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JACKETED REACTOR FUEL ELEMENT

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This invention deals with new ternary alloys and in particular with vanadium-base alloys and fuel elements jacketed with these alloys.

Uranium fuel elements for sodium-cooled fast neutronic reactors, such as they are described, for instance, in copending application, Serial No. 437,017, filed by Walter H. Zinn on June 15, 1954, now Patent No. 2,841,545, granted July 1, 1958, grow under the effect of radiation which causes jamming of the fuel elements; operation of such reactors is therefore hazardous. It has been tried to enclose the fuel elements of uranium metal, which is to include elemental uranium and uranium-containing alloys, with a jacket or can that has a high strength so that the fuel elements are restrained from expanding.

Zirconium and stainless steel have been used for this purpose, and some improvement was obtained with the jackets made of these metals. However, there are certain disadvantages in connection with the jackets used heretofore. For instance, the iron of the stainless steel forms a low-melting (about 725° C.) eutectic with the uranium metal of the core which means destruction of the fuel element. Zirconium and the zirconium alloys, primarily the zirconium alloy containing from 1 to 2.5 percent tin and up to 0.2 percent of iron, chromium, and nickel, do not show this drawback, but they are not strong enough at elevated temperatures to prevent the fuel element from growing. Other metals tested did not show a sufficiently good heat conductivity which is a vital factor for satisfactory operativeness of the reactor. Of the two metals used heretofore stainless steel was the preferred material for uranium fuel element jackets.

It is an object of this invention to provide an alloy suitable for jacketing uranium fuel elements which does not have the disadvantages set forth above.

It is also an object of this invention to provide an alloy for jacketing uranium fuel elements which is superior to stainless steel.

It is an object of this invention to provide an alloy for jacketing uranium fuel elements which does not form a comparatively low-melting eutectic with uranium.

It is another object of this invention to provide an alloy for jacketing uranium fuel elements which has a sufficiently high mechanical strength and good creep resistance at elevated temperatures so that the uranium core is retrained from growing.

It is still another object of this invention to provide an alloy for jacketing uranium fuel elements which has a good thermal conductivity.

It is furthermore an object of this invention to provide an alloy for jacketing uranium fuel elements which has a low neutron-capture cross section.

It is another object of this invention to provide an alloy for jacketing uranium fuel elements which has good corrosion resistance to practically oxygen-free sodium.

Finally, it is also an object of this invention to provide an alloy for jacketing uranium fuel elements that can be fabricated and welded.

It was found that ternary vanadium alloys containing from 2.5 to 15 percent by weight of titanium and from 0.5 to 10 percent by weight of niobium have the characteristics required and set forth above. The alloys containing about 10 percent of titanium and from 1 to 3 percent of niobium were the preferred compositions, and the alloy containing 10 percent of titanium and 3 percent of niobium yielded the most satisfactory results.

Vanadium forms a eutectic with uranium which melts at 1040° C. When immersed in sodium that contains some oxygen (the sodium in fast reactors usually has a negligibly low oxygen content, though) vanadium forms lower comparatively stable oxides, such as VO and V_2O_3, which form a barrier film on the surface and protect the vanadium or alloy against further corrosion at elevated temperatures.

Nonalloyed vanadium metal was first examined for the prime purpose of this invention, but it was found not to be superior, as to mechanical strength, to stainless steel 347 (17 to 19 percent of chromium, 9 to 12 percent of nickel, up to 0.08 percent of carbon and niobium in a quantity tenfold of that of carbon), the steel heretofore preferred for jacketing uranium fuel elements for fast neutronic reactors.

The alloys of this invention can be prepared by any method known to those skilled in the art. The inventors preferred melting in an arc furnace. The ingots obtained were heated to about 1350° C. and press- and hammer-forged to ½-inch- and/or ¾-inch-diameter bars. The bars were then ground to size on a belt centerless grinder that had a belt 4 inches x 54 inches and a grit size of 36; the grinding material was aluminum oxide.

All bars were tested as to tensile strength at room temperature and at 650° C. at a crosshead speed of 0.05"/min. after they had been annealed at 650° C. for two days and water-quenched. Similar experiments were carried out at 800° C., the annealing conditions in that instance having been 800° C. for 24 hours followed by water-quenching. The results of these tests together with the values obtained for yield strength, elongation and reduction of area are combined in the table below, and the corresponding data for stainless steel and zirconium are added for the sake of comparison. (Whenever heating of the alloys was carried out, it was done in an inert atmosphere of helium or argon gas.)

Alloy	Tensile Strength, p. s. i.	Yield Strength, p. s. i.	Elongation, Percent	Reduction of Area, Percent
25° C.				
V—10 Ti—1 Nb	84,600	63,200	11	20
V—10 Ti—3 Nb	97,600	64,500	22	38
650° C.				
V—10 Ti—1 Nb	80,400	58,000	15	41
V—10 Ti—3 Nb	86,000	64,000	21	48
Stainless Steel 347	51,200	41,000	46	71
Zirconium	15,200	5,000	30	60
Zr-alloy 1.4% Sn, 0.2 Fe, Cr, Ni	[1] 22,000	[1] 10,500	[1] 36	[2]
800° C.				
V—10 Ti—1 Nb	55,200	41,600	13	33
Stainless Steel 347	23,000			

[1] At 480° C.
[2] Not determined.

It is obvious from this table that tensile and yield strengths of the vanadium-titanium-niobium alloys are much superior to those of stainless steel and zirconium

metals at elevated temperature and that the ductility of these new alloys is lower, as is obvious from the data for elongation and reduction of area; however, the ductility is still sufficient to make the alloys suitable and workable for the purpose of this invention.

The vanadium-10 percent Ti-1 percent Nb ternary alloy was also examined as to stress rupture strength by applying different loads and determining the number of hours that were required to cause rupture. From a load-time curve obtained from the results of these rupture tests the strength bringing about exactly a 100-hour life was determined. It was found that at 650° C. the alloy withstood a load of 62,000 lbs./sq. in. for 100 hours which compares with a strength of 27,000 p. s. i. for stainless steel 347 at the same temperature. At 800° C. the stress rupture strength, for 100 hours, was 22,000 p. s. i., which compares with a stress rupture strength of 9000 p. s. i. for 100 hours with stainless steel 347 at 816° C.

The alloys were furthermore tested for corrosion resistance in sodium that had a low oxygen content, such as it is present in the sodium coolant of fast neutronic reactors. (The oxygen content in fast reactors has to be low to minimize "transport corrosion" or in other words to prevent oxidation and pickup of the oxide formed from hot surfaces and deposition on cold surfaces.) The oxygen corresponded to a content of less than 0.001 percent by weight of Na_2O. For the corrosion test, the alloys were immersed in the sodium at 700° C. for twelve days, and the weight gain, which is an indication of the degree of corrosion, was determined in each case. For the 10 percent titanium-1 percent niobium and the 10 percent titanium-3 percent niobium vanadium-base alloys the weights increased by 0.17 and 0.19 percent, respectively.

Both alloys, that containing 1 percent and that containing 3 percent of niobium, in addition to 10 percent of titanium, were found to be superior to zirconium as to heat conductivity and at least as good as stainless steel 347. The alloys were welded in an inert atmosphere, e. g. of helium, using a tungsten electrode and an additional supply of shielding gas to prevent contamination. The preferred conditions were a welding rate of 14"/min., an electric current of 65 amps. at 20 volts, and a total gas flow of 35 $ft.^3/hr.$; however, other conditions are also suitable.

The 10 percent Ti-1 percent Nb ternary vanadium-base alloy was cold-rolled (at room temperature, about 25° C.) satisfactorily to 95 percent of reduction in thickness whereby a 2.5-mil thick sheet was obtained.

While the invention has been described primarily in connection with jackets for fuel elements, it is understood that the alloys can be used for any purpose where one or several of the properties of the alloys of this invention are of importance, for instance, they can be used as construction material of aircraft engines.

It is also understood that the invention is susceptible to various modifications and changes, and that it is to be limited only by the scope of the appended claims.

What is claimed is:

1. A fuel element for fast neutronic reactors, comprising a core of uranium metal-containing material and a jacket around said core, said jacket consisting of from 2.5 to 15 percent by weight of titanium, from 1 to 5 percent of niobium and from 80 to 96.5 percent of vanadium.

2. The fuel element of claim 1 in which the titanium content is 10 percent and the niobium content is 1 percent.

3. The fuel element of claim 1 in which the titanium content is 10 percent and the niobium content is 3 percent.

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