United States Patent Office 2,840,469 Patented June 24, 1958

2,840,469

NICKEL-CHROMIUM-MOLYBDENUM ALLOY

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No Drawing. Application June 2, 1955
Serial No. 512,876

Claims priority, application Great Britain June 18, 1954

8 Claims. (Cl. 75—171)

This invention relates to a nickel-chromium-molybdenum base alloy.

Claim is made for the benefit of the filing date of patent application No. 18040/54 filed in Great Britain the 18th day of June 1954.

As the power of the gas-turbine engine is raised by using higher gas temperatures, existing alloys for both the rotating turbine blades and the nozzle guide vanes or static blades not only have a shorter creep life but, owing to the steeper time-temperature rise, are liable to fail by cracking after a limited number of thermal cycles before their static creep life is expended at the higher temperature. The latter failure is because the temperature gradients on both blades and vanes on heating and cooling cause very severe stress conditions in these high powered engines.

The latter form of stressing, more commonly referred to as "Thermal Shock," has become a very serious problem. The edges of the blade or vane in a modern gas-turbine engine in starting up can be raised in a matter of seconds from cold to temperatures in the order of 900° C. on the blade and 1200° C. on the vane while the central portion remains relatively cool and, on shut down of the engine, the edges are cooled again almost as quickly while the central portion remains hot.

An alloy which has very good creep strength usually has poor thermal shock resistance and one which has satisfactory thermal shock resistance usually has poor creep strength. No alloy is known to us which is easy to cast, and in both the as cast and the forged conditions possesses a thermal shock index at 950° C. of 60 or more combined with high creep strength at temperatures in the range of 825 to 1225° C.

It is at present the practice in Great Britain to use nickel-chromium base alloys both for blades and vanes, and to incorporate in such alloys various hardeners, usually including substantial amounts of aluminum and titanium as hardeners, along with molybdenum. When using alloys of this type, it has heretofore been necessary to utilise one species for the manufacture of blades where, because of operation under heavy centrifugal stress at slightly lower temperatures, the most important property to be emphasized is creep strength. On the other hand, this particular species of alloy cannot be satisfactorily used in the vanes where, because of the higher temperatures of operation, a different species of the above alloy has been developed to provide adequate resistance to thermal shock. Thus, two different alloys had heretofore been required for blades and vanes.

In the United States it is common practice to cast both blades and vanes in cobalt base materials such as those known under the name "Stellite," the compositions of which are summarized below.

An alloy according to the present invention possesses a thermal shock index at 950° C. of at least about 60 and an hours to fracture characteristic (creep strength) under stress of 4480 lbs. per square inch at 1050° C. of at least about 30 hours. In its preferred form it has

such index of about 70, and an hours to fracture under the stated conditions of about 350, each substantially higher than the corresponding property of any known alloy. Consequently, we believe we have discovered an alloy which can be used equally well in either blades or vanes, and which is better in either service than the alloys previously used for that purpose.

According to the present invention in its broadest sense, the alloy consists by weight of about 18 to 25% chromium, about 8.5 to 12% molybdenum, about 0.20 to 0.85% carbon, about 5 to 15% cobalt, and the balance essentially nickel, except for impurities.

The effect of variations in the amounts of the foregoing ingredients, according to our present information, is as follows:

Chromium.—The corrosion and creep resistance of the alloy is best when the chromium is between about 20% and 23%. As the amount of chromium is reduced below 20%, there is a progressive falling off in corrosion and creep resistance. When the amount of chromium has been reduced to about 18%, the alloy is no longer sufficiently resistant to be acceptable for the purposes mentioned. Increasing the amount of chromium above 23% appears to be without detriment to the qualities of the alloy. Since however chromium appears to serve no useful function in amounts larger than about 23 to 25%, we do not recommend its use in larger amounts.

Molybdenum.—Our alloy appears to be at its best when the molybdenum is about 9.5 to 11%. As the amount of molybdenum is reduced below about 9.5%, the creep strength falls off progressively. If the molybdenum is less than about 8.5%, the alloy is unacceptable for use in turbine blades because its creep strength is less than that of other alloys. We do not find that any significant advantage (or detriment) is produced in the properties of our alloy by increasing the molybdenum above 11 to 12%, and therefore do not recommend its use in larger amounts.

Carbon.—The highest creep strength is attained when the carbon is in the approximate range 0.30 to 0.50%, combined with optimum amounts of cobalt as pointed out below. A reduction of carbon below about 0.30% produces detectable reduction in the thermal shock and creep properties of the alloy, and when carbon is below about 0.20% these properties are so far reduced that the alloy is no longer useful for its intended purpose. Likewise, an increase of carbon from about 0.50 to 0.85%, with the same amount of cobalt, produces a progressive deterioration of the thermal shock and creep properties, and when the carbon exceeds about 0.85% these properties have fallen off so far that the alloy is no longer useful for its intended purpose.

Cobalt.—The best results are obtained using cobalt within the range of about 9 to 11%, with carbon held constant in the optimum portion of its range. As the amount of cobalt is progressively reduced from about 9 to 5%, there is a slight but progressive reduction in the creep strength of the alloy, and when the amount of cobalt is reduced below about 5% the creep properties are such that the alloy is no longer useful for its intended purpose. Increase of cobalt from about 11 to 15% does not appear to cause any significant improvement (or detriment) in the properties of the alloy. Since cobalt is costly and scarce, it is not believed that it would serve any useful function in the present alloy in amounts above 15%. Above about 15% there is a significant falling off of the thermal shock properties.

Impurities.—While aluminum and titanium have regularly been included as hardeners in the several kinds of alloys heretofore used for the blades and vanes of gas-turbine engines, we find that in the alloy of the present invention they seriously reduce creep strength and, if

present as impurities, are to be kept at a minimum. In making up alloys according to this invention, aluminium should not exceed about 0.2%, titanium should not exceed about 0.3%, iron should not exceed about 0.75%, and residual traces of cleansers and deoxidisers such as silicon and manganese should not exceed about 1%. Furthermore, as will be understood by experts in this art, all of the impurities stated should not simultaneously be present at their stated maximum amounts. The total of all of the foregoing impurities, together with such other impurities as may be present, should not exceed about 2%.

The following table contains data with respect to the creep strength of various alloys within and without our invention. Each of the five alloys set forth in Table I below contained about 21% chromium, 10% molybdenum, the amounts of carbon and cobalt respectively stated for each, and the balance essentially all nickel plus impurities as above described:

TABLE I

Effect on creep strength of variations in carbon and cobalt

Alloy No.	Carbon, percent	Cobalt, percent	Hours to fracture, 2 t. s. i./ 1,050° C.
1	0.14	4.8	15.5
2	0.14	8.6	28.0
3	0.29	5.0	78.0
4	0.33	10.0	357.5
5	0.58	9.72	133.3
6	0.75	9.55	40.0

The expression "t. s. i." means long tons (of 2240 lbs. each) per square inch.

Of the foregoing examples alloys Nos. 3, 4, 5 and 6 are within the scope of our invention having an hours to fracture characteristic under the stated conditions of at least about 30 hours. On the other hand, alloys Nos. 1 and 2 are not within the scope of our invention. In each of these the carbon is too low, and in the case of alloy No. 1 the cobalt is also too low. Alloys Nos. 3, 4 and 5 are within the preferred range of our alloy in that the hours to fracture characteristic is at least about 50 hours or more. The best form of our alloy known to us is approximately that indicated by alloy No. 4, which has an hour to fracture characteristic under the stated condition above 350 hours.

The deleterious effects of the addition of excessive amounts of the impurities aluminium and titanium are indicated in Table II below. The alloys referred to in this table consist of about 21% chromium, 10% molybdenum, the amounts of carbon, cobalt, aluminium and titanium respectively set forth in the table, and the balance essentially nickel plus residual impurities. Alloy No. 5 in this table is the same as the alloy of the same number in Table I.

TABLE II

Effect on creep strength of addition of aluminium and titanium

Alloy No.	Carbon, Percent	Cobalt, Percent	Aluminium, Percent	Titanium, Percent	Hours to Fracture, 2 t. s. i./ 1,050° C.
5	0.58	9.72	0	0	133.3
7	0.56	9.9	0.93	2.04	22

The superior thermal shock resistance of our alloy, in comparison with that of other known alloys heretofore used in the nozzle vanes of internal combustion turbine engines, was shown by the following thermal shock test, by which the thermal shock index for the alloy was determined.

According to this test a piece of the alloy is cast in such manner as to have an acute-angle edge, the contained angle between the two flat sides of the piece being about 25°. The edge itself is rounded so that the distance between the points at each side where the rounded edge merges into the flat side of the piece is approximately .062 inches. In each cycle of the test, such a piece is raised in temperature from room temperature to the indicated maximum temperature of the particular test (i. e. 850°, 950° C., etc.) at an average rate of about 30° to 50° C. per second, held at the indicated maximum temperature for five seconds, and then cooled at approximately the same rate by a spray of water or compressed air, or both, to room temperature. The spray is maintained for a period of about forty seconds, and the cycle is then repeated. In these tests the "thermal shock index" for the designated temperature is the number of complete cycles reaching that temperature which the piece will withstand before appearance of a crack visible to the naked eye extending completely across the rounded edge from one side or point of tangency to the other.

As shown in Table III below, these tests were carried out at various maximum temperatures. The alloys used in these tests for comparison with the alloy according to the present invention are alloys which have heretofore been used in the guide vanes and turbine blades of internal combustion turbine engines.

TABLE III

Thermal shock index at various maximum temperatures

[Number of cycles to crack]

Alloy No.	850° C.	950° C.	1,050° C.	1,150° C.
8	10	10	5	4
9	25	37	20	----
10	90	58	20	----
11	[1] 125	70	25	10
12	85	60	17	8
13	5	6	12	5

[1] Test suspended, no sign of cracking or other failure.

The alloys used in the above tests were as follows:

Alloy No. 8 was the alloy known in Great Britain as "H. R. Crown Max" which, until about November 1953, was in regular use in the guide vanes of Rolls-Royce "Dart" engines. This alloy, which does not contain molybdenum or cobalt, consists approximately of 0.15 to 0.30% carbon, 0.75 to 2% silicon, a maximum of 1% manganese, 10 to 15% nickel, 20 to 25% chromium, 2.5 to 3.5% tungsten, and the remainder (over 50%) iron.

The alloy referred to above as alloy No. 9 is the alloy sold in Great Britain under the name "Nimonic 90" which has been widely used in the turbine blades of internal combustion turbine engines. It does not contain any molybdenum. Its composition is approximately not more than 0.10% carbon, not more than 1.5% silicon, not more than 1% manganese, not more than 5% iron, 0.8 to 2% aluminium, 1.8 to 3% titanium, 18 to 21% chromium, 15 to 21% cobalt, and the balance (about 50%) nickel.

The alloy referred to above as alloy No. 10 is the alloy known commercially in Great Britain as "C.130" which since November 1953 has been in regular use in the nozzle guide vanes of Rolls-Royce "Dart" engines. This alloy does not contain any appreciable amount of cobalt nor more than trace amounts of carbon and relies upon the presence of substantial amounts of aluminium and titanium. Such alloy consists of about 21 to 23% chromium, 9.5 to 0.5% molybdenum, 0.7 to 1% aluminium, 2.4 to 2.9% titanium, not more than 0.06% carbon, not more than 0.75% iron, not more than 0.60% silicon, not more than 0.60% manganese, no cobalt, and the balance (nearly 60%) nickel plus traces of impurities.

Alloy No. 11, which was made according to the present invention, consists of about 21% chromium, 9.6%

molybdenum, 0.35% carbon, 10% cobalt, and the balance essentially nickel plus impurities as above described.

The alloy referred to above as alloy No. 12 is the alloy known commercially as "Stellite 21" and commonly used in the United States as a casting material for vanes and blades. This alloy is of cobalt base and its composition is approximately 0.2 to 0.3% carbon, 1% max. manganese, 1% max. silicon, 0.007% max. boron, 3% max. iron, 25 to 29% chromium, 1.75 to 3.75% nickel, 5 to 6% molybdenum, and the remainder cobalt.

The alloy No. 13 referred to above is that known as "Stellite No. 31" and is also commonly used in the United States for casting vanes and blades. It is of cobalt base and its composition is approximately 0.45 to 0.55% carbon, 1% max. manganese, 1% max. silicon, 0.04% max. phosphorus, 0.04% max. sulphur, 2% max. iron, 24.5 to 26.5% chromium, 9.5 to 11.5% nickel, 7 to 8% tungsten, and the remainder cobalt.

Our alloy may be prepared by any of the electric furnace melting processes which are well-known to those skilled in the art.

The alloy may be used as cast or in the forged condition by which we mean mechanically reduced in cross-section area. Stationary blades and vanes are preferably cast and turbine rotating blades preferably forged.

When forged a suitable heat treatment is solution treatment at 1200° to 1280° C. for a period of 1 to 4 hours, followed by air cooling and thereafter followed by an ageing heat treatment of 1 to 8 hours at 750° to 1000° C.; the part is again air cooled. Normally where the alloy is used in the cast condition it is not heat treated.

Percentages of composition throughout this specification are percentages by weight of the whole alloy.

What is claimed is:

1. An alloy having a thermal shock index at 950° C. of at least about 60, and an hours to fracture characteristic under stress of 4480 lbs. per sq. inch at 1050° C. of at least about 30 hours, said alloy consisting essentially by weight of about 18 to 25% chromium, about 8.5 to 12% molybdenum, the impurities iron, aluminium and titanium not exceeding respectively about 0.75% of iron, about 0.2% of aluminium and about 0.3% of titanium, all impurities including residual traces of cleansers and de-oxidizes not exceeding about 2%, and the balance nickel, said alloy being characterized in that it contains about 0.20 to 0.85% carbon and about 5 to 15% cobalt.

2. An alloy having a thermal shock index at 950° C. of at least about 60, and an hours to fracture characteristic under stress of 4480 lbs. per sq. inch at 1050° C. of at least about 30 hours, said alloy consisting essentially by weight of about 18 to 25% chromium, about 8.5 to 12% molybdenum, about 0.20 to 0.85% carbon, about 5 to 15% cobalt, and the balance nickel plus impurities.

3. An alloy having a thermal shock index at 950° C. of at least about 60, and an hours to fracture characteristic under stress of 4480 lbs. per sq. inch at 1050° C. of at least about 50 hours, said alloy consisting essentially by weight of about 18 to 25% chromium, about 8.5 to 12% molybdenum, the impurities iron, aluminium and titanium not exceeding respectively about 0.75% iron, about 0.2% aluminium and about 0.3% titanium, all impurities including residual traces of cleansers and de-oxidizers not exceeding about 2%, and the balance nickel, said alloy being characterized in that it contains about 0.20 to 0.60% carbon and about 5 to 11% cobalt.

4. An alloy having a thermal shock index at 950° C. of at least about 60, and an hours to fracture characteristic under stress of 4480 lbs. per. sq. inch at 1050° C. of at least about 50 hours, said alloy consisting essentially by weight of about 20 to 23% chromium, about 9.5 to 11% molybdenum, about 0.30 to 0.60% carbon, about 9 to 11% cobalt, and the balance nickel plus impurities.

5. An alloy having a thermal shock index at 950° C. of at least about 60, and an hours to fracture characteristic under stress of 4480 lbs. per sq. inch at 1050° C. of about 78 hours, said alloy consisting by weight of about 21% chromium, about 10% molybdenum, the impurities iron, aluminium and titanium not exceeding respectively about 0.75% of iron, about 0.2% of aluminium, and about 0.3% of titanium, all impurities including residual traces of cleansers and de-oxidizers not exceeding about 2%, and the balance essentially nickel, said alloy being characterized in that it contains about 0.20% carbon and about 5% cobalt.

6. An alloy having a thermal shock index at 950° C. of at least about 60, and an hours to fracture characteristic under stress of 4480 lbs. per sq. inch at 1050° C. of about 133.3 hours, said alloy consisting by weight of about 21% chromium, about 10% molybdenum, the impurities iron, aluminium and titanium not exceeding respectively about 0.75% of iron, about 0.2% of aluminium, and about 0.3% of titanium, all impurities including residual traces of cleansers and de-oxidizers not exceeding about 2%, and the balance essentially nickel, said alloy being characterized in that it contains about 0.58% carbon and about 9.72% cobalt.

7. An alloy having a thermal shock index at 950° C. of at least about 60, and an hours to fracture characteristic under stress of 4480 lbs. per sq. inch at 1050° C. of about 40 hours, said alloy consisting by weight of about 21% chromium, about 10% molybdenum, the impurities iron, aluminium and titanium not exceeding respectively about 0.75% of iron, about 0.2% of aluminium, and about 0.3% of titanium, all impurities including residual traces of cleansers and de-oxidizers not exceeding about 2%, and the balance essentially nickel, said alloy being characterized in that it contains about 0.75% carbon and about 9.55% cobalt.

8. An alloy having a thermal shock index at 950° C. at least about 60, and an hours to fracture characteristic under stress of 4480 lbs. per sq. inch at 1050° C. of at least about 30 hours, said alloy consisting essentially by weight of about 21% chromium, about 9.6% molybdenum, the impurities iron, aluminium and titanium respectively about 0.75% of iron, about 0.2% of aluminium, and about 0.3% of titanium, all impurities including residual traces of cleansers and de-oxidizers not exceeding about 2%, and the balance nickel, said alloy being characterized in that it contains about 0.35% carbon and about 10% cobalt.

References Cited in the file of this patent

UNITED STATES PATENTS

2,712,498 Gresham et al. ---------- July 5, 1955

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 2,840,469 June 24, 1958

Harold E. Gresham et al.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 2, line 37, after "above" insert -- about --; line 68, for "aluminum" read -- aluminium --; column 4, line 69, for "0.5%" read -- 10.5% --; column 5, line 44, for "de-oxidizes" read -- de-oxidizers --; column 6, line 21, for "0.20%" read -- 0.29% --; line 52, after "titanium" insert -- not exceeding --.

Signed and sealed this 16th day of September 1958.

(SEAL)
Attest:
KARL H. AXLINE
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