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A. W. COCHARDT

2,829,048

HIGH DAMPING ALLOY AND MEMBERS PREPARED THEREFROM

Filed Jan. 16, 1956

2 Sheets-Sheet 1

Fig. 1.

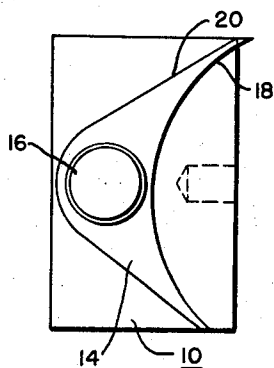


Fig. 2.

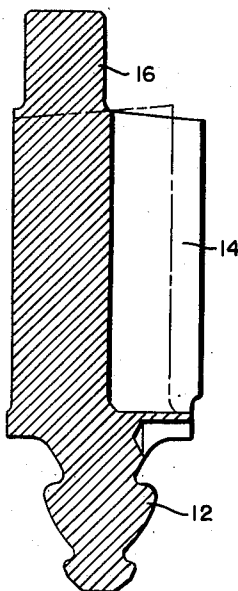
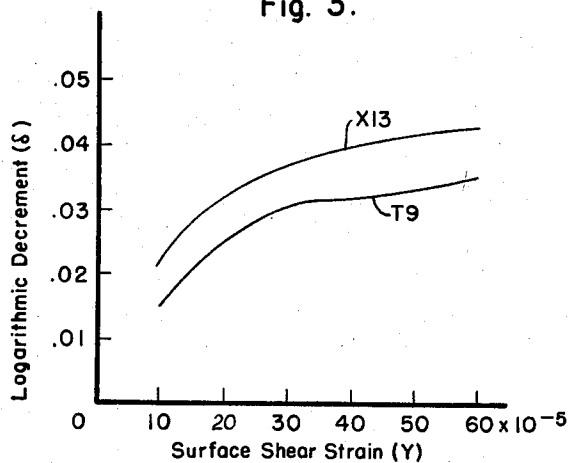


Fig. 3.



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2 Sheets-Sheet 2

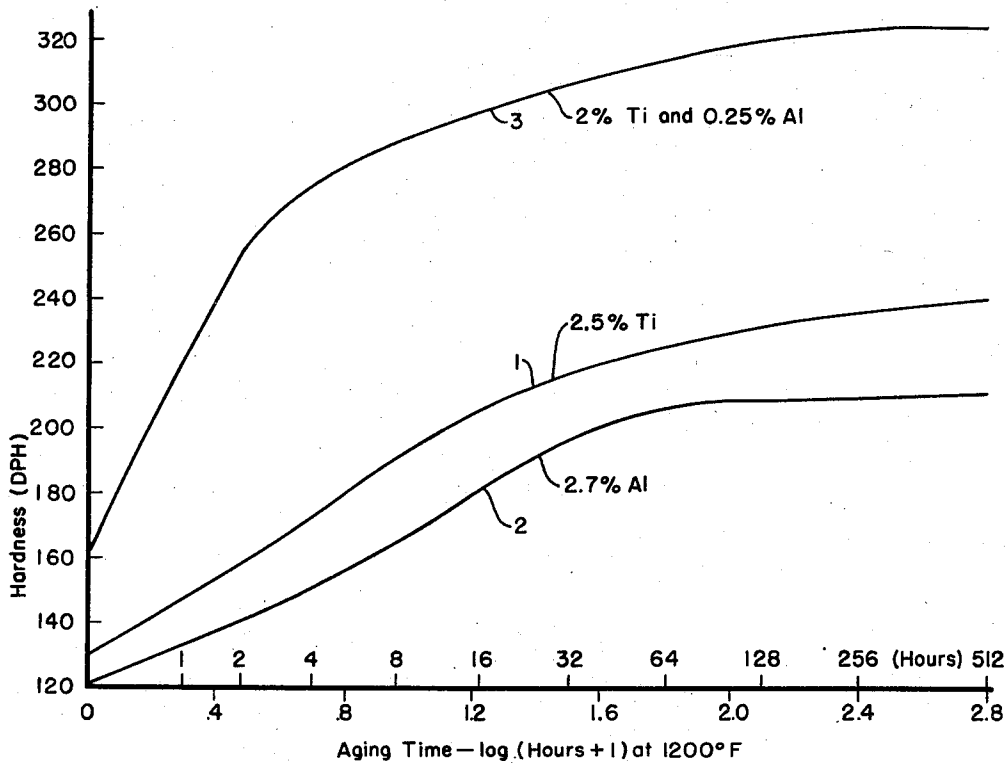


Fig. 4.

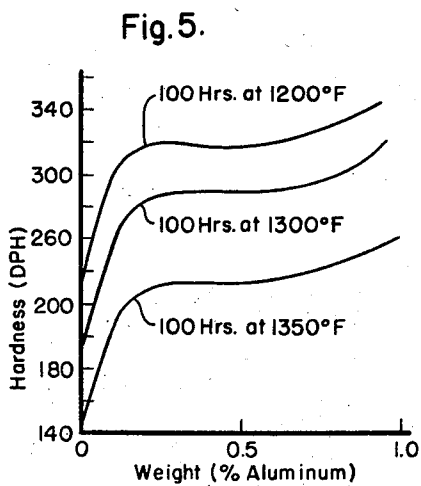


Fig. 5.

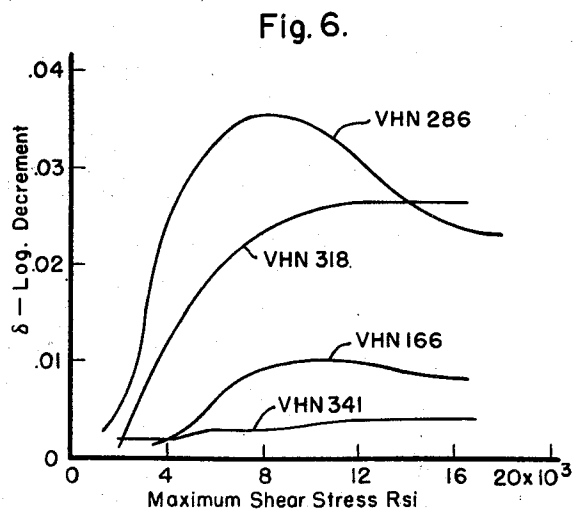


Fig. 6.

1

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HIGH DAMPING ALLOY AND MEMBERS PREPARED THEREFROM

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8 Claims. (Cl. 75—171)

This invention relates to a high damping alloy particularly suitable for use at temperatures of the order of 1200° F., and members such as turbine blades prepared therefrom.

At the present time, one of the great difficulties in building turbines that will operate satisfactorily with steam temperatures of from 1000° F. to 1200° F. has been the unavailability of any alloy that has both high damping properties and high strength at such steam temperatures. These problems are even more severe when operations at 1300° F. are considered. In particular, the first rows of blades upon which the high temperature steam impinges are subjected to extreme vibration which may cause premature fatigue failure of the blades.

One of the best available alloys for steam turbine blading presently employed is a 12% chromium-iron alloy corresponding to AISI 403. This alloy, however, cannot be safely employed above 1050° F. and ordinarily its practical operating temperature limit is approximately 1000° F. The creep strength properties of this alloy are relatively poor above 1000° F.

We have determined the relative damping characteristics of the alloys of this invention by employing the vibration tests described in the following publications by one of the present inventors:

(1) "The Origin for Damping in High Strength Ferromagnetic Alloys," on pages 196 to 200 of the June 1953 issue of *Journal of Applied Mechanics*.

(2) "A Method of Determining the Internal Damping of Machine Members," Paper No. 53-A-44, ASME, Applied Mechanics Division, February 17, 1953; and

(3) "Effect of Static Stress on the Damping of Some Engineering Alloys," vol. 47, Preprint No. 26, "Transactions," American Society for Metals, 1954.

The torsional test apparatus described in the article entitled "Some new magneto-mechanical torsion experiments," on pages 670-673 of the May 1954 issue of *Journal of Applied Physics*, vol. 25, No. 5, was employed. The logarithmic decrement, as there defined, was determined for the alloys at various surface shear strain values.

The object of this invention is to provide a high-damping, high-strength cobalt base alloy with predetermined amounts of nickel, titanium, aluminum and silicon.

Another object of the invention is to provide for members such as turbine blades prepared from a high-damping, high-temperature corrosion resistant cobalt base alloy containing predetermined amounts of nickel, titanium, aluminum, and silicon.

A still further object of the invention is to provide a process for preparing high-damping, corrosion-resistant members from a predetermined cobalt base alloy.

Other objects of the invention will, in part, be obvious and will, in part, appear hereinafter.

For a better understanding of the nature and objects of the invention, reference should be had to the following detailed description and drawings, in which:

Figure 1 is a plan view of a turbine blade;

Fig. 2 is a vertical cross section through the turbine blade of Fig. 1;

2

Fig. 3 is a graph plotting damping in terms of the logarithmic decrement against surface shear strain for two alloys of the present invention at 1200° F.;

Fig. 4 is a graph wherein the hardness of three alloys is plotted against various aging periods at 1200° F.;

Fig. 5 is a graph plotting the hardness of a given alloy against varying aluminum content for three different aging conditions; and

Fig. 6 is a graph plotting the damping coefficient against maximum shear stress for any alloy of different degrees of hardness.

We have discovered certain cobalt base alloy compositions which, when suitably heat treated and aged, exhibit greatly increased damping characteristics at temperatures of 1200° F. along with greatly increased corrosion resistance and high creep strength at temperatures of the order of 1200° F., as compared to any alloy presently used in steam turbines. More particularly, the alloy of the present invention comprises essentially by weight from 65% to 88% cobalt, 1% to 2% titanium, from 0.1% to 1.5% aluminum, the total of aluminum and titanium being at least 1.5%, carbon below 0.1% and preferably not exceeding 0.05%, and the balance, at least 8%, and preferably between 16% and 25%, being nickel, with incidental impurities not exceeding 1%, and preferably below 0.3%.

The high strength and damping properties of the alloy are produced by precipitation hardening by employing suitable aging heat treatment. Both the aluminum and titanium act jointly in producing the desired hardness. The best results, especially for use at temperatures of 1200° F., are obtained if the titanium and aluminum are present in the alloy in a total of from 1.5% to 2.5% with at least 0.2% aluminum.

The aluminum is highly beneficial in the alloy because it promotes stability at turbine operating temperatures. In particular, the aluminum delays the time when overaging of the alloy occurs during high temperature turbine operations, and, in addition, the rate of overaging is greatly reduced because of the presence of this amount of aluminum. It should be understood that the aluminum as used in our alloy is a true alloying component. It is not employed as a deoxidizer and any aluminum present as the oxide is not effective for the purpose of the invention. Consequently, we add aluminum, in the form of shot or small pieces, at the last stages of the melting operation just preceding casting of the melt so as to avoid undue oxidation.

The alloy will usually include small amounts of chromium, up to 1% by weight, usually in amounts of from 0.2% to 1% chromium. We have found that silicon in amounts of up to 2.0% greatly enhances the resistance of the alloy to oxidation or corrosion at elevated temperatures. The basic alloy may include up to 2% of at least one metal selected from the group consisting of molybdenum and tungsten. Up to 4% of iron may be present in lieu of equal amount of cobalt. It is desirable to maintain phosphorous and sulfur in amounts below about 0.01%. Manganese may be present in amounts up to 0.5% in order to promote forgeability. Vanadium may be present in amounts up to 0.5%. Additional precipitation hardening components such as boron in amounts of up to 0.1%, and beryllium, zirconium, and columbium may be present in the alloy in amounts totaling up to 2%. In the event that columbium, tungsten and molybdenum are present to assist in promoting hardening, there should be present carbon to allow formation of carbides from at least a part of these metals.

The properties of our alloys are radically different from the usual austenitic alloys. In particular our alloys are ferromagnetic at temperatures of well above 1250°

F., and the Curie points are of the order of 1500° F. As a result of these characteristics of our alloys, they have excellent damping properties at low and medium stress levels due to magnetomechanical hysteresis effects. For use in high temperature turbines and the like, the alloys are compounded and prepared to give as high a Curie point as possible. Since even small amounts of non-ferromagnetic metals, such as chromium, in solid solution in the alloys will greatly lower the Curie point, their use should be restricted to the minimum.

The practically usable degree of damping in our alloys is obtained when they have been aged to a hardness of from 250 to 330 VHN (Vickers hardness number) or DPH (diamond pyramid hardness) as determined by a Vickers or other hardness test device. The damping characteristics decrease rapidly as the hardness of the alloy drops below 250 or exceeds 330 VHN. The optimum damping has been obtained when the hardness is between 280 and 320 VHN.

In preparing the alloy of this invention, vacuum melting is desirable in order to produce the best product since this procedure eliminates gases, removes volatile impurities therefrom and prevents oxidation of the alloy components. However, ordinary melting in an inert atmosphere using good metallurgical practice will result in a product that will give acceptable results. The molten alloy may be cast directly into members of desirable shape by precision casting or shell molding techniques. For most applications, however, it is desirable to cast an ingot of the alloy which is then subjected to suitable forging and working treatment to refine the grain structure and to produce homogeneous forgings. The ingot may be heated to a temperature of from 1800° F. to 2200° F. and hot rolled or forged to shape with suitable reheating if necessary.

The cast or wrought members are annealed above the recrystallization temperature, above 1600° F., and ordinarily at a temperature of the order of 1800° F. to 1950° F. for an hour or so in order to solution heat-treat the alloy. Thereafter the solution heat-treated member is aged at a temperature of from about 1200° F. to 1400° F. for a period of at least four hours to precipitation harden the alloy. The maximum hardness for any given aging treatment is reached more rapidly at the higher aging temperatures. Aging for 100 hours at 1200° F. will produce an adequate hardness. In some cases the forged or cast members, as the case may be, need be simply solution treated and then installed in a high temperature turbine or the like where steam at 1200° F. will produce the proper aging. It will be appreciated that in this last instance the turbine will, of necessity, be operated at low loads during the first 100 hours or so of operation and this will produce the desired aging. Ordinarily steam turbines when first installed are operated under these reduced loads for several weeks in order to make certain that they are functioning properly. Consequently, there is no disadvantage in attaining suitably aged alloy blading in this manner.

The following examples of alloys having high creep strength and excellent corrosion resistance in 1200° F. steam illustrate the practice of the invention:

Example I

In an induction heated vacuum furnace there was melted an alloy identified as No. 955, having the following weight analysis:

	Percent
Cobalt	72.7
Nickel	23.7
Aluminum	0.98
Titanium	1.0
Silicon	0.1
Carbon	0.006
Chromium	.78
Impurities	Bal.

This alloy contained small fractions of a percent of iron, vanadium, manganese and other elements. The cast alloy had an austenitic matrix. The alloy was cast in a precision casting mold into a blade such as the blade 10 in Figs. 1 and 2 of the drawing and suitable test specimens were made. Ingots of the alloy were cast and hot worked to shape. The wrought members were then solution heat-treated for one hour at 1950° F. and aged for 12 hours at 1200° F. The members had a hardness of 270 VHN. When tested at 1200° F. at a constant strain rate of 750% per hour the ultimate tensile strength of the alloy of this example was over 100,000 p. s. i. and the 0.2% yield strength exceeded 80,000 p. s. i. The damping capacity of the alloy at 1200° F. was equivalent to that of the 12% chromium steel AISI 403 at 900° F.

Example II

An alloy of the following composition identified as No. 956, was prepared by vacuum melting:

	Percent
Cobalt	74.3
Nickel	22.8
Aluminum	0.23
Titanium	2
Silicon	0.1
Chromium	0.5
Carbon	0.006
Sulfur	0.008
Impurities	Bal.—less than 0.1

The molten alloy was cast into an ingot and forged in accordance with the procedure set forth in Example I. The forged specimens after solution heat-treatment at 1950° F. and aging at 1200° F. for 100 hours had a hardness of 320 VHN. The damping properties were comparable to the alloy of Example I.

Example III

The following alloy identified as VM 55, was prepared by vacuum melting:

	Percent
Cobalt	73.2
Nickel	23.4
Aluminum	1.25
Titanium	1.25
Chromium	0.75
Impurities	Bal. less than 0.2

The alloy was cast into members and solution treated at 1900° F. and then aged at 1200° F. for 100 hours. The hardness of the aged alloy was 280 VHN. The alloy had a damping coefficient exceeding that of AISI 403 alloy at 900° F. The members had high strength on standard tensile tests and also on elevated creep strength tests.

Referring to Figs. 1 and 2 of the drawings, there is illustrated a typical turbine blade 10 which comprises a root portion 12 by means of which it may be fastened to a turbine shaft in association with a plurality of other turbine blades. The blade proper 14 terminates in a pin 16 by means of which it may be fastened to a shroud ring. The blade portion 14 comprises suitably curved surfaces 18, against which the high temperature steam will impinge and impart energy thereto. The back surface of each of the blades 20 is suitably curved in order to permit free flow of steam without detrimental contact therewith. It will be appreciated that turbine blades of many different sizes and shaped from that shown may be prepared depending upon the particular application.

While the range of alloy compositions above set forth wherein titanium was present from 1% to 2% is especially suited for use at temperatures of up to 1200° F., turbine blades and the like usable at higher temperatures of 1250° F. and 1300° F. may be prepared from these alloys wherein titanium may be present in amounts of up to 3%, with the aluminum in this latter case being

present up to 1.8%. Thus a suitable alloy blade for use at 1300° F. would comprise 77% cobalt, 19% nickel, 2.3% titanium, 0.5% aluminum, 1.0% chromium, and the balance impurities.

For turbines operating at 1100° F., a highly damping alloy for the turbine blades would comprise 65% cobalt, 30% nickel, 1% chromium, 1.5% titanium and 0.2% aluminum, and the balance being impurities.

Fig. 3 of the drawing plots the damping capacity against shear strain of two of the alloys of the present invention. The X13 alloy comprised 86% cobalt, 9% nickel, 1% aluminum, 2.5% titanium, 1.5% silicon and 0.1% of calcium. The T9 alloy comprises 72% cobalt, 24% nickel, 2% aluminum, 2% titanium, and small amounts silicon, calcium and the like. The 0.2% yield strength of the T9 alloy at 1200° F. was 79,200 p. s. i., the elongation being 16.5%.

A series of three alloys each containing 74.5% cobalt and 22.8% nickel, were prepared with (1) 2.5% titanium, (2) 2.7% aluminum and (3) 2% titanium and 0.25% aluminum. Ingots of each alloy were similarly worked and solutions heat-treated at 1950° F. Specimens of the three alloys were aged at 1200° F. and the hardness determined at intervals. The curves of Fig. 4 were plotted from these tests. It will be observed that alloys (1) and (2) did not reach the desired hardness of 250 VHN even after 512 hours' aging, whereas alloy (3) had reached the optimum hardness of 280 VHN in less than 8 hours' aging, and the hardness curve had flattened out at 320 VHN in less than 100 hours. These curves illustrate the unique cooperation resulting from the joint presence of aluminum and titanium in the alloys.

A series of alloys were prepared by adding from 0.1% to 1% of aluminum to a base composed of 72% cobalt, 23% nickel and 2% titanium, the balance being small amounts of iron, chromium, silicon, and other elements. Wrought specimens of the alloys were all solution treated for one hour at 1900° F., then specimens of each alloy were aged at 1350° F., 1300° F. and 1200° F., for varying periods of times, and the hardness tested. The curves of Fig. 5 were plotted from these tests. In each case a pronounced increase in hardness of about 80 hardness numbers was obtained by adding the initial 0.1% aluminum. The addition of from 0.25% to 0.75% aluminum increased the hardness number by approximately 100. These curves emphasize the definite improvement in hardness contributed by the aluminum along with titanium in these alloys.

In order to show the critical effect of hardness on damping, a series of tests were made on an alloy comprising 70.7% cobalt, 22.8% nickel, 1.8% aluminum and 3% titanium, which alloy was solution treated at 1900° F. and aged at 1200° F. for various periods to a hardness of 166 VHN, 286 VHN, 318 VHN and 341 VHN. Each specimen was subjected to a torsional damping test at various shear stress values. These data gave the results shown in the four curves plotted in Fig. 6. It will be evident that at hardnesses of 166 VHN and 341 VHN, the logarithmic decrement is below 0.01 at loads of 4000 to 16,000 p. s. i. The samples of hardnesses of 286 VHN and 318 VHN both exhibited much greater damping properties.

It will be understood that the above specification and drawing are exemplary and not limiting.

We claim as our invention:

1. A member suitable for use as a turbine blade, having high damping properties at 1200° F., comprising a member of an alloy composed of, by weight, from 65% to 88% cobalt, from 1% to 2% titanium, from 0.1% to 1.5% aluminum, the total of titanium and aluminum being at least 1.5%, carbon not exceeding 0.05%, and the balance, at least 8%, being nickel, with impurities not exceeding 1%, the wrought blade having been solution treated above 1600° F. and above the recrystallization temperature of the alloy, and then aged at from about

1200° F. to 1400° F. for at least 4 hours to precipitation harden the alloy to a hardness of between 250 and 330 VHN, and having a Curie temperature of over 1450° F.

2. The member of claim 1 wherein the alloy also contains from 0.2% to 1% chromium and from 0.1% to 2% silicon.

3. A turbine blade having high damping properties at 1200° F., comprising a wrought member of an alloy composed of, by weight, from 65% to 88% of cobalt, from 1% to 2% of titanium, from 0.1% to 1.5% aluminum, the total of aluminum and titanium being at least 1.5%, from 0.1% to 2% silicon, up to 1% chromium, up to 2% of at least one metal selected from the group consisting of molybdenum and tungsten, carbon not exceeding 0.05%, and the balance, at least 8%, being nickel, with impurities not exceeding 1%, the wrought blade having been solution treated above 1600° F. and above the recrystallization temperature of the alloy, and then aged at from about 1200° F. to 1400° F. for at least 4 hours to precipitation harden the alloy to a hardness of from 250 to 330 VHN.

4. The alloy of claim 3, wherein up to 4% by weight of iron is present.

5. A member having high damping properties at 1200° F., high creep strength at 1200° F., and high corrosion resistance at elevated temperatures, comprising an alloy composed, by weight, from 65% to 88% cobalt, from 1% to 2% titanium, from 0.1% to 1.5% aluminum, the total of aluminum and titanium being at least 1.5% from 0.1% to 2% silicon, from 0.2% to 1.0% chromium, carbon not exceeding 0.05%, and the balance, at least 8%, being nickel, and not over 1% impurities, the member having been solution heat treated above 1600° F. and above the recrystallization temperature of the alloy, and then aged at a temperature of from about 1200° F. to 1400° F. for a period of at least 4 hours to provide a hardness of between 250 and 330 VHN.

6. A member having high damping properties at 1200° F., high creep strength at 1200° F., and high corrosion resistance at elevated temperatures, comprising an alloy composed, by weight, from 65% to 88% cobalt, from 1% to 2% titanium, from 0.1% to 1.5% aluminum, the total of aluminum and titanium being from 1.5% to 2.5%, from 0.1% to 2% silicon, up to 1.0% chromium, up to 2% of at least one metal selected from the group consisting of molybdenum and tungsten, carbon not exceeding 0.05%, and the balance, at least 8%, being nickel, and not over 1% impurities, the member having been solution heat treated above 1600° F. and above the recrystallization temperature of the alloy, and then aged at a temperature of from about 1200° F. to 1400° F. for a period of at least 4 hours to provide a hardness of between 250 and 330 VHN.

7. A member having high damping properties at temperatures of from 1100° F. to 1300° F., along with high creep strength and high corrosion resistance, comprising an alloy composed, by weight, of from 65% to 88% cobalt, from 1% to 3% titanium, from 0.1% to 1.8% aluminum, not exceeding 0.05% carbon, and the balance at least 8%, being nickel, and not over 1% of impurities, the member having been solution heat treated above 1600° F. and above the recrystallization temperature of the alloy, and then aged at a temperature of from about 1200° F. to 1400° F. for a period of at least 4 hours to provide a hardness of between 250 and 330 VHN.

8. The member of claim 7, wherein the alloy includes from 0.1% to 2% silicon and up to 1% chromium.

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