1. GENERAL

Columbium (also known as Niobium) is an extremely high melting, moderately dense ductile metal, which despite its high melting point, is too soft for structural use at temperatures above 1200 F. The metal absorbs large quantities of oxygen when exposed to atmosphere at moderately high temperatures. Columbium has a low thermal-neutron-capture cross section and is readily fabricated which makes the metal attractive for nuclear applications, (4, p.3).

1.01 Commercial Designation. Columbium, commercially pure.

1.02 Alternate Designation. Niobium.

1.03 Specifications. None.

1.04 Composition. Typical compositions, Table 1.04.

TABLE 1.04

Source	DMIC (4, p.21)	DMIC (6, p.2)	
Process	Electron beam refined	Powder metallurgy	Electron bombardment
	Percent	Percent	Percent
Aluminum		0.002	< 0.002
Boron			< 0.0001
Carbon	< 0.003	0.005	: 0.010
Chromium			< 0.002
Copper	< 0.004	0.003	0.007
Iron	< 0.010	0.003	< 0.01
Lead			0.004
Magnesium		< 0.001	< 0.002
Manganese		0.001	< 0.002
Molybdenum		0.01	0.004
Nickel		0.006	< 0.002
Silicon	< 0.010	0.01	< 0.01
Tantalum	0.039		0.096
Tin			< 0.002
Titanium	< 0.015	0.002	< 0.015
Tungsten	< 0.030		< 0.03
Vanadium			< 0.002
Zinc			< 0.002
Zirconium		0.01-0.6	< 0.05
Oxygen	0.0062	0.05	0.0131
Nitrogen	0.0044	0.01	0.0103
Hydrogen		0.0001	
Others	< 0.002		
Columbium	Balance	Balance	Balance

1.05 Heat Treatment

1.051 Vacuum or special atmosphere is required to avoid oxidation, (10, p.109).

1.052 For powder metallurgy-columbium, anneal at 2012 F for 1 hr. Full recrystallization varies with amounts of cold working. 50 percent cold working requires 2282 F for 1 hr and 97.3 percent cold working requires 2066 F for 1 hr, (6, p.1).

1.053 For electron-beam-refined columbium anneal at 1832 F, (6, p.3).

1.06 Hardenability

1.061 The strength of columbium depends to some extent upon strain-hardening induced by mechanical processing, (3, p.15).

1.062 Work hardening of cold rolled columbium, Fig. 1.062.

1.063 Effect of oxygen content on hardness of columbium, Fig. 1.063.

1.07 Forms and Conditions Available

1.071 Columbium is supplied as powder, granules or wrought forms. Sheet, strip, foil, wire and rods are produced by powder metallurgy or fusion processes followed by cold-working, (6, p.5).

1.08 Melting and Casting Practice

Columbium is obtained by vacuum consumable electrode arc melting and electron-beam melting in vacuum, or by powder-metallurgical processes. It is melted under vacuum and under inert gas, (6, p.1).

2. PHYSICAL AND CHEMICAL PROPERTIES

2.01 Thermal Properties

2.011 Melting point. 4474 F, (4, p.8). 4380 F, (9).

2.012 Phase changes. None.

2.013 Thermal conductivity, Fig. 2.013.

2.014 Thermal expansion, Fig. 2.014.

2.015 Specific heat, Fig. 2.015.

2.02 Other Physical Properties

2.021 Density. 0.313 lb per cu in. 8.66 gr per cu cm, (9).

2.022 Electrical resistivity, Fig. 2.022.

2.023 Spectral emissivity, Fig. 2.023.

2.03 Chemical Properties

2.031 Corrosion resistance. The metal is unattacked by most of the organic and mineral acids at ordinary temperatures but shows less resistance to the alkalies. Hydrofluoric acid and a mixture of hydrofluoric and nitric acids dissolve the metal. Above 212 F the resistance of columbium to attack by acids is reduced. It has a good corrosion resistance to rural, marine and industrial atmospheres. Columbium is generally inferior to tantalum in corrosion resistance, (10, p. 109).

2.032 Oxidation resistance. At low temperatures oxidation proceeds at a low linear rate and no scale is formed. It forms a visible tarnish near 752 F and microscopic blisters between 752 to 932 F. Above 1292 F the rate of oxidation increases quite rapidly with temperature. Nitrogen in air does not apparently modify the oxidation process, (8, p.1).

2.0321 Oxidation rates in air at various temperatures, Fig. 2.0321.

2.04 Nuclear Properties

2.041 Absorption cross section, 1.1 ± 0.1, (4, p.10).

2.042 Capture cross section, 1.0 ± 0.5, (4, p.10).

3. MECHANICAL PROPERTIES

3.01 Specified Mechanical Properties

3.02 Mechanical Properties at Room Temperature

3.021 Typical mechanical properties for sheet and extrusions, Table 3.021.

TABLE 3.021

Source	(9)		(6, p.3)
Metal	Columbium, comm. pure		
Form	Sheet		Tubing
Condition	Ann	CW	Forward extrusion at 800 F
Thickness - in	1/8		
F_{tu}, typ-ksi	45-55	80-100	64.4
F_{ty}, typ-ksi			62.2
e (1 in), typ-percent	15-40	5-15	9 (2 in)

3.022 Effect of annealing temperature and cold working on the room temperature tensile properties of powder-metallurgy Columbium, Fig. 3.022.

3.023 Effect of annealing temperature and cold working on the room temperature tensile properties of arc-cast Columbium, Fig. 3.023.

3.024 Effect of oxygen content on room temperature tensile properties of Columbium, Fig. 3.024.

3.03 Mechanical Properties at Various Temperatures

3.031 Short time tension properties

3.0311 Effect of low test temperature and oxygen content on tensile properties of annealed Columbium, Fig. 3.0311.

3.0312 Effect of test temperature on tensile strength of Columbium, Fig. 3.0312.

3.0313 Effect of moderate test temperatures on tensile properties of Columbium, Fig. 3.0313.

Cb. COMM PURE 3.0314 Effect of moderate test temperatures on tensile strength of cold rolled Columbium, Fig. 3.0314.

3.0315 Stress strain curves in tension at room and low temperatures for wrought stress relieved and recrystallized bar, Fig. 3.0315.

3.032 Short time properties other than tension

3.0321 Effect of test temperature on impact properties of annealed Columbium, Fig. 3.0321.

3.033 Static stress concentration effects

3.0331 Effect of low test temperature on tensile strength of smooth and notched recrystallized wrought bar, Fig. 3.0331.

3.0332 Effect of low test temperature on tensile strength of smooth and notched stress relieved wrought bar, Fig. 3.0332.

3.04 Creep and Creep Rupture Properties

3.041 Total strain curves for Columbium at 750 and 930 F, Fig. 3.041.

3.042 Creep rupture curves at 1600 to 2200 F for Columbium, Fig. 3.042.

3.05 Fatigue Properties

3.06 Elastic Properties

3.061 Modulus of elasticity at various temperatures, Fig. 3.061.

3.062 Modulus of rigidity at room temperature. 5.44×10^6 psi, (4, p. 24).

4. FABRICATION

4.01 Forming and Casting

4.011 General. All forming operations must be performed cold. Columbium can be drawn, stamped and formed into complicated shapes. 60 percent reduction can be made in one operation due to the slow rate of work-hardening, (10, p. 109).

4.012 Columbium is more resistant to tearing and slitting in deep drawing operations than most metals, (10, p. 109).

4.013 Annealed strip can be cold rolled to 0.0002 in. Kerosene or palm oil is used as a lubricant when rolled below 0.010 in, (6, p. 3).

4.02 Machining
The metal can be machined with tools similar to those used for machining steel. Carbon tetrachloride as a cutting fluid reduces the tendency of the metal to tear or gall, (10, p.109).

4.03 Welding

4.031 General. Columbium can be welded to itself and some other metals by some of the common techniques, (10, p. 109).

4.032 Resistance welding. Methods similar to those used for tantalum, (10).

4.033 Arc welding. Usually performed with a tungsten arc in an inert gas atmosphere, (6, p. 5).

4.034 Gas welding. Not recommended, (10).

4.035 Ultrasonic welding. Sheet material up to 0.030 in can be welded by this method, (6, p. 5).

4.036 Copper brazing is possible, (6, p. 5).

4.04 Heating and Heat Treating

4.05 Surface Treating

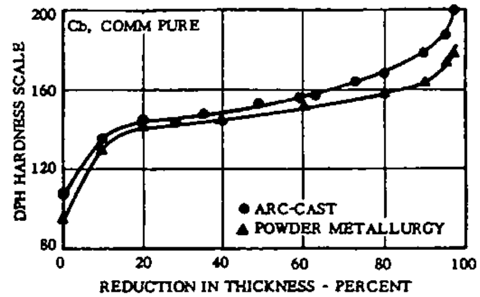

FIG. 1.062 WORK HARDENING OF COLD ROLLED COLUMBIUM (11, p. 46)

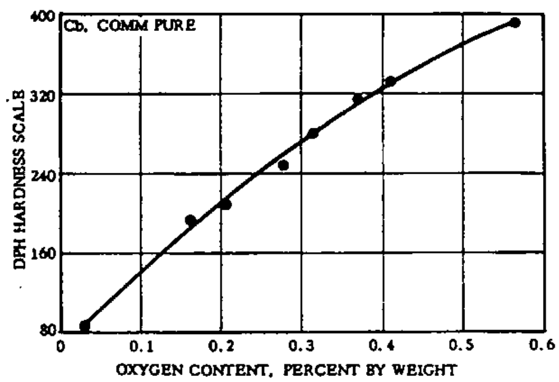

FIG. 1.063 EFFECT OF OXYGEN CONTENT ON HARDNESS OF COLUMBIUM (12, p. 377)

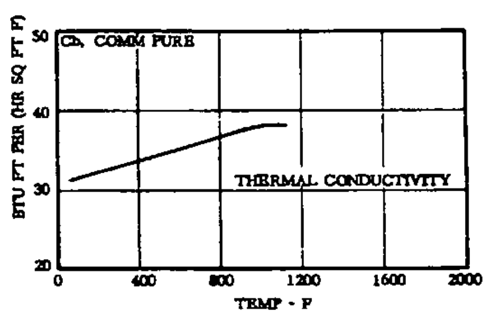

FIG. 2.013 THERMAL CONDUCTIVITY (4, p. 11)

Cb, COMM PURE

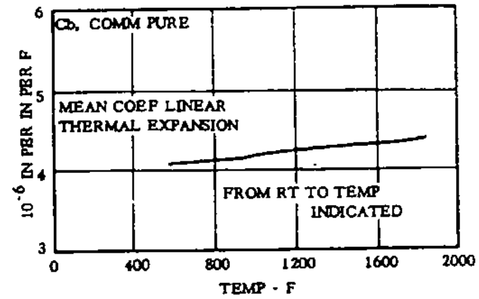

FIG. 2.014 THERMAL EXPANSION (4, p.11)

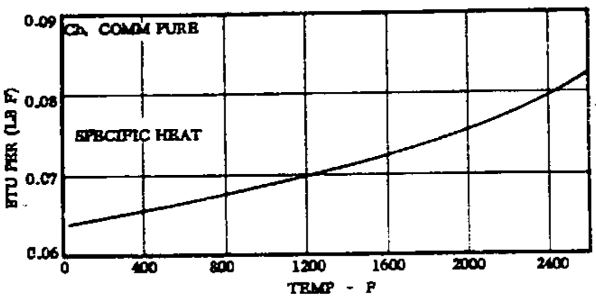

FIG. 2.015 SPECIFIC HEAT (4, p.12)

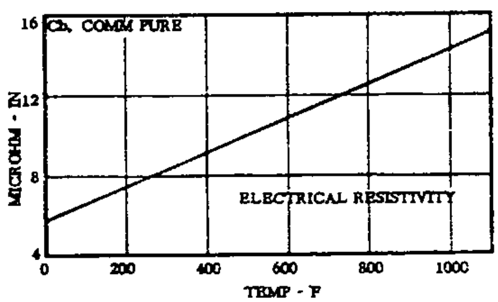

FIG. 2.022 ELECTRICAL RESISTIVITY (4, p.13)

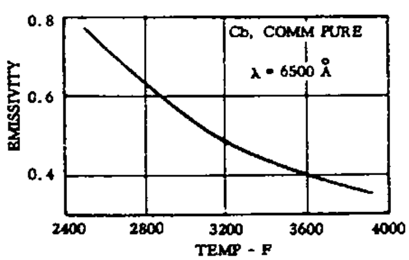

FIG. 2.023 SPECTRAL EMISSIVITY (4, p.13)

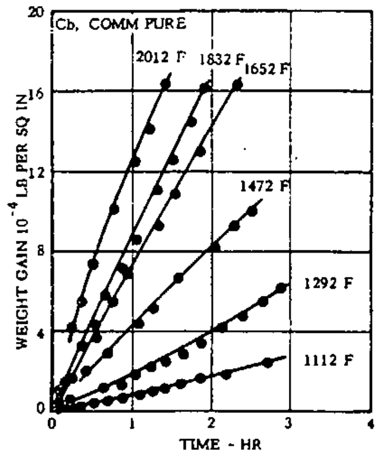

FIG. 2.0321 OXIDATION RATES IN AIR AT VARIOUS TEMPERATURES (8, p.24)

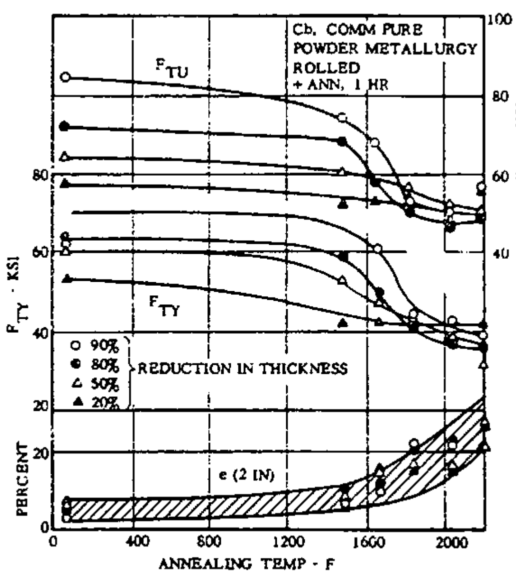

FIG. 3.022 EFFECT OF ANNEALING TEMPERATURE AND COLD WORKING ON THE ROOM TEMPERATURE TENSILE PROPERTIES OF POWDER METALLURGY COLUMBIUM (11, p.49, 50)

Cb, COMM PURE

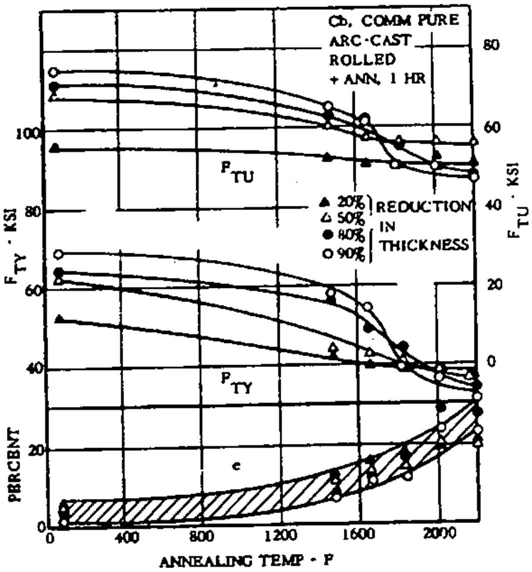

FIG. 3.023 EFFECT OF ANNEALING TEMPERATURE AND COLD WORKING ON THE ROOM TEMPERATURE TENSILE PROPERTIES OF ARC-CAST COLUMBIUM (11, p.47, 48)

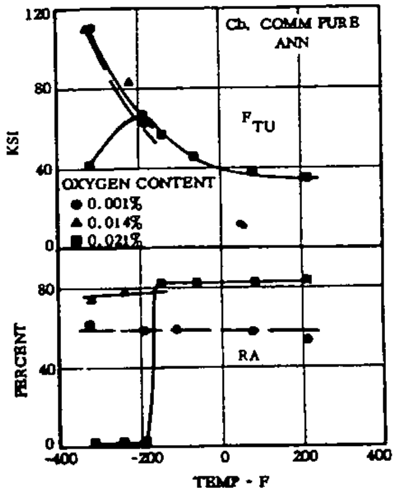

FIG. 3.0311 EFFECT OF LOW TEST TEMPERATURE AND OXYGEN CONTENT ON TENSILE PROPERTIES OF ANNEALED COLUMBIUM (4, p.35)

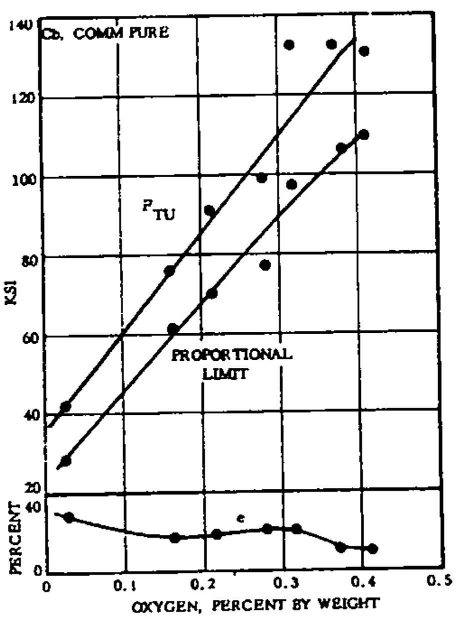

FIG. 3.024 EFFECT OF OXYGEN CONTENT ON ROOM TEMPERATURE TENSILE PROPERTIES OF COLUMBIUM (12, p.377)

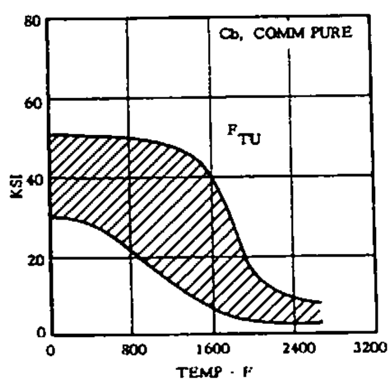

FIG. 3.0312 EFFECT OF TEST TEMPERATURE ON TENSILE STRENGTH OF COLUMBIUM (4, p.29)

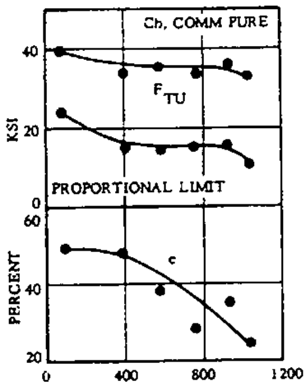

FIG. 3.0313 EFFECT OF MODERATE TEST TEMPERATURES ON TENSILE PROPERTIES OF COLUMBIUM (12, p.376)

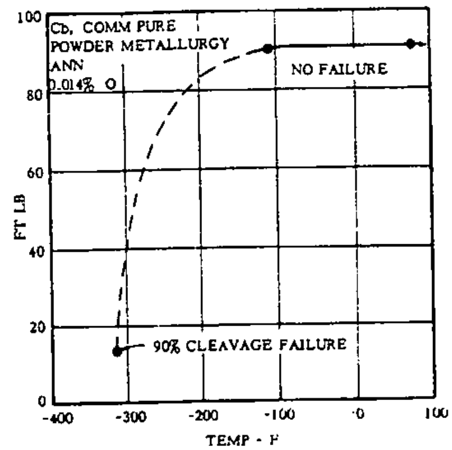

FIG. 3.0321 EFFECT OF TEST TEMPERATURE ON IMPACT PROPERTIES OF ANNEALED COLUMBIUM (4, p.34)

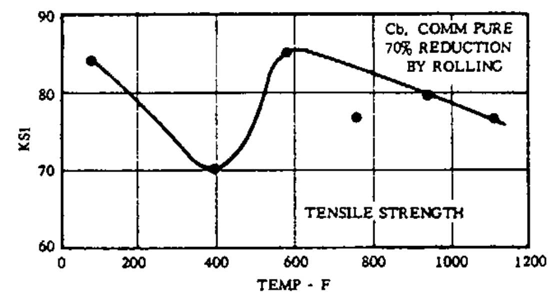

FIG. 3.0314 EFFECT OF MODERATE TEST TEMPERATURES ON TENSILE STRENGTH OF COLD ROLLED COLUMBIUM (4, p.30)

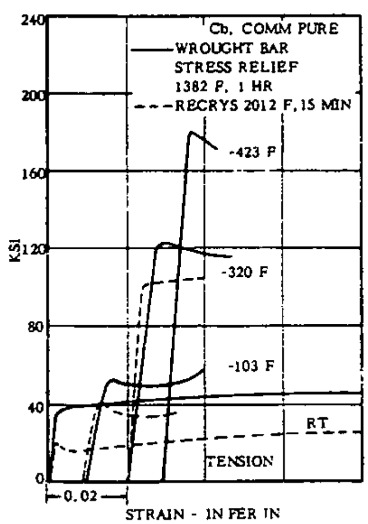

FIG. 3.0315 STRESS STRAIN CURVES IN TENSION AT ROOM AND LOW TEMPERATURES FOR WROUGHT STRESS RELIEVED AND RECRYSTALLIZED BAR (1, p.59)

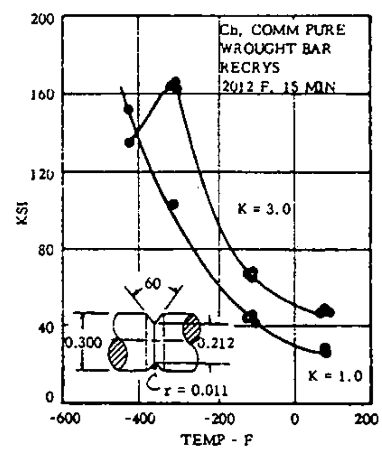

FIG. 3.0331 EFFECT OF LOW TEST TEMPERATURE ON TENSILE STRENGTH OF SMOOTH AND NOTCHED RECRYSTALLIZED WROUGHT BAR (1, p.63)

Cb, COMM PURE

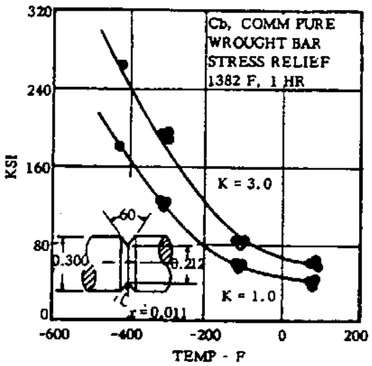

FIG. 3.0332 EFFECT OF LOW TEST TEMPERATURE ON TENSILE STRENGTH OF SMOOTH AND NOTCHED STRESS RELIEVED WROUGHT BAR

(1, p.62)

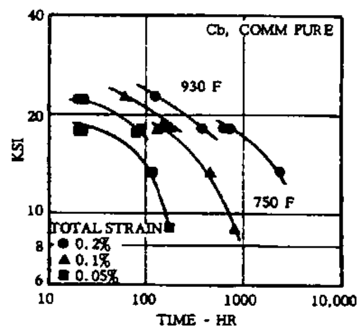

FIG. 3.041 TOTAL STRAIN CURVES FOR COLUMBIUM AT 750 AND 930 F

(4, p.33)

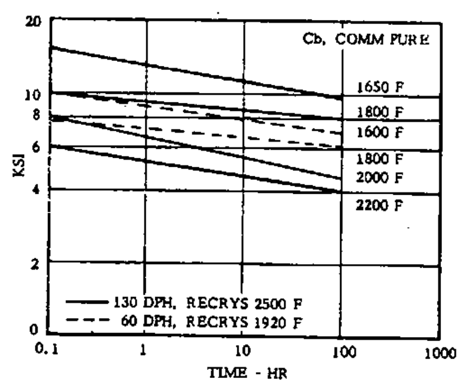

FIG. 3.042 CREEP RUPTURE CURVES AT 1600 TO 2200 F FOR COLUMBIUM

(4, p.33)

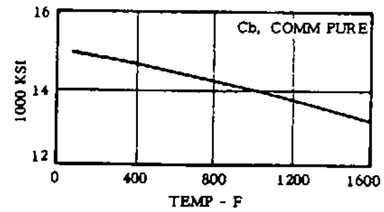

FIG. 3.061 MODULUS OF ELASTICITY AT VARIOUS TEMPERATURES

(4, p.24)

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