United States Patent Office

2,744,010

Patented May 1, 1956

2,744,010

HIGH TEMPERATURE Co-Cr ALLOYS

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No Drawing. Application February 12, 1951, Serial No. 210,630

4 Claims. (Cl. 75—171)

This invention relates to an improved high temperature creep-resistant alloy and particularly to an alloy which is characterized by outstanding ductility, high oxidation resistance and considerable strength under elevated temperature conditions.

A principal object of this invention, therefore, is to provide an alloy which is especially suitable for use in parts which must withstand high mechanical stresses under temperatures in the range of 1500° and which must resist oxidation at temperatures up to 2000° F. while at the same time possessing high ductility. Turbine blades or buckets and nozzle guide vanes for gas turbines are examples of such parts for which my alloy is particularly adapted.

Alloys in accordance with my invention which are especially adapted to be cast by precision methods to form parts, such as turbine blades, requiring high strength and creep-resistance at elevated temperatures in combination with good ductility include 0.25% to 0.50% carbon, 0.30% to 1.25% manganese, 0.30% to 1.1% silicon, 12.0% to 15.0% nickel, 18.0% to 24.0% chromium, 8.0% to 12.0% tungsten, 0.0% to 5.5% iron, 0.015% to 0.09% boron and the balance substantially all cobalt.

In this type of alloy I have found that the balance between creep strength and ductility is affected by the carbon content. As the carbon content is increased the alloy becomes more resistant to creep under stress at elevated temperatures but at the same time becomes somewhat less ductile. On the other hand, as the carbon content is lowered, the creep strength at elevated temperatures decreases and the ductility increases. However, such alloys having a carbon content below 0.30% possess extremely good ductility while still having adequate high temperature strength. When the carbon content is reduced to a value below 0.20%, the alloy may be rolled into sheet form having excellent oxidation and corrosion resistance with high temperature strength and possessing such a high ductility that it may be fabricated into parts by bending and forming operations. At the lower end of the carbon range the material may be rolled in bar stock and similar wrought products. In certain applications where high temperature strength and creep-resistance are of primary consideration and ductility is of lesser importance, advantage may be taken of the strength and creep-resistance obtained by increasing the carbon content to as high as approximately 1.0%. In general, therefore, the carbon content for different applications may range from as low as about 0.05% up to 1.0%.

The boron content also has a decided effect on the physical properties of this alloy, the creep strength at elevated temperatures being increased by raising the boron content above 0.10%. Thus, increased boron and carbon content are both accompanied by increased creep-resistance at elevated temperatures and reduced ductility. Advantage may be taken of these properties within the limits imposed by the need for ductility in the particular application involved. In general, the boron in my alloy may range from about 0.01% to approximately 0.30%

to produce the most desired of these physical properties in a particular case.

The manganese and silicon content may likewise each be lowered below 0.30% to enhance certain alloy characteristics. Similarly, under particular conditions it may be advantageous to raise the manganese and silicon contents above 1.25% and 1.0%, respectively. Thus, depending on the individual purpose for which the alloy is to be used, the amount of each of these constituents in my invention may range from appreciably less than 0.30% up to as high as about 1.50%. The use of either silicon or manganese in amounts of less than 0.30% make the alloy more difficult to cast, whereas, the use of greater amounts of these elements result in a cleaner melt and less trouble from oxide films. However, I have found that an oxide-resistant alloy of this type which possesses adequate castability may be obtained with a melt having each of these elements added in quantities as low as 0.20%.

In certain applications, lesser amounts of chromium and tungsten may also be employed. My tests indicate that chromium and tungsten contents as low as about 16.0% and 6.0%, respectively, result in producing an alloy having adequate strength at high temperatures.

The iron content also may range as high as approximately 10.0%. However, I have found that in most instances the percentage of iron should be within the approximate range of 3.0% to 5.5%, this composition producing more satisfactory results than either an iron-free or a high iron content alloy.

The following examples are illustrative of typical alloys in accordance with my invention, showing results of tests thereon.

Example I

A test bar was precision cast in a hot investment mold from an alloy composed substantially as follows: 0.45% carbon, 1.2% manganese, 1.04% silicon, 13.5% nickel, 18.1% chromium, 8.72% tungsten, 5.1% iron, 0.087% boron and the balance substantially all cobalt. This test bar, while in the as cast condition, was subjected to a static tensile load of 25,000 pounds per square inch at a test temperature of 1500° F. Under these test conditions it required 6.5 hours to elongate the test bar 1% and 136 hours to rupture it, the bar being elongated 10.1% before rupturing. These results compare favorably with those obtained with many conventional cobalt base alloys, which normally elongate 1% in a period of time on the order of 1.5 to 3.5 hours and rupture in about 20 to 30 hours.

Example II

An alloy test bar having the same composition as that illustrated above was precision cast in a hot investment mold and aged 16 hours at 1350° F. This bar was then subjected to a static tensile load of 25,000 pounds per square inch in combination with an alternating dynamic load of 19,250 pounds per square inch. In other words, the stress rapidly varied during the test from 5750 pounds per square inch to 44,250 pounds per square inch. Fifteen hours were required under these test conditions to obtain 1% elongation. Moreover, it was necessary to subject the bar to this combined stress for 403 hours in order to rupture it, the percentage elongation at rupture being 5.75%.

Some of the desirable characteristics of this alloy, such as high ductility at elevated temperatures, were shown by my tests on turbine wheels, wherein each wheel was provided with cast turbine blades of this alloy and with blades of a similar cobalt base alloy in which other metals were wholly or partially substituted for tungsten. After four hours of operation, inspection revealed that foreign matter

had passed through the turbine wheel, resulting in damage to the leading edges of most of the blades. The blades which contained approximately 9% tungsten with no metals substituted therefore, although slightly dented, were not cracked or chipped, whereas the damage became progressively more severe as the tungsten content was lowered and replaced by other elements. These turbine wheels were subsequently operated for an additional 116 hours without the loss of a single blade having a tungsten content in accordance with my invention, thus indicating that this alloy possesses considerable creep-resistance and high temperature strength as well as ductility and impact strength.

Example III

A test bar was precision cast in a hot investment mold from an alloy composed substantially as follows: 0.38% carbon, 0.55% manganese, 0.47% silicon, 13.5% nickel, 22.0% chromium, 9.51% tungsten, 4.13% iron, 0.022% boron and the balance cobalt. This bar was then aged 16 hours at 1350° F. Under the test conditions of Example II but with the temperature elevated to 1600° F., 54.5 hours elapsed before this test bar was elongated 1%, and the combined stress load had to be applied 128 hours before the bar ruptured. The percentage elongation at rupture was 5.15%.

Example IV

A test bar was precision cast in a hot investment mold from an alloy composed substantially as follows: 0.34% carbon, 0.66% manganese, 0.41% silicon, 12.9% nickel, 23.8% chromium, 9.5% tungsten, 4.1% iron, 0.04% boron and the balance substantially all cobalt. Under the test conditions of Example II, but with the bar subjected to the same combined stress load while in the as cast condition, 28 hours were required to elongate the bar 1%, and 320.5 hours were required to produce rupture. This bar was elongated 3.3% at rupture.

Example V

A test bar was precision cast in a hot investment mold from an alloy composed substantially as follows: 0.28% carbon, 0.53% manganese, 0.51% silicon, 14.8% nickel, 24.0% chromium, 8.8% tungsten, 4.08% iron, 0.025% boron and the balance cobalt. When this test bar, while in the as cast condition, was subjected to the same test conditions as in Example II, it elongated 1% after 13 hours. The bar did not rupture until after 262 hours, the test bar having elongated 7.63% at the time of rupture.

Example VI

A test bar was precision cast in a hot investment mold from an alloy composed substantially as follows: 0.34% carbon, 0.43% manganese, 0.39% silicon, 13.5% nickel, 22.8% chromium, 9.32% tungsten, 3.91% iron, 0.023% boron and the balance substantially all cobalt. When this bar was aged 16 hours at 1350° F. and subjected to the same test conditions as Example II, 80 hours elapsed before the bar elongated 1%. After 187 hours this bar had elongated 1.25%, at which time the static tensile load was increased to 30,000 pounds per square inch. A total of 194 hours of stress application were necessary to produce rupture, the percentage elongation of the bar at rupture being 4.1%.

Some of the typical results of other similar tests are summarized in the following table. This data illustrates representative compositions of the alloy in accordance with my invention which are characterized by particularly desirable physical properties for various purposes. In each case the test bar was subjected to the combined stress load described in Example II, wherein the bar was placed under a static tensile load of 25,000 pounds per square inch in combination with an alternating dynamic load of 19,250 pounds per square inch. The test bars formed from heats 1, 2, 3, 5, 7 and 9 were aged 16 hours at 1350° F. before being tested, while the bars from heats 4, 6, 8, 10 and 11 were tested in the as cast condition. All the test bars were cast in hot investment molds except the bars of heats 2, 4, 8 and 9, which were cast in sand-resin molds at 450° F. In each instance the test temperature was maintained at 1500° F.

Heat	Composition of Alloys in Percentage									Hours to Produce 1% elongation	Hours to Produce rupture	Percent Elongation at rupture
	C	Mn	Si	Ni	Cr	W	Fe	B	Co			
1	.34	.51	.35	13.8	21.9	9.61	3.82	.026	Bal.	119	595	2.75
2	.36	.61	.46	13.6	22.9	9.82	4.08	.038	Bal.	320	745	1.44
3	.34	.66	.41	12.9	23.8	9.52	4.09	.040	Bal.	18	143	4.7
4	.37	.59	.44	13.2	23.5	10.0	4.12	.035	Bal.	44	580	2.75
5	.28	.53	.51	14.8	24.0	8.80	4.08	.025	Bal.	34	203	3.30
6	.28	.51	.50	14.7	23.2	9.79	4.00	.028	Bal.	20	127	3.13
7	.28	.51	.50	14.7	23.2	9.79	4.00	.028	Bal.	55	410	4.7
8	.30	.56	.68	14.5	22.5	10.4	3.61	.022	Bal.	166	230	1.28
9	.30	.56	.68	14.5	22.5	10.4	3.61	.022	Bal.	185	[1] 345	[1] 1.25
10	.35	.51	.46	13.4	22.9	9.37	4.22	.034	Bal.	18	102	3.69
11	.30	.64	.47	14.6	22.8	10.6	4.1	.016	Bal.	28	[1] 67	[1] 1.5

[1] No rupture occurred.

As indicated in the above table, no rupture occurred during the tests on the bars from heats 9 and 11, these bars being subjected to the application of the aforementioned combined stress for 345 hours and 67 hours, respectively, without producing rupture. The 1.25% and the 1.5% elongation were the amounts these bars had elongated after 345 hours and 67 hours, respectively, but before rupture.

The results of the stress-rupture tests which are summarized in the preceding table show that excellent physical properties of high creep-resistance, high temperature strength, ductility and impact strength are obtained with alloys having the following preferred composition: 0.28% to 0.38% carbon, 0.50% to 0.70% manganese, 0.30% to 0.50% silicon, 12.0% to 15.0% nickel, 21.0% to 24.0% chromium, 9.0% to 11.0% tungsten, 3.0% to 5.5% iron, 0.02% to 0.04% boron and the balance substantially all cobalt. This data also shows that generally test bars having the above composition which are cast in sand-resin molds have longer life to 1% elongation and a lower elongation at rupture than test bars cast in hot investment molds. Moreover, the additional creep-resistance obtained by casting in sand-resin molds is advantageous for certain applications.

The alloy of my invention can be compounded or made up in any desired manner and any suitable melting furnace may be used. Typical examples of melting furnaces which have been employed are the indirect arc and the induction types. At present, it has been found preferable to add the boron in the form of boron carbide.

Various changes and modifications of the embodiments described herein may be made without departing from the spirit and scope of the invention as set forth in the following claims.

I claim:

1. A high temperature creep-resistant alloy consisting essentially of 0.25% to 0.5 carbon, 0.3% to 1.25% manganese, 0.3% to 1.1% silicon, 12.0% to 15.0% nickel, 18.0% to 24.0% chromium, 8.0% to 12.0% tungsten,

0.0% to 5.5% iron, 0.015% to 0.09% boron, and the balance cobalt plus incidental impurities.

2. An alloy characterized by high temperature creep-resistance and ductility, said alloy consisting of 0.28% to 0.38% carbon, 0.5% to 0.7% manganese, 0.3% to 0.5% silicon, 12.0% to 15.0% nickel 21.0% to 24.0% chromium, 9.0% to 11.0% tungsten, 3.0% to 5.5% iron, 0.02% to 0.04% boron, and the balance cobalt plus incidental impurities.

3. A high temperature creep-resistant alloy characterized by high room-temperature ductility consisting of 0.05% to 1.0% carbon, 0.3% to 1.25% manganese, 0.3% to 1.1% silicon, 12.0% to 15.0% nickel, 18.0% to 24.0% chromium, 8.0% to 12.0% tungsten, 0.0% to 5.5% iron, 0.015% to 0.09% boron, and the balance cobalt plus incidental impurities.

4. An alloy characterized by high temperature creep-resistance and ductility, said alloy consisting of 0.34% carbon, 0.66% manganese, 0.41% silicon, 12.9% nickel, 23.8% chromium, 9.5% tungsten, 4.1% iron, 0.04% boron, and the balance cobalt.

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