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INTRODUCTION

The search for metals for high-temperature service and corrosion resistance in nuclear reactors has increased at a rapid pace in recent years. One of these metals that shows promise is Niobium. A literature survey on Niobium indicates that information is scarce regarding its properties especially at high temperature. This condition is undoubtedly due to the high cost of the metal and its relative newness in the role of a construction material.

This report contains a literature survey of the properties and general information of Niobium (Columbium). This information is presented in the hope that others may find information on the subject more readily. The information given is not all inclusive and may contain some errors, since the author was dependent upon the accuracy of the literature.

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CKM:h

NIObIUM (Columbium)

3.

<u>Atomic Properties</u>	<u>Value</u>	<u>Reference</u>
1. Atomic Number	41	1
2. Atomic Weight	92.91	1
3. Atomic Volume (cc/g-atom)	10.83	1
4. Isotopes, a. Natural	93	1
b. Artificial	90, 91, 92, 94, 95, 96, 97, 98(?), 99	1
5. Lattice Structure	Body Centered Cubic	1
6. Lattice Constant ($\text{\AA}$)	3.294	1
7. Closest Approach of Atoms ($\text{\AA}$)	2.852	7
8. Phase Transformation at Any Temperature	None	7
9. Cross Section, Thermal Neutron Absorption (Barns)	1.1	1
10. Cross Section, Thermal Neutron Scattering (Barns)	6.9	7
11. Work Function (ev)	4.01	1
12. Ionization Potential (Volts)	6.77	1
13. Positive Ion Emission (ev)	5.5	1
14. Refractive Index	1.80	7
15. Segre reports that radioactive niobium has a half life of 6.6 minutes to 10,000 years. It emits negative beta particles of 1.3-million electron volts and gamma rays of 0.42-million electron volts.		7

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<u>Thermal Properties</u>	<u>Value</u>	<u>Reference</u>
1. Melting Point ($^{\circ}\text{F}$)	4460	1
2. Boiling Point ($^{\circ}\text{F}$)	5972	1
3. Heat of Sublimation (Kcal/g-atom)	170.9	1
4. Heat of Combustion (cal/gm)	2379	1
5. Thermal Conductivity	See Fig. 2	1
6. Coefficient of Linear Expansion (per $^{\circ}\text{C}$)	7.1×10^{-6}	1
7. Density (lbs/in ³)	0.31	1
8. Specific Heat	See Fig. 1	2
9. Vapor Pressure (mm/Hg)	Very low, comparable to Ta and Mo	1
a. Ta. Vapor Pressure (mm/Hg) at 1737°C	9.5×10^{-11}	1
b. Mo. Vapor Pressure (mm/Hg) at 1600°C	2.5×10^{-8}	1
10. Specific Gravity	5.2	7 0
11. Minimum Effective Softening Temperature ($^{\circ}\text{F}$)	2012	7
12. Heat of Vaporization (BTU/lb)	3312	7

<u>Electrical Properties</u>	<u>Value</u>	<u>Reference</u>
1. Electrical Resistance (microhms-cm)	See Fig. 3	1
2. Temperature Coefficient (Resist ^o /°C)	0.00395	1
3. Conductivity (% IACS)	13.3	1
4. Transition to Superconductivity (°K)	8.74-8.18	7
5. Electrochemical Equivalent (valence 5) mg/coulomb	0.1926	5
6. Magnetic Susceptibility (cgs)	2.28×10^{-6}	7
7. Electrical Resistance (ohms/mil.ft)	79	7

<u>Mechanical Properties</u>	<u>Value</u>	<u>Reference</u>
1. Youngs Modulus (psi)	12.4×10^6	1
2. Tensile Strength and Elongation	See Figs. 4 and 5	3
3. Yield Strength	See Figs. 6 and 7	3
4. Hardness	See Fig. 8	3
5. Short Time Stress Rupture Test		
a. Time (Hrs)	0.1 - 0.3	4
b. Rupture Stress (psi)	14,800	4
c. Elongation in 2 in (%)	15.5	4
d. Temperature (°F)	2200	4
e. Atmosphere	Helium	4
Cold Rolled (90% Reduction)		
Commercial Cb. Sheet		
6. Creep Rupture Test	See Fig. 9	4
7. Coefficient of Linear Expansion	See Fig. 10	7
8. Poisson's Ratio	0.30	7

General Information

1. Discovered in 1801, by Hatchett and named columbium and in 1844 by Rose and named niobium (usually found in nature in combination with tantalum ores). Metallic columbium was first produced by Balke in 1929.
2. Niobium is generally resistant to inorganic acids. It is readily attacked by hydrofluoric acid and by alkali hydroxides. At elevated temperature the metal reacts with the halogens, nitrogen, hydrogen, oxygen and carbon. The oxides are moderately refractory and the mono-carbide has a particularly high melting point. (Reference 1).
3. Composition Limits - For sheet, wire and compacts the allowable percentages for various impurities are:

0.20 Ta; 0.002 Ti, 0.03 Si, 0.01 Fe, and 0.02 C. (Reference 5).
4. Annealing Temperature - Above 1050°C in vacuum. (Reference 5).
5. Cost - \$200-\$300 per pound. This price is considered artificial and a sizeable demand for this material would reduce this cost considerably.
6. The most important mineral source of tantalum and columbium is a ferrous columbate-tantalate, $\text{Fe}(\text{Cb-TaO}_3)_2$. When columbium predominates, the mineral is called columbite, and when tantalum predominates, tantalite. Nigeria, Africa is the principal source of columbium ores. Approximately 2 1/2 tons of ore are required to produce 1 pound of niobium metal.
7. Commercial quantities of niobium metal are usually produced by sintering niobium powders in vacuum. The powder is pressed into bars 24 or 30 inches long and up to one square inch in cross section. After sintering, the bar, which has a density of about 90% of theoretical, is rolled or forged and again heated to weld the new contacts. All working of niobium is done cold. After a reduction of 70-80%, sheet stock may be annealed in vacuum to facilitate further working. Sheet 0.0002 inch in thickness which is solid and free from pores can be produced. The Arc casting method is also used to produce the metal. (Reference 6).
8. The Fansteel Metallurgical Corporation, of North Chicago, Illinois, is the principal producer of niobium metal and it can be obtained in various shapes such as bars, rods, wire, sheet and tubing.
9. Columbium today has its widest application in the form of ferrocolumbium. Ferrocolumbium is used principally to act as a stabilizer to prevent intergranular corrosion in stainless steel. Type 347 stainless steel contains 0.10% columbium. (Reference 7).

General Information (Con't.)

10. Reaction of Various Elements and Compounds with Niobium.

- a. Air - Niobium starts to oxidize in air at approximately 392°F . The oxide thus formed is film-like and adherent, preventing further oxidation until the temperature is raised. Niobium oxides dissolve into the metal when heated in vacuum to temperatures above a red heat and below 2192°F and the metal will increase in weight.
- b. Hydrogen - At high temperatures, hydrogen is absorbed with the metal losing its ductility and becoming very brittle and "glass hard". The safe operating temperature for niobium in hydrogen is limited to something below 3452°F for either short or long term operation because of grain growth, change in dimensions, and hydrogen embrittlement.
- c. Nitrogen - Nitrogen will start penetrating niobium metal at 752°F and the metal will also start to increase in hardness. (See Fig. 11).
- d. Ammonia - At red heat niobium decomposes ammonia forming the nitride.
- e. Chlorine - Niobium is attacked by chlorine at a temperature of 392°F to form the pentachloride.
- f. Bromine - Niobium unites with bromine at 392°F to form the pentabromide. (Reference 7).

11. Effect of Oxygen and Nitrogen in Niobium on Melting Point (See Fig. 11).

- 12. Static corrosion screening tests at ORNL show that niobium is very slightly attacked by liquid lead, sodium, and lithium. Immersion in liquid lead shows some solution loss and the mass-transfer effect, while sodium makes a slight intergranular attack upon the niobium. After being immersed in liquid lithium for 400 hours at 1000°C , niobium is attacked intergranularly to a depth of 0.002 inch. (Reference 7).

Fabrication

1. Most of the procedures in working and fabricating niobium are conventional, and can be mastered without too much difficulty. At the outset, however, two important characteristics must be kept constantly in mind:

- a. Niobium, like copper, lead, stainless steel, and some other metals, is "sticky", having a strong tendency to seize, tear and gall.
- b. All forming, bending, stamping or deep drawing operations must be done cold. Heating the metal does not increase ductility, in fact, heating in air or any of the common gases embrittles the metal.

(Reference 6).

2. Cleaning and degreasing present no special problems, and conventional methods and materials may be used, although hot caustics must be avoided.

Niobium parts may be made chemically clean by use of the hot chromic acid cleaning solution commonly used for cleaning glass. Chromium trioxide is preferred to potassium dichromate. After the chromic acid wash, the parts must be thoroughly rinsed, preferably with hot distilled water. Three dip washes will suffice if running distilled water is not present. (Reference 6).

3. Welding - Niobium may be welded to itself, and to certain other metals by resistance welding and to itself by heliarc welding. Acetylene torch welding is destructive to the metal. Resistance welding can be done with conventional equipment, except that seam welding is done under water to prevent oxidation of the metal. Properly made welds are ductile and have substantially the same strength as the metal itself. (Reference 6).

A program is underway now at the X-10 Metallurgy Department to improve existing welding techniques and develop new techniques that will produce welds that will withstand various reactor conditions.

4. Machining - In lathe operations, high speed steel tools, with high cutting speeds, have been found most satisfactory. A minimum speed of 100 surface feet per minute will be found correct for most turning operations. Carbon tetrachloride is recommended as a cutting medium, and the work must be flooded at all times. It is better to use sharp tools and light feeds and finish the work in one cut rather than to take the usual roughing and finishing cut. (Reference 6).

Grinding is difficult and should be avoided.

Niobium wire, especially when annealed, is very malleable and ductile, and easily worked cold. It can be bent to 180 degrees or more with practically no radius, and can be coiled around a mandrel of its own diameter. (Reference 6).

REFERENCES

1. Wehrmann, Ralph, "Some Properties of Columbium", Technical Data Bulletin, Fansteel Metallurgical Corporation (March 1957).
2. ORNL Report No. CF-51-8-256 (1951).
3. Page, J. P., "The Annealing Behavior of Cold-Rolled Niobium", ORNL Report No. 2371 (September 19, 1957).
4. Saller, E. A., Stacy, J.T., Porembka, S. W., "Initial Investigation of Niobium and Niobium-Base Alloys", Battelle Memorial Institute (1955).
5. Metals Handbook, American Society of Metals, p. 1137 (1948).
6. Yntema, L. F., Percy, A. L., "Tantalum and Columbium", Rare Metals Handbook, Edited by Hampel, C. A., Reinhold Publishing Corp., pp. 389-404 (1954).
7. Hagel, W. C., "Literature Survey on Columbium", ORNL Report 51-8-256 (1951).

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FIGURE 2
Specific Heat Of Columbium.

FIGURE 4 (Y-23161). Room-temperature tensile strength and elongation (2-in. gage length) of arc-cast niobium deformed by rolling and annealed 1 hr at indicated temperature.

FIGURE 5 (Y-23163). Room-temperature tensile strength and elongation (2-in. gage length) of powder-metallurgy niobium deformed by rolling and annealed 1 hr at indicated temperature.

FIGURE 6 (Y-23167). 0.2% Offset yield strength at room temperature: powder-metallurgy niobium deformed by rolling and annealed 1 hr at indicated temperature.

FIGURE 7 (Y-23166). 0.2% Offset yield strength at room temperature: arc-cast niobium deformed by rolling and annealed 1 hr at indicated temperature.

FIGURE 8 (Y-23162). Work-hardening of cold-rolled arc-cast and powder-metallurgy niobium.

CREEP RUPTURE TESTS OF COLD ROLLED NIOBIUM SHEET AT 1800°F IN VACUUM

STRESS (psi)	RUPTURE TIME (hrs)	ELONGATION IN 1 1/2 in. (%)	TIME FOR 1% DEFORMATION (hr)	TIME FOR 2% DEFORMATION (hr)	MINIMUM CREEP RATE (%/hr)
25,000	1.9	15.6	0.2	0.4	4.5
20,000	31.6	19.7	0.5	3.5	0.39
17,500	53.0	24.4	1.0	4.0	0.32
16,500	110.8	17.7	7.0	20.0	0.077
15,500	277.9	16.9	36.0	85.0	0.021

(Reference 4)

Figure 9

FIGURE 10
Average Coefficient Of Linear Expansion For Columbium.

EFFECT OF OXYGEN AND NITROGEN ON COLUMBIUM HARDNESS AND MELTING POINT

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