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ALLOY ARTICLES FOR HIGH-TEMPERATURE SERVICE

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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 has 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 used 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., up to about 1500° 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 iron-base 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

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temperatures the materials become excessively brittle.

It is the principal object of this invention to provided 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 alloys for use at such elevated temperatures. Another object is the provision of alloys capable of withstanding severe mechanical stress at elevated temperatures above about 700° F. A more specific object is the provision of alloys and articles wrought or cast therefrom capable of withstanding severe mechanical stress at elevated temperatures above about 700° 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 tungsten, at least one element selected from the group consisting of columbium, tantalum and titanium, and at least one element selected from the group consisting of boron and aluminum to iron-chromium-cobalt alloys produces a remarkable increase in the high temperature strength of such alloys without detrimentally affecting their high temperature stability.

The invention comprises alloys containing 10% to 30% chromium, 10% to 45% cobalt, 0.5% to 15% tungsten, 0.5% to 7% in the aggregate of at least one metal selected from the group consisting of columbium, tantalum, and titanium, and 0.01% to 3% in the aggregate of at least one element selected from the group consisting of boron and aluminum, the maximum boron content being 0.7% and the minimum aluminum content in the absence of boron being 0.5%, the remainder of the alloys being iron except for incidental impurities and small quantities of elements customarily present in steels of good quality. The iron content should always be more than 5%. No more than 2% of titanium should be present in the alloys. Up to about 7.5% molybdenum may be present in the alloys, a generally preferred range for molybdenum being 0.5% to 5%. In the absence of molybdenum, the tungsten content should be at least 7.5%. If both molybdenum and tungsten are present, the tungsten content preferably should not exceed 10% of the alloy.

Carbon is always present in the alloys of the invention, but should be less than 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 1000 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 high temperature strength of chromium-cobalt steels imparted by the addition of molybdenum, tungsten, columbium and boron or aluminum in various combinations are indicated by the data in the table below. In this table are reported the results of stress-rupture tests in which stresses of 25,000, 30,000 and 35,000 pounds per square inch ("p. s. i.") were applied to cast samples of the steels to be tested while the samples were maintained at a temperature of 1500° F. The time in hours required for the sample to fail under these extremely severe conditions is reported in the table.

Table

Composition—Remainder Substantially All Fe								Hours to Fail at 1500° F. and stress indicated		
Percent Cr	Percent Co	Percent Mo	Percent W	Percent Cb	Percent B	Percent Al	Percent C	25,000 p. s. i.	30,000 p. s. i.	35,000 p. s. i.
18.5	35	4	4	1	0.51	Nil	0.10	917	195	no test
18.5	35	4	4	1	Nil	1	0.11	113	14	no test
18	40	3	10	1	0.5	Nil	0.10	no test	no test	451
18	40	Nil	15	1	0.5	Nil	0.10	no test	no test	443

The data in the above table clearly illustrate the ability of the alloys of the invention to withstand large stresses at elevated temperatures for prolonged periods of time without failure.

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 exceed 0.35% but should be less than 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, aluminum, and boron present in the alloys affect hot-workability and weldability. A preferred upper limit for columbium and tantalum is 5%. 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.

Likewise, the proportion of cobalt is important, and should be sufficient to produce a stable austenitic alloy.

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.

This application is a continuation-in-part of our copending application, Serial No. 599,305, filed June 13, 1945, now Patent No. 2,432,614, issued December 16, 1947.

We claim:

1. A heat resisting alloy article which is useful at elevated temperatures upwards of 700° F. and has great strength and stability when subjected to severe stresses at such elevated temperatures for prolonged periods of time, said article being composed of a machinable, weldable, castable and hot-workable alloy consisting of 10% to 30% chromium; 10% to 45% cobalt; 0% to 7.5% molybdenum; 0.5% to 15% tungsten, the tungsten content being at least 7.5% when molybdenum is absent and the tungsten content being not more than 10% when both molybdenum and tungsten are present; 0.5% to 7% in the aggregate of at least one metal selected from the group consisting of columbium, tantalum and titanium, the titanium content not exceeding 2%; 0.01% to 3% in the aggregate of at least one element selected from the group consisting of boron and aluminum, the maximum boron content being 0.7% and the

minimum aluminum content in the absence of boron being 0.5%; carbon in a proportion less than 0.35%; nitrogen in a proportion up to 0.25%; the remainder of the alloys being iron and incidental impurities, the iron content exceeding 5%.

2. A heat resisting alloy article for service at elevated temperatures upwards of 700° F. and capable of withstanding severe stresses for prolonged periods of time when used at such elevated temperatures, said article being composed of a hot-workable alloy consisting of 10% to 30% chromium; 10% to 45% cobalt; 0% to 7.5% molybdenum; 0.5% to 15% tungsten, the tungsten content being at least 7.5% when molybdenum is absent and the tungsten content being not more than 10% when both molybdenum and tugnsten are present; 0.5% to 7% in the aggregate of at least one metal selected from the group consisting of columbium, tantalum and titanium, the upper limit for columbium and tantalum being 5% and the titanium content not exceeding 2%; 0.01% to 3% in the aggregate of at least one element selected from the group consisting of boron and aluminum, the maximum boron content being 0.7% and the minimum aluminum content in the absence of boron being 0.5%; carbon in a proportion not exceeding 0.2%; nitrogen in a proportion up to 0.25%; the remainder of the alloy being iron and incidental impurities, the iron content exceeding 5%.

3. A heat resisting alloy article for service at elevated temperatures upwards of 700° F. and capable of withstanding severe stresses for prolonged periods of time when used at such elevated temperatures said article being composed of a machinable, weldable, castable and hot-workable alloy containing 10% to 30% chromium; 10% to 45% cobalt; 0.5% to 5% molybdenum; 0.5% to 10% tungsten; 0.5% to 7% in the aggregate of at least one metal selected from the group consisting of columbium, tantalum and titanium, the upper limit for columbium and tantalum being 5% and the titanium content not exceeding 2%; 0.01% to 3% in the aggregate of at least one element selected from the group consisting of boron and aluminum, the maximum boron content being 0.7% and the minimum aluminum content in the absence of boron being 0.5%; carbon in an

effective amount not exceeding 0.2%; nitrogen in a proportion up to 0.25%; the remainder of the alloy being iron and incidental impurities, the iron content exceeding 5%.

4. A heat resisting alloy article for service at elevated temperatures as high as 1500° F. and capable of withstanding stresses upwards of 25,000 p. s. i. at such elevated temperatures for prolonged periods of time without failure, said article being composed of an alloy consisting substantially of 18% chromium; 40% cobalt; 15% tungsten, 1% columbium; 0.5% boron; 0.10% carbon; the remainder iron and incidental impurities.

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