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VANADIUM-BASE ALLOY

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4 Claims

ABSTRACT OF THE DISCLOSURE

A vanadium-base alloy containing molybdenum, titanium, yttrium and carbon exhibits high strength as well as good fabricability. Strength is further improved by addition of silicon. The alloy finds use as a structural material in instruments, piping, containers, etc.

Vanadium is not widely used as a structural material even in special applications because of its relatively low strength at ambient temperatures, and much lower strength at elevated temperatures. This lack of mechanical strength has prevented the advantageous use of the attractive properties of vanadium, such as its excellent corrosion resistance to many liquids and gases, excellent fabricability, moderately low density and low neutron capture cross section. If the strength properties could be improved without severely degrading the attractive properties of vanadium its uses could be considerably enlarged. Thus, a resource material that has been largely wasted could be made to serve a useful purpose.

It has now been found, according to the present invention, that the above deficiencies of vanadium may be overcome by providing a vanadium-base alloy containing molybdenum, titanium, yttrium and carbon. Proportions of the essential elements are preferably approximately as follows: vanadium, 60 to 80 percent; molybdenum, 15 to 25 percent; titanium, 5 to 15 percent; yttrium, 0.1 to 1.0 percent and carbon 0.05 to 0.2 percent. In addition, about 0.2 to 0.75 percent of silicon has been found to further improve the strength of the alloy.

The specific purpose of the molybdenum in the alloy of the invention is to strengthen the vanadium by solid solution hardening. The titanium serves a similar purpose and, in addition, combines with the carbon to form a carbide which, by appropriate heat treatment and mechanical working, forms very small insoluble particles to provide further strengthening of the vanadium. One specific purpose of the yttrium is to act as a deoxidizer during the melting process to increase the malleability of the alloy by removal of the deleterious element, oxygen. After melting, a major portion of the yttrium is present as a black oxide scale on the ingot which is mechanically removed prior to further working.

Preparation of the alloy of the invention is accomplished by conventional procedures and various alternative procedures will be apparent to those of ordinary skill in the art. Typically, vanadium crystals, molybdenum crystals, titanium crystals, crushed powders of a vanadium-carbon master alloy, and chunks or powders of pure yttrium are thoroughly dry mixed. When silicon is added, it is also dry mixed using commercially pure silicon powders. The vanadium comprises from 60 to 80% by weight of the mix, the molybdenum from 15 to 25%, the titanium from 5 to 15%, the yttrium from 0.1 to 1.0 percent and the carbon from 0.05 to 0.2 percent. The state of division of

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the crystals and powders is not critical and any convenient method of incorporating the constituents may be used. As a specific example, a mix may contain 53.4 grams of vanadium crystals, 16 grams of molybdenum crystals, 8 grams of titanium crystals, 0.08 gram of carbon added as a vanadium-carbon master alloy containing 3.3% by weight of carbon, and 0.2 gram of yttrium to produce a mix of the proportions 20% Mo, 10% Ti, 0.1% C, 0.25% Y and the balance vanadium.

The mix is then pressed in a die into a compact for ease in handling and the compact is melted into an ingot under an inert atmosphere. The melting conditions are subject to considerable variation and any suitable technique that provides an inert atmosphere can be used provided the material becomes fully melted to produce a homogeneous ingot. The ingot is then enclosed or encapsulated in a suitable material to prevent atmospheric contamination and is hot-worked to a size such that the cross-sectional area of the enclosed alloy is about twice that desired in the final product. At this stage the rod or sheet is solution-heat treated and rapidly cooled to room temperature for the purpose of relieving internal strains generated during the hot working, and to dissolve the small particles of hardening elements in the matrix alloy and maintain them in solution. The encapsulating material is then removed by any convenient technique and the alloy is further warm-worked to the final desired size in air. The purpose of this latter fabricating step is to cause the hardening elements or compounds to precipitate out of solution as extremely fine sized particles while the metal is being deformed, thus increasing the strength further.

The following examples will serve to more particularly illustrate the invention and its advantages.

EXAMPLES 1-8

In these examples a pressed compact, prepared according to the above procedure and weighing 80 grams, was melted into an ingot under a helium atmosphere on a water cooled copper hearth by a tungsten electrode arc. The slag which appeared on the surface of the ingot was mechanically removed and the ingot, measuring about 0.4 inch in diameter by 3½ inches in length was encapsulated in a completely closed stainless steel sheath by welding under an inert atmosphere such as helium. The sheathed ingot, measuring about ¾ inch in diameter by 6 inches in length, was heated in a furnace to about 1,200° C. for about ½ hour and was reduced in cross section by swaging hot to successively small sizes, the size after each swaging pass being 0.650 inch, 0.550 inch, 0.475 inch, and 0.400 inch with a 10-minute reheat at 1,200° C. being made between each swaging pass. The 0.400-inch rods thus produced were then reheated for 10 minutes at 1,200° C. and rolled in a rolling mill to sheet about 0.185 inch thick in 3 passes of about 0.075 inch reduction each with no further reheat. The sheet was then solution heat treated for about 15 minutes at about 1,200° C. and quenched in water to room temperature, after which the steel sheath was removed by machining or other means.

The bare vanadium alloy sheet, about 0.135 inch thick, was heated in air to about 500° C. and rolled to the final desired thickness of 0.040 to 0.060 inch with reductions of about 0.025 inch per pass, reheating to 500° C. for each pass.

Vanadium alloy sheet produced in the above manner, and unalloyed vanadium sheet, were tested at various temperatures in vacuum. Results are shown in Table I.

TABLE I

	Test temp., °C.	0.2 percent yield strength, p.s.i.	Tensile strength, p.s.i.	Percent elongation
Vanadium alloy.....	25	110,000-147,000	140,000-163,000	3-7
Vanadium unalloyed.....	25	92,000	110,000	5
Vanadium alloy.....	600	88,000-111,000	121,000-123,000	2-8
Vanadium unalloyed.....	600	50,000	55,000	16
Vanadium alloy.....	800	50,000-60,000	64,000-73,000	30-40
Vanadium unalloyed.....	800	26,000	30,000	22
Vanadium alloy.....	1,000	35,000	43,000	30
Vanadium unalloyed.....	1,000	3,100	5,300	90

It will be seen that at a temperature of 1,000° C. the alloy of this invention has a yield strength 11 times that

above described, at various temperatures, the silicon-containing alloy had the following properties:

TABLE III

	Temp., °C.	0.2 percent yield stress	Tensile strength, p.s.i.	Percent elongation
Vanadium alloy.....	25	110,000-147,000	140,000-163,000	3-7
Vanadium alloy plus 0.50% Si....	25	130,000-170,000	160,000-183,000	1-9
Vanadium alloy.....	600	88,000-111,000	121,000-123,000	2-8
Vanadium alloy plus 0.50% Si....	600	123,000-139,000	148,000-159,000	2-7
Vanadium alloy.....	800	50,000-60,000	64,000-73,000	30-40
Vanadium alloy plus 0.50% Si....	800	65,000-85,000	85,000-97,000	20-60

of unalloyed vanadium and has a tensile strength 8 times that of unalloyed vanadium.

Because of the improved yield and tensile strength characteristics, the present alloy has application for structural or other similar members which are to be operated at elevated temperatures and in inert atmosphere. The improved yield and tensile strength is achieved without impairing the excellent corrosion resistance of pure vanadium. The alloy, produced in the manner above described, was tested for corrosion resistance in the severely corrosive environment of a 3 N HNO₃ acid solution maintained at 23° to 50° C. for 24 hours with the following results:

TABLE II

	Density, g./cc.	Loss in weight, g./cm. ² /day	Penetration, mils per year
Vanadium alloy.....	6.25	0.063	1,445
Vanadium.....	6.10	.081	1,902

Under these conditions, the alloy has a corrosion rate only 76% that of pure vanadium which by itself is resistant to corrosion at room temperature. Thus, the alloy also is suitable for applications that require high strengths in corrosive environments at ambient temperature.

EXAMPLES 9-14

In these examples, silicon, in a quantity sufficient to produce 0.50% Si by weight, is added to the mix of metal powder constituents and the mix is then compacted, melted, and fabricated as above described. When tested as

The improved strength of the silicon-containing alloy is achieved with only slight changes in corrosion resistance and ductility. When tested for corrosion resistance under rigorous conditions in a 3 N HNO₃ acid solution as described above, the silicon-containing alloy had a corrosion rate of 1,943 mils per year (mpy) penetration compared with 1,902 m.p.y. for pure vanadium and 1,445 m.p.y. for the non-silicon-containing alloy. This high strength silicon alloy still retained the excellent corrosion resistance of unalloyed vanadium.

It should be understood that the foregoing swaging-rolling-annealing-rolling procedures are given in detail only by way of specific example and may be varied considerably to achieve substantially the same end result. For example, initial fabrication can be by extrusion or forging, as well as swaging. Additional intermediate anneals may be incorporated as desired prior to the final solution heat treatment and quench at about twice the final desired size.

What is claimed is:

1. A vanadium-base alloy consisting essentially of, by weight, about 60 to 80 percent vanadium, 15 to 25 percent molybdenum, 5 to 15 percent titanium, 0.1 to 1.0 percent yttrium and 0.05 to 0.2 percent carbon.

2. The alloy of claim 1 containing about 67 percent vanadium, about 20 percent molybdenum, about 10 percent titanium, about 0.25 percent yttrium and about 0.12 percent carbon.

3. The alloy of claim 1 additionally containing about 0.2 to 0.75 percent silicon.

4. The alloy of claim 3 containing about 0.50 percent silicon.

References Cited

W. Rostoker: "The Metallurgy of Vanadium," chapter 5, New York: Wiley, 1958.

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