Vanadium

INTRODUCTION

Vanadium is widely dispersed in the earth's crust occurring in many types of deposits. Most vanadium is currently obtained as a by-product or co-product from titanomagnetites, petroleum, uranium ores, and phosphate rock. Table 1 shows the abundance of vanadium in the earth's crust relative to some familiar elements.

Commercial production of vanadium was begun in the 1960s when it was required for evaluation as a structural material for breeder reactors. Wah Chang and several other companies produced small quantities for this purpose. In 1979, Wah Chang again began to produce vanadium in 400-700 lb. ingots. Recent demand has justified scale-up to produce 16" diameter ingots weighing up to 4500 lbs. This increased demand for vanadium has been due, in part, to its many attractive properties. These unique properties include:

- relatively low density (6.1 gms/cc)
- low neutron capture cross section
- relatively high strength at elevated temperature
- good fabricability
- low rate of neutron embrittlement
- relative abundance
- corrosion resistance
- superconductivity
- low-temperature ductility

TABLE 1 - RELATIVE ABUNDANCE OF VANADIUM IN THE EARTH'S CRUST*

	Al	**Fe**	**Mg**	**Ti**	**Mn**	**Zr**	**Cr**
ppm	81,300	50,000	20,800	4,400	1,000	220	200
	V	**Zn**	**Ni**	**Cu**	**W**	**Nb**	**Mo**
ppm	150	130	80	70	69	24	15

*From CF'C Handbook, 61st Edition, Weast.

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For many years, the major application for vanadium has been as a micro-alloying element for steel products. Added in amounts between 0.01% to 0.1%, vanadium lowers the ductile to brittle transition temperature of steel and increases toughness. Vanadium is currently being used in the production of high-strength low-alloy (HSLA) steels for applications in the automobile industry and the Alaskan pipeline where high strength to weight ratios are important.

However, the most promising new applications for vanadium are in alloy development. The ternary alloys V-Cr-Ti are being considered for the first wall and blanket in fusion reactors because of their low cross section to neutrons and because the isotopes formed upon neutron capture all have short half-lives. These V-Cr-Ti alloys also resist swelling and maintain ductility under a high neutron flux. V-Nb alloys are less dense than other refractory alloys and ductile even with strengths up to 160 ksi. V_3Ga is a superconducting compound with excellent properties in high magnetic fields (18-20 tesla) that has been successfully tested by the U.S. Navy.

Wah Chang has decades of experience in the production of reactive and refractory metals. In addition to being one of the world's largest producers of vanadium, Wah Chang manufactures zirconium, niobium, titanium, and hafnium.

One of Wah Chang's major strengths in vanadium production is our ability to meet your product requirements-whether large or small. If you have a special application and think vanadium might present a viable solution, let our technical engineers put their expertise to work for you.

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SUPERCONDUCTING WIRE

The extremely high ductility of vanadium and niobium makes them useful in superconducting wire manufactured through the Modified Jelly-Roll (MJR) process. The MJR and Tin Core MJR processes, both developed at Wah Chang, allow a billet which contains all the components of superconductors to be extruded and cold-drawn to final wire size without annealing. The billet to wire reductions without annealing have routinely exceeded 100,000 to 1 and recently a wire was made which had been reduced by 1,000,000 to 1. Pure vanadium has also been used as a diffusion-barrier to tin in Nb_3Sn wires. The vanadium surrounds the zones containing niobium filaments and tin or tin-bronze and prevents the tin from diffusing into the copper cladding. These superconducting wires are being used in a variety of applications including superconducting magnets for medical diagnostic devices and for fusion reactor research.

FUSION REACTOR TECHNOLOGY

The ternary alloys of V-Cr-Ti and V-Ti-Si are being evaluated for use in fusion reactors for the first wall and blanket structure. Pure vanadium must be used to produce these alloys and may be important in producing other vanadium-containing alloys with improved properties. The following properties make vanadium a leading candidate for this application:

- low long-term activation
- high operating temperature
- high surface heat load capability
- good liquid metal compatibility
- good radiation damage resistance

Low long-term activation is a property of vanadium, chromium, titanium and silicon. Under a high flux of neutrons, radioisotopes of vanadium, chromium and titanium are formed in the alloy. These radioisotopes have short half-lives which result in rapid radioactive decay. This short decay-time allows for safer disposal than is possible with alloys containing many other elements. In the next few decades, years, it is predicted that fusion energy may replace fission energy. Two important advantages of the fusion process are that its fuel supply is almost inexhaustible and that it generates almost no radioactive waste if low-activation alloys, such as V-Cr-Ti, are used in the first wall and blanket.

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ALLOYS

Vanadium has been available for years for alloying as FeV or VA master-alloys. Wah Chang's pure vanadium allows production of alloys which do not contain Fe or Al. The production of whole new families of alloys with different properties is now possible on a large scale.

Pure vanadium and vanadium alloyed with chromium and titanium are very resistant to corrosion from liquid lithium or lithium-lead. This property makes vanadium a prime candidate for liquid metal heat exchangers. At room temperature, vanadium and its alloys have excellent resistance to corrosion in salt-water and dilute hydrochloric acid. Vanadium also exhibits good corrosion resistance in sodium hydroxide solutions and resists attack by liquid alkali metals. V-Cr-Ti alloys have corrosion resistance to high temperature water (240°C) equal to the best stainless steels, and superior to stainless steels in stress corrosion cracking.

Vanadium and vanadium alloys are much lighter than most refractory metals. This property makes vanadium a logical choice for applications where strength to weight ratios are important such as in the aerospace and aircraft industries. Of all the refractory alloys, vanadium alloys have the highest strength to weight ratios.

One of our specialties at Wah Chang is the ability to develop alloys to meet your specifications. If you have an unusual alloy requirement, call us and we will be happy to help you in the developmental process.

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ALUMINOTHERMIC REDUCTION

Wah Chang produces vanadium through aluminothermic reduction of high purity vanadium pentoxide as follows:

$1OAl+3V_2 0_5$ -------> $6V+5Al_2 0_3$

Excess aluminum is added to lower the oxygen content of the reduced metal and to increase the yield of vanadium The excess aluminum also assists in the removal of oxygen during the subsequent electron beam melting.

ELECTRON BEAM MELTING

Electron beam melting is an accepted method for purifying refractory metals such as tantalum, niobium, and vanadium. The high melting points and comparatively low vapor pressures allow purification by vaporization of impurities with higher vapor pressures. Vanadium does not purify as readily as tantalum or niobium because of its lower melting point and higher vapor pressure; however, purities of up to 99.9% can be achieved by melting the ingot several times.

TYPICAL CHEMISTRY

Typical chemistry for current production commercial vanadium is given in **Table 2.**

TABLE 2 - TYPICAL CHEMISTRY FOR COMMERCIAL VANADIUM

	0	**N**	**H**	**C**	**P**	**S**	**Si**
ppm	350	180	<5	60	<30	<20	400
	Fe	**Al**	**Cr**	**Mo**	**Nb**	**Ni**	
ppm	<400	300	<20	80	60	<20	

Figures calculated by weight • Hardness BHN Average 60 (500Kg load)

MILL PRODUCTS

Vanadium, a soft and very ductile metal, is available in plate, sheet, foil, billet, bar, rod and wire. Tubing is available by special order.

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PHYSICAL PROPERTIES

Atomic Number	23
Atomic Weight	50.942
Density (g/cc at 200°C) (lbs./in^3)	6.1 0.221
Crystal Structure	body centered cubic
Laftice Parameters, Calcium reduced (Iodide)	3.0278 3.0258
Recrystallization Temperature ° C	800° to 1010°C
Melting Point	1900°C
Boiling Point	3400°C
Coefficient of Linear Thermal Expansion per °C, 23° to 100°C	 8.3 x 10^{-6}
Thermal Conductivity (cal/°C/cm^2/cm/sec) (100°C)	0.074
Electrical Resistivity (microhm-cm at 20°C)	24.8 to 26.0
Specific Heat (cal/g/°C 32° to 100°C)	0.119
Superconductivity (Tc)	-268.7°C H. R. E.
Magnetic Susceptibility (Paramagnetic)	+1.4 x 10^6
Electronic Work Function	3.79 e. V.

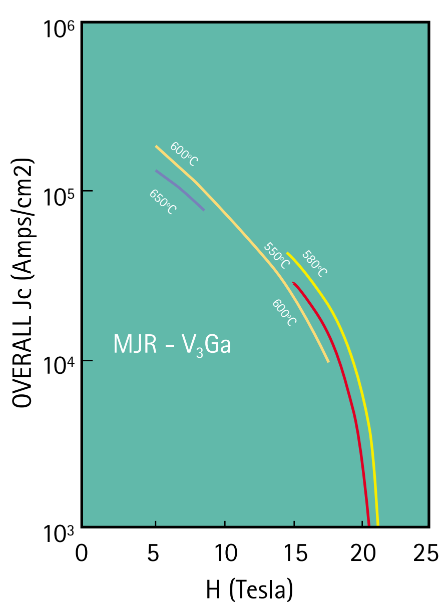

Figure 1: Critical current density (non-copper) vs magnetic field for V_3Ga wire at various reaction temperatures.

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MECHANICAL PROPERTIES (TYPICAL)

Modulus of Elasticity in Ten, psi	20×10^6
Tensile Strength, annealed sheet, (psi)	29-35,000
Yield Strength, annealed sheet, 0.2% offset (psi)	18-25,000
Elongation, annealed sheet, % in 2 inches	35-60
Young's Modulus, annealed sheet, (psi)	18 to 20×10^6
Hardness, Brinell, electron beam ingot	60
Poisson's Ratio	0.36

NUCLEAR PROPERTIES

Thermal Neutron Absorption Cross Section, Barns 4.7 ± .02

REACTOR APPLICATION

Vanadium has a low fusion-neutron cross section, and its inelastic-scattering cross section is also quite small. These favorable nuclear properties, coupled with vanadium's high melting point, ductility, and good physical properties, make the metal of particular interest as a structural material for fast reactors. Favorable alloying characteristics with uranium also make the metal of interest as a diluent, although the transport cross section is small. The thermal neutron cross section of vanadium is large, however, and its usefulness in thermal reactors is limited.

CORROSION RESISTANCE

At room temperature, vanadium and its alloys have excellent resistance to corrosion in salt water and dilute hydrochloric acid; good corrosion resistance in sodium hydroxide solutions; poor corrosion resistance in nitric acid solutions. Resistance to attack by liquid-lithium metal is excellent. With liquid-sodium metal resistance is excellent, if oxygen is rigorously excluded.

CORROSION LABORATORY SERVICES

Wah Chang's Corrosion Laboratory offers the following services:

- Materials selection and evaluation of customers' test results and specimen.
- Corrosion testing according to the methods established by ASTM, NACE, EPA, as well as other groups and agencies.
- Corrosion testing according to the methods established by Wah Chang customers.
- Material failure analysis.

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TABLE 3 - TYPICAL PROPERTIES OF PURE VANADIUM PRODUCED AT WAH CHANG (ASTM-E8)

Sample	Reduction In Area	Elongation	Tensile Strength	Yield Strength
0.125" wire	96	42	31,700	18,400
0.250" wire	95	60	31,300	25,700
0.010" foil 92% cold work No anneal	Longitudinal	2	69,500	63,900
		2	69,900	64,100
	Transverse	2	80,300	70,600
		2	79,900	70,200

MACHINING

High speed steel and carbide tools may be used to machine vanadium. Speed as well as tool angles and lubrication should be monitored to avoid galling.

TURNING

See general instructions for turning vanadium given in **Table 4**. These instructions are recommended as a starting point for working with vanadium. Adjustments to these procedures should be made to accommodate the different compositions of each vanadium alloy.

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TABLE 4 - TOOLING RECOMMENDATIONS FOR MACHINING VANADIUM

Approach Angle	15° to 20°
Side Rake	30° to 35°
Side and End Clearance	5°
Plan Relief Angle	15° to 20°
Nose Radius	0.020" to 0.030"
Cutting Speed	60 to 80 ft./min. with HSS 250 to 300 ft./min. with carbide
Feed, Roughing	0.008" to 0.012"/revolution
Feed, Finishing	0.005" maximum/revolution
Depth of Cut	0.030"to 0.125"

FORMING

Vanadium has excellent cold working properties and can be forged, rolled or swaged at room temperature. Annealing is necessary after 80 to 85% reduction of the cross sectional area. Typically vacuum annealing ($<1 \times 10^{-4}$ TORR) is done at 900°C for 1-2 hours to recrystallize cold worked material. Vanadium is well suited to deep drawing and exhibits little springback.

Vanadium cannot be readily anodized like other reactive and refractory metals. The principle oxide of vanadium is V_20_5 which melts at 675°C and is corrosive. Vanadium and its alloys must be fabricated below the melting point of the oxide or must be protected from an oxidizing atmosphere if higher temperatures are used.

WELDING

Vanadium is very reactive with the gases nitrogen, oxygen and hydrogen, therefore, precautions must be taken to protect any weld from these gases. TIG and plasma welding work well when precautions are taken to flood all surfaces of the weld (front and back) with inert gas (argon, helium).

Vanadium can be welded to most of the transition metals and their alloys. Welding with titanium, zirconium, niobium, tantalum, and chromium as well as austenitic and ferritic stainless steels has been successful. Welding to other steels is possible if chromium is introduced into the weld at the time of welding.

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VANADIUM SPECIFICATION

1. General

1.1 Scope. This specification defines the minimum requirements for high purity vanadium, electron beam melted.

2. Requirements

2.1 Material shall be electron beam melted vanadium.

2.2 Chemical Composition. Chemical composition by weight percent shall conform to the following limits:

Element	Guarantee (W/O)
Vanadium	99.6 minimum (by difference)
Hydrogen	0.005 maximum
Carbon	0.02 maximum
Nitrogen	0.02 maximum
Oxygen	.06 maximum
Aluminum	0.05 maximum
Silicon	0.20 maximum
Iron + Nickel + Chromium + Niobium + Molybdenum + Tantalum + Titanium + Zirconium + Hafnium	0.4 Total Maximum 0.05 Individual Maximum

3. Fabrication

3.1 To customer requirements.

4. Product Forms

4.1 Vanadium is available in all mill product forms including plate, sheet, foil, billet, bar, rod and wire. Tubular products are quoted upon request.

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HEALTH AND SAFETY

Metallic vanadium is considered nontoxic, however, vanadium compounds are toxic. Finely-divided vanadium is reactive enough to convert slowly to toxic forms. Any potential hazards of working with vanadium can be avoided by following proper safety procedures as outlined in the Material Safety Data Sheets listed below.

MATERIAL SAFETY DATA SHEETS

A Material Safety Data Sheet (MSDS) is available for each vanadium product produced by Wan Chang Albany. The list below gives the MSDS reference number by product line.

Product	**Reference Number**
Vanadium Metal	901
Vanadium Metal Powder Fines & Dust	903

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