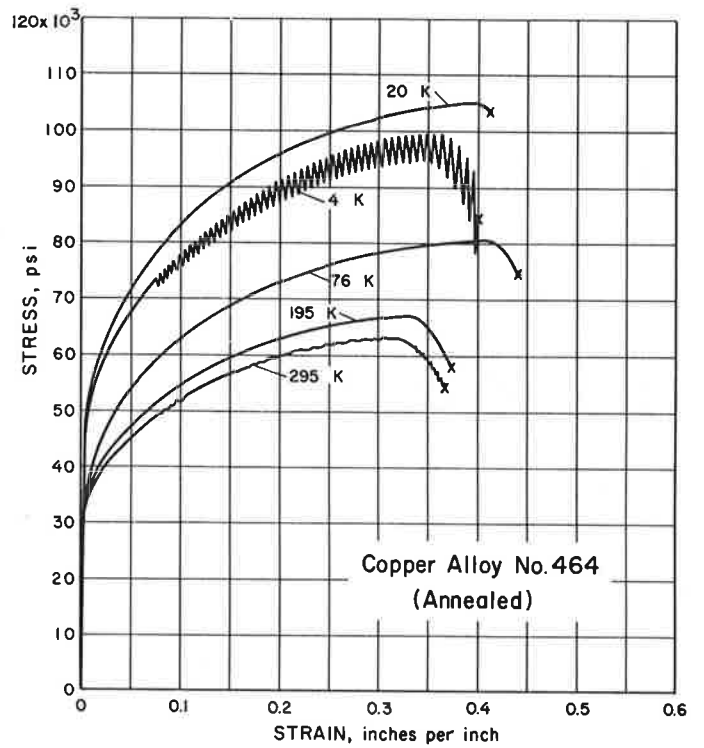
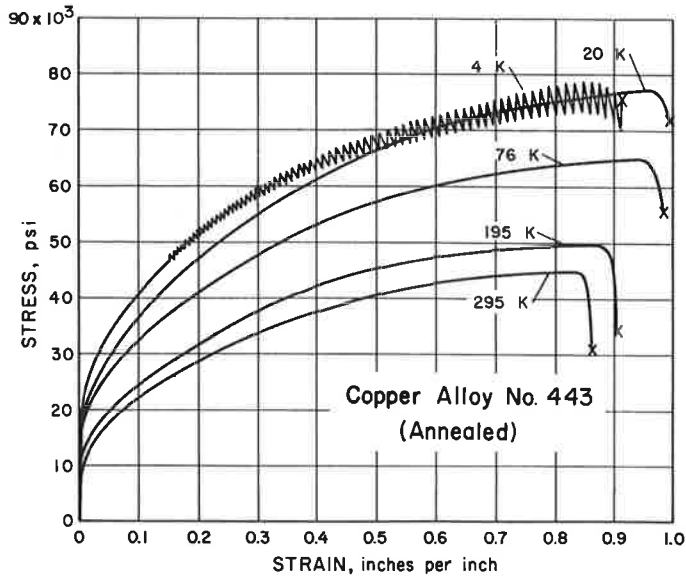
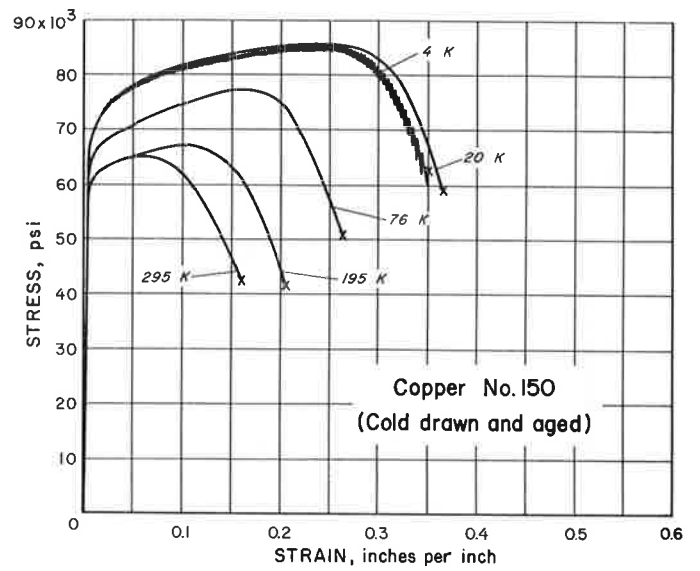
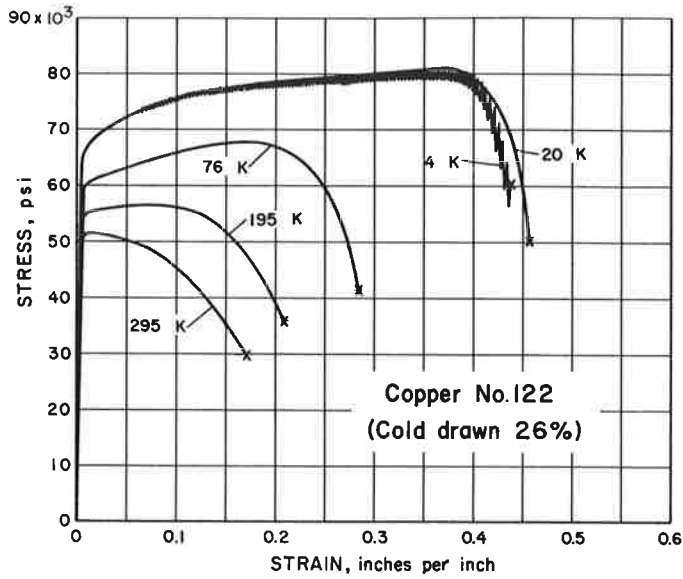
* Material was 3/4-in. bar, except nickel-aluminum bronze which was a billet.

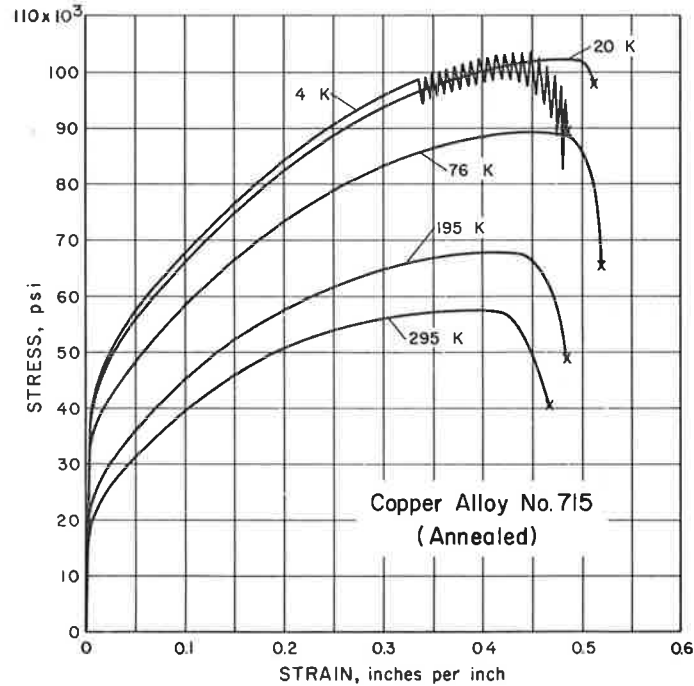
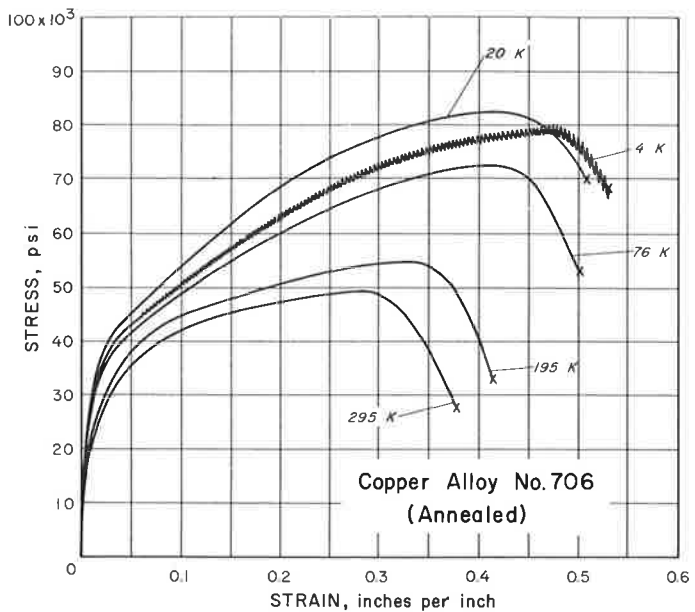
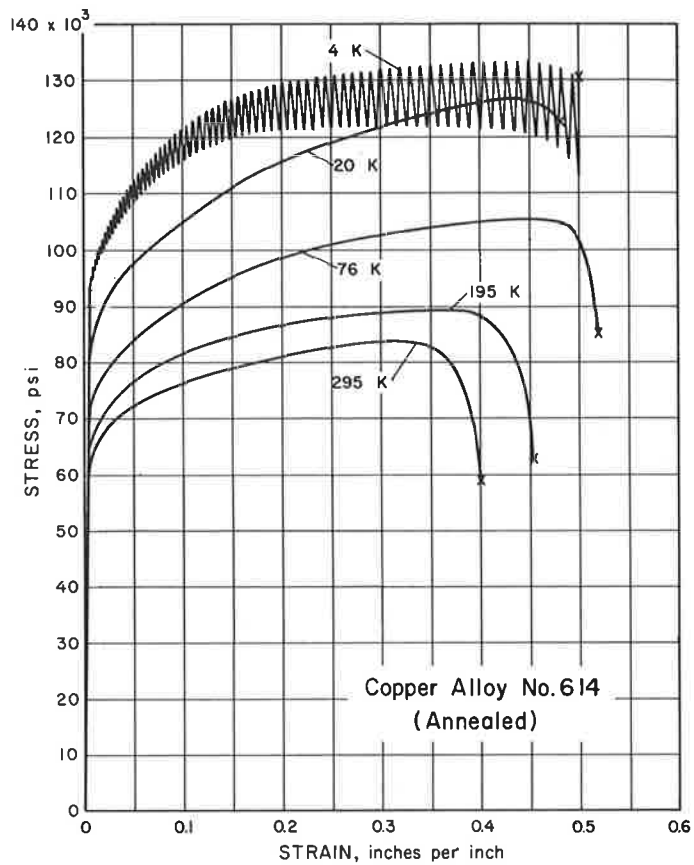
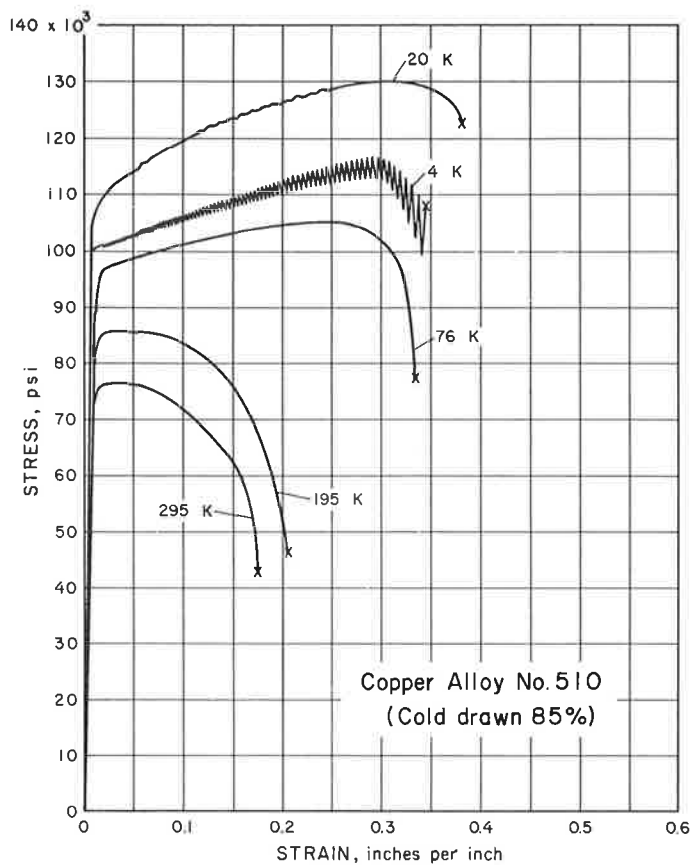
** 16 ppm Ag; 12 ppm S; 2 ppm As; 5 ppm Sb; less than 3 ppm O; traces of Au, Bi, Mn, Hg, Cd, Zn

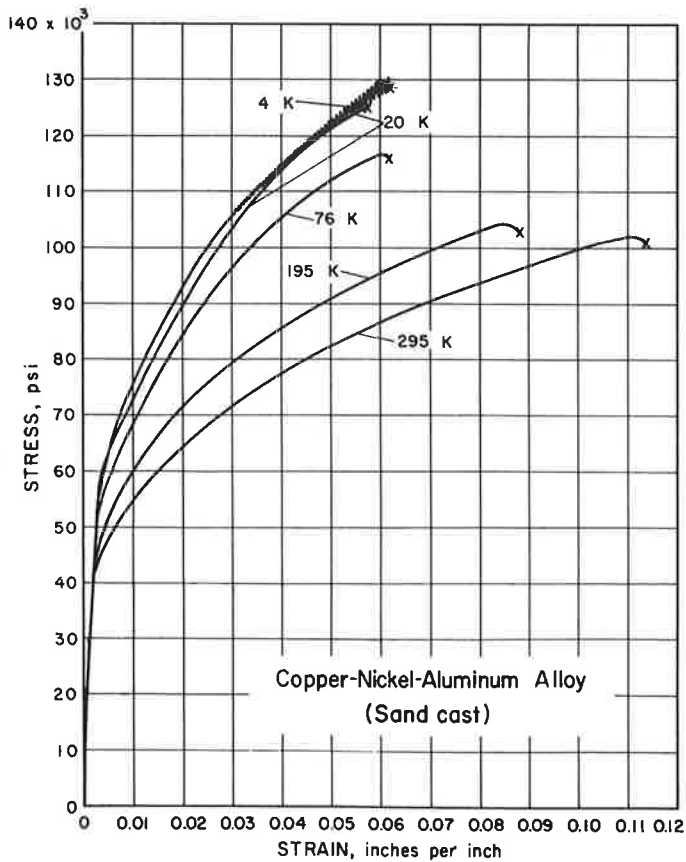
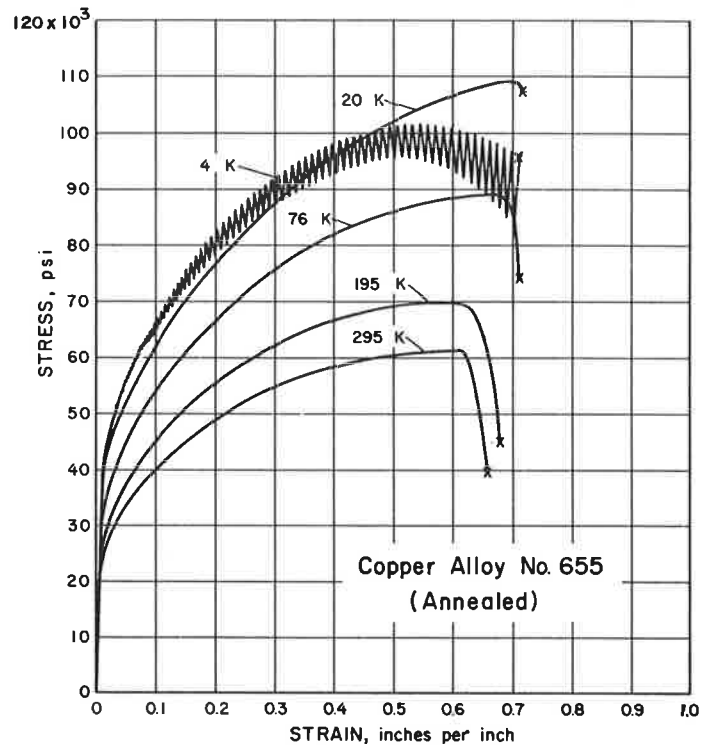
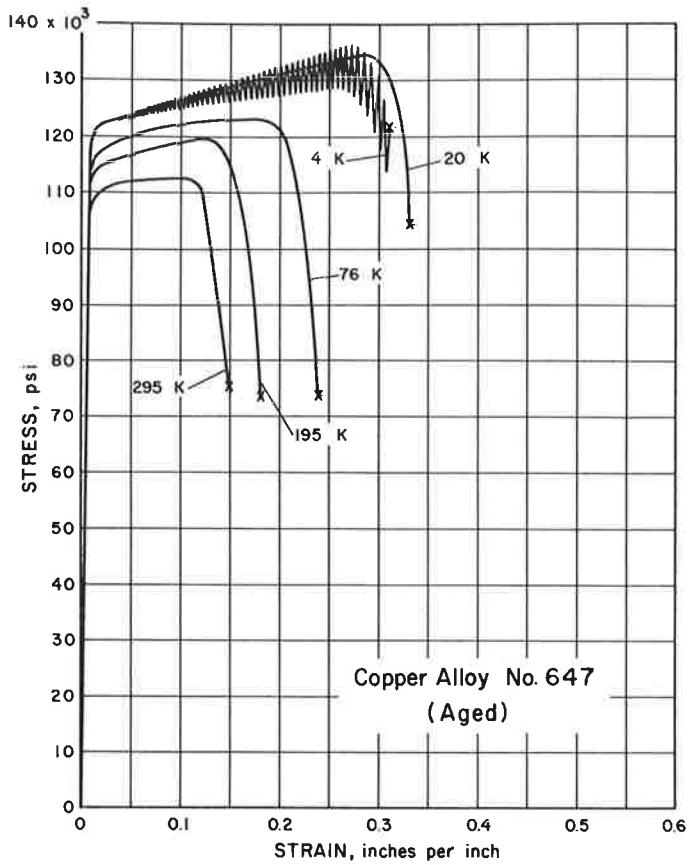
TABLE 2. Average Properties of Copper and Copper Alloys at Low Temperatures

Copper and Copper Alloy		Test Temperature, K	Elastic Properties		Plastic Properties					
					Uniaxial			Triaxial		
No.	Name and Treatment		Youngs Modulus, 10 ⁶ psi (± 5%)	Shear Modulus, 10 ⁶ psi (± 2%)	Tensile Strength, psi	Yield Strength, psi	Elongation, % in 4D	Reduction of Area, %	Notch Tensile Strength (K _T = 5.0), psi	Impact Charpy Energy Absorbed, ft-lb
102	Oxygen Free (Cold drawn 60%)	295	17.3		48,400	46,800	17	77	75,700	96
		195			52,900	49,800	20	74	82,200	101
		76	20.0		66,400	54,400	29	78	93,600	95
		20			74,500	58,500	42	76	102,400	84
		4	22.0		74,600	58,600	41	75	100,600	
122	Phosphorus Deoxidized, High Residual Phosphorus (Annealed)	295	15.1	6.46	31,300	6,700	45	76	43,300	111
		195	16.0	6.81	38,300	6,600	56	87	50,400	112
		76	16.2	7.20	50,600	7,400	62	84	62,300	112
		20	16.3	7.44	63,800	8,400	68	83	72,000	118
		4	16.4		60,400	7,900	65	81	74,700	
	(Cold drawn 26%)	295	18.9		51,800	49,400	17	76	81,000	112
		195	19.9		56,800	53,600	21	79	86,800	112
		76	20.3		68,400	59,900	28	76	99,800	112
		20	20.8		81,400	64,100	46	78	108,600	119
		4	21.1		81,000	63,600	44	72	109,300	
150	Zirconium Copper (Cold drawn, aged)	295	15.8		64,450	59,600	16	62	97,600	89
		195			67,200	61,300	20	66	103,100	105
		76	17.2		77,400	65,700	26	71	112,400	114
		20			85,200	66,400	37	72	119,000	114
		4	17.2		85,700	64,700	36	69	121,600	
220	Commercial Bronze, 90% (Annealed)	295	15.1	6.59	38,500	9,600	56	84	49,900	112
		195	16.4	6.97	41,800	10,200	57	80	55,600	114
		76	17.7	7.24	55,200	13,200	86	78	69,200	112
		20	18.0	7.37	73,200	15,600	95	73	76,300	115
		4	18.1		68,200	15,000	91	73	78,900	
230	Red Brass, 85% (Cold drawn 14%)	295	14.9	6.55	40,400	13,000	48	74	53,900	96
		195	15.8	6.77	46,500	14,000	63	79	58,500	82
		76	17.6	7.06	62,000	16,400	83	77	71,200	78
		20	18.1	7.20	79,200	20,900	80	75	72,000	76
		4	18.2		71,000	18,300	82	71	74,900	
443	Admiralty Arsenical (Annealed)	295	14.6	5.94	44,800	10,600	86	81	53,800	112
		195	14.9	6.15	49,600	12,600	91	79	58,800	113
		76	15.5	6.48	64,600	18,700	98	73	75,200	114
		20	16.0	6.55	76,800	20,800	99	68	89,400	114
		4	16.2		78,600	21,100	92	72	86,200	
464	Naval Brass (Annealed)	295	14.0	5.76	63,300	31,000	37	52	74,700	38
		195	14.5	5.94	67,400	33,800	37	54	84,800	42
		76	14.8	6.16	80,400	38,000	44	48	100,700	38
		20	15.0	6.26	105,200	47,600	41	42	113,900	35
		4	15.1		99,600	43,700	40	48	115,400	
510	Phosphor Bronze, 5% A (Cold drawn 85%, spring)	295	15.6		77,400	72,000	18	78	136,500	106
		195	16.5		85,600	78,700	20	78	147,100	82
		76	16.7		105,200	89,200	34	67	167,000	54
		20	16.5		131,000	104,800	39	62	185,000	51
		4	16.4		116,400	100,400	34	58	185,400	
614	Aluminum Bronze D (Annealed)	295	15.8		83,200	59,400	40	66	122,500	110
		195	16.1		89,500	64,800	45	71	133,300	100
		76	16.3		105,800	69,500	52	64	148,100	72
		20	16.3		126,400	80,600	48	58	174,300	66
		4	16.3		134,500	82,400	52	59	160,800	
647	Copper-Nickel Silicon (Aged)	295	21.4		112,400	105,000	15	60	189,700	110
		195	22.3		119,400	110,800	18	66	194,800	106
		76	23.2		123,600	114,100	24	70	204,600	109
		20	23.5		133,700	118,400	33	68	255,800	116
		4	23.6		135,800	119,800	31	65	212,200	
655	High Silicon Bronze A (Annealed, soft)	295	15.6		61,400	24,200	66	79	81,200	112
		195	15.8		69,900	26,800	68	79	92,000	112
		76	16.1		89,000	31,900	71	69	110,700	114
		20	17.0		108,900	37,600	72	69	126,300	116
		4	17.5		101,200	36,900	71	70	122,100	
706	Copper Nickel 10% (Annealed)	295	17.7		49,600	21,400	37	79	65,000	114
		195			54,700	24,700	42	77	73,100	113
		76	19.5		72,000	24,800	50	77	87,200	115
		20			82,500	30,200	50	73	96,800	116
		4	20.5		80,600	24,900	53	73	100,000	
715	Copper Nickel 30% (Annealed)	295	22.0		57,800	18,700	47	68	79,400	115
		195			68,000	22,200	48	70	90,500	114
		76	23.0		89,800	31,600	52	70	112,900	114
		20			103,100	38,100	51	66	127,600	114
		4	23.2		104,600	40,100	48	65	130,500	
	Nickel-Aluminum Bronze (Sand cast)	295	16.8		101,200	44,000	11	9	105,200	10
		195	17.8		104,600	47,800	9	9	112,800	8
		76	18.5		117,100	54,900	6	7	118,900	6
		20	18.5		126,600	61,600	6	2	121,800	6
		4	18.5		130,500	60,100	6	5	118,400	











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