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FERROUS ALLOYS FOR HIGH TEMPERATURE USE

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This invention relates to ferrous alloys for use at high temperatures, referring more particularly to alloys suitable for use in applications where great strength at high temperatures is required.

The trend of modern engineering is toward the utilization of high temperatures for many and diverse operations. For example, chemical processes are today conducted at very high temperatures, a notable instance being petroleum refining. Also, the quest for improved power sources had led to the investigation and development of such devices as superchargers, gas turbines, jet propulsion apparatus and the like all operating at high temperatures. These developments demand of the metallurgist metals and alloys which will withstand prolonged exposure to temperatures well above about 700° F. and in many instances well above about 1200° F. The problem is complicated by the fact that severe mechanical stress is often encountered at these temperatures.

For parts of such devices as superchargers, gas turbines, jet propulsion apparatus and the like, it is necessary to employ alloys that are capable of withstanding severe mechanical stress at high temperatures. Depending upon the design and the intended use of such devices, the temperature ranges at which they operate may be separated into a range between 900° F. and about 1200° F. and into a range upwards of 1200° F. Associated parts and apparatus may be required to withstand temperatures of about 700° F. and above. In devices operating within the lower temperature range, generally much higher stresses are applied than in devices operating above 1200° F. In many instances it is desired that alloys for use in such apparatus be capable of being hot-worked and machined, while in other instances the alloys may be employed in the form of castings. In any event, the alloys must have high strength.

A number of alloys have been proposed for use at high temperatures, but the utility of these alloys has been limited either because they are not hot-workable or machinable, or because they become brittle upon prolonged exposure to high temperatures. One of the characteristics of highly alloyed ferrous materials is that as the ferrous solid solution alloy contains more and more of the alloying metals to increase high temperature strength, the stability of the materials at high temperatures tends to decrease so that on prolonged exposure to high temperature the materials become excessively brittle.

It is the principal object of this invention to

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provide ferrous alloys suitable for use in applications where temperatures above about 700° F. are normally encountered. A further object is the provision of hot-workable and machinable ferrous alloys for use at such elevated temperatures. Another object is the provision of ferrous alloys capable of withstanding severe mechanical stress at elevated temperatures above about 700° F. A more specific object is the provision of ferrous alloys and articles wrought or cast therefrom capable of withstanding severe mechanical stress at elevated temperatures above about 1200° F. up to about 1500° F.

The invention by means of which these objects are achieved is based on the discovery that the addition of small, properly-proportioned quantities of molybdenum, tungsten, at least one element selected from the group consisting of columbium, tantalum, tatanium, and vanadium and at least one element selected from the group consisting of aluminum and boron to iron-chromium-nickel alloys produces a remarkable increase in the high temperature strength of such alloys without detrimentally affecting their high temperature stability.

The invention comprises ferrous alloys containing 10% to 30% chromium, 2% to 40% nickel, 0.5% to 7.5% molybdenum, 0.5% to 10% tungsten, 0.5% to 5% in the aggregate of at least one metal selected from the group consisting of columbium, tantalum, titanium, and vanadium, and 0.1% to 3% in the aggregate of at least one metal selected from the group consisting of aluminum and boron, the boron content not exceeding 0.7%, and the aluminum content being not less than 0.5% in the absence of boron, the remainder of the alloys being iron except for incidental impurities and small quantities of elements customarily present in steels of good quality. Generally preferred ranges for molybdenum and tungsten are 1% to 5% molybdenum and 0.5% to 5% tungsten. No more than 2% each of titanium and vanadium should be present in the alloys.

Carbon is always present in the alloys of the invention. Preferably it does not exceed about 1%, and if hot working of the alloys is desired, the maximum carbon content should be 0.35%. Nitrogen is importantly beneficial and is preferably present in a proportion up to 0.25%. Silicon and manganese may be present, the silicon content preferably not exceeding 1% and the manganese content not exceeding 2% if hot working is desired.

A useful test for determining the suitability of materials for use at high temperatures is the so-

called stress-rupture test. In this test several samples of an alloy to be tested are maintained at a given temperature, each sample being subjected to a different measured stress. The time required to cause failure of the samples under these conditions of temperature and stress is determined, and the time and stress values obtained are plotted to yield a curve for the particular material under test. From this curve can be determined the stress the material will withstand for a given period of time, say 1,000 hours, at the particular temperature for which the curve was drawn. This test provides a convenient method of determining the load carrying ability of a material. It also gives some indication of whether or not the material becomes embrittled upon prolonged exposure at the temperature of the test. A brittle material will break without elongation, whereas ductile material will elongate before failure.

Stress-rupture tests conducted in the manner just described indicate that the alloys of the invention maintain great strength at temperatures as high as 1500° F. and that even at such high temperature the alloys possess good ductility.

Typical examples of the improvement in high temperature strength of chromium-nickel steels imparted by the addition of molybdenum, tungsten, columbium, titanium, and boron in various combinations are indicated by the data in Table I below. In this table are reported the results of stress-rupture tests in which a stress of 20,000 pounds per square inch was applied to a sample of the steel (in the as-forged condition) to be tested while the sample was maintained at a temperature of 1500° F. The time in hours required for the sample to fail under these extremely severe conditions is given in the table.

Table

Composition; Remainder Substantially all Fe									Hours
% Cr	% Ni	% Mo	% W	% Cb	% B	% C	% N	% Other	
18.5	8.5	Nil	Nil	Nil	Nil	0.07	0.04	Nil	0.10
19	9	1.3	1.5	0.54	0.61	0.05	0.04	0.1 Ti	55.5
19	9	1.5	1.8	Nil	0.7	0.07	0.04	0.2 Ti	95.5
18.5	9	1.25	1.4	Nil	0.4	0.03	0.04	0.3 Ti	95
18.5	9	1.25	1.4	0.5	0.4	0.03	0.04	0.3 Ti	55

The data in the above table demonstrate the remarkable improvement in high temperature strength of a steel containing about 19% chromium and 9% nickel imparted by the addition of small quantities of molybdenum, tungsten, columbium, and titanium. From a life of six minutes at 1500° F. under stress of 20,000 pounds per square inch the life of the steel was raised to nearly 100 hours by the addition of these elements.

In manufacturing the alloys of this invention care should be taken that the composition limits set forth be closely adhered to with regard to the intended use of the alloys since material variations in the proportions of the several ingredients detrimentally affect the desired properties. For example, if the alloys are to be employed as castings, the carbon content may be as high as 1%; but if hot-workability is desired, the carbon content should be kept at a maximum of about 0.35% and preferably should not exceed 0.2%.

Similarly, the proportions of molybdenum, tungsten, columbium, tantalum, titanium, vanadium, aluminum, and boron present in the alloys affect hot-workability and weldability. Too high a proportion of any of these elements has a detrimental effect on hot-workability and weldability, particularly the latter property. Alloys within the composition limits defined may be welded readily by any of the common welding methods, for example, electric arc, oxyacetylene, submerged-melt electric welding, or solid-phase pressure welding, sound, strong and tough welds being produced without undue embrittlement of weld metal or base metal, and such welds retain their toughness at elevated temperatures. However, if too high a proportion of any of these elements is present in the alloys, welds produced usually suffer from loss of toughness at elevated temperatures.

The presence of nitrogen in the alloys of the invention within the range indicated is important, nitrogen having a beneficial effect on the high temperature stability of the alloys.

Being hot-workable, machinable, weldable, and castable, and possessing remarkable strength at elevated temperatures up to about 1500° F., the alloys of the invention are particularly well suited to use in the fabrication of articles such as parts of superchargers, gas turbines, jet propulsion apparatus and the like which are required to withstand severe mechanical stress at elevated temperatures. Their freedom from embrittlement upon prolonged exposure at high temperatures recommends their use where dependability of operation is essential.

Related subject matter is disclosed and claimed in our copending application Ser. No. 599,308, filed June 13, 1945.

We claim:

1. An alloy containing about 10% to 30% chromium; 2% to 40% nickel; 0.5% to 7.5% molybdenum; 0.5% to 10% tungsten; an aggregate of 0.5% to 5% of at least one metal selected from the group consisting of columbium, tantalum, titanium, and vanadium, the titanium and vanadium contents each not exceeding 2%; nitrogen in an effective proportion up to 0.25%; an aggregate of 0.1% to 3% of at least one metal selected from the group consisting of aluminum and boron, the boron content not exceeding 0.7%, and the aluminum content being not less than 0.5% in the absence of boron; the remainder substantially all iron and incidental impurities.

2. An alloy containing about 10% to 30% chromium; 2% to 40% nickel; 1% to 5% molybdenum; 0.5% to 5% tungsten; an aggregate of 0.5% to 5% of at least one metal selected from the group consisting of columbium, tantalum, titanium, and vanadium, the titanium and vanadium contents each not exceeding 2%; nitrogen in an effective proportion up to 0.25%; an aggregate of 0.1% to 3% of at least one metal selected from the group consisting of aluminum and boron, the boron content not exceeding 0.7%, and the aluminum content being not less than 0.5% in the absence of boron; the remainder substantially all iron and incidental impurities.

3. An alloy containing about 10% to 30% chromium; 2% to 40% nickel; 1% to 5% molyb-

denum; 0.5% to 5% tungsten; an aggregate of 0.5% to 5% of at least one metal selected from the group consisting of columbium, tantalum, titanium, and vanadium, the titanium and vanadium contents each not exceeding 2%; nitrogen in an effective proportion up to 0.25%; an aggregate of 0.1% to 3% of at least one metal selected from the group consisting of aluminum and boron, the boron content not exceeding 0.7%, and the aluminum content being not less than 0.5% in the absence of boron; carbon in an effective proportion not exceeding 1%, the remainder substantially all iron and incidental impurities.

4. A hot-workable alloy containing about 10% to 30% chromium; 2% to 40% nickel; 1% to 5% molybdenum; 0.5% to 5% tungsten; an aggregate of 0.5% to 5% of at least one metal selected from the group consisting of columbium, tantalum, titanium, and vanadium, the titanium and vanadium contents each not exceeding 2%; nitrogen in an effective proportion up to 0.25%; an aggregate of 0.1% to 3% of at least one metal selected from the group consisting of aluminum and boron, the boron content not exceeding 0.7%, and the aluminum content being not less than 0.5% in the absence of boron; carbon in an effective proportion not exceeding 0.35%, the remainder substantially all iron and incidental impurities.

5. A cast article which in its normal use is required to withstand mechanical stress at elevated temperatures up to about 1500° F., which article is composed of an alloy containing about 10% to 30% chromium; 2% to 40% nickel; 0.5% to 7.5% molybdenum; 0.5% to 10% tungsten; an aggregate of 0.5% to 5% of at least one metal selected from the group consisting of columbium, tantalum, titanium, and vanadium, the titanium and vanadium contents each not exceeding 2%; nitrogen in an effective proportion up to 0.25%; an aggregate of 0.1% to 3% of at least one metal selected from the group consisting of aluminum and boron, the boron content not exceeding 0.7%, and the aluminum content being not less than 0.5% in the absence of boron; the remainder substantially all iron and incidental impurities.

6. A cast article which in its normal use is required to withstand mechanical stress at elevated temperatures not exceeding about 1500° F., which article is composed of an alloy containing about 10% to 30% chromium; 2% to 40% nickel; 0.5% to 7.5% molybdenum; 0.5% to 10% tungsten; 0.5% to 5% columbium; 0.1% to 0.7% boron; manganese in an effective proportion up to 2%; silicon in an effective proportion to 1%; nitrogen in an effective proportion up to 0.25%; carbon in an effective proportion not exceeding 1%; remainder substantially all iron.

7. A wrought article which in its normal use is required to withstand mechanical stress at elevated temperatures up to about 1500° F., which article is composed of an alloy containing about 10% to 30% chromium; 2% to 40% nickel; 0.5% to 7.5% molybdenum; 0.5% to 10% tungsten; an aggregate of 0.5% to 5% of at least one metal selected from the group consisting of columbium, tantalum, titanium, and vanadium, the titanium and vanadium contents each not exceeding 2%; nitrogen in an effective proportion up to 0.25%; an aggregate of 0.1% to 3% of at least one metal selected from the group consisting of aluminum and boron, the boron content not exceeding 0.7%, and the aluminum content being not less than 0.5% in the absence of boron; the remainder substantially all iron and incidental impurities.

8. A wrought article which in its normal use is required to withstand mechanical stress at elevated temperatures not exceeding about 1500° F., which article is composed of an alloy containing about 10% to 30% chromium; 2% to 40% nickel; 0.5% to 7.5% molybdenum; 0.5% to 10% tungsten; 0.5% to 5% columbium; 0.1% to 0.7% boron; manganese in an effective proportion up to 2%; silicon in an effective proportion up to 1%; nitrogen in an effective proportion up to 0.25%; carbon in an effective proportion not exceeding 0.35%; remainder substantially all iron.

9. A welded article which in its normal use is required to withstand mechanical stress at elevated temperatures not exceeding about 1500° F., which article is composed of an alloy containing about 10% to 30% chromium; 2% to 40% nickel; 0.5% to 7.5% molybdenum; 0.5% to 10% tungsten; 0.5% to 5% columbium; 0.1% to 0.7% boron; manganese in an effective proportion up to 2%; silicon in an effective proportion up to 1%; nitrogen in an effective proportion up to 0.25%; carbon in an effective proportion not exceeding 0.35%; remainder substantially all iron.

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