# United States Patent [19]

**Baldwin et al.**

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[54] **NICKEL-BASE ALLOYS HAVING A LOW COEFFICIENT OF THERMAL EXPANSION**

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[22] Filed: **Dec. 21, 1973**

[21] Appl. No.: **427,311**

[52] **U.S. Cl.** .................. **75/171**; 75/134 F; 148/32; 148/32.5
[51] **Int. Cl.**$^2$ ........................................ **C22C 19/05**
[58] **Field of Search** .................. 75/171, 170, 134 F; 148/32, 32.5

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*Attorney, Agent, or Firm*—Finnegan, Henderson, Farabow & Garrett

## [57] ABSTRACT

Alloy compositions consisting predominantly of nickel, chromium, molybdenum, carbon, and boron are disclosed. The alloys possess a duplex structure consisting of a nickel-chromium-molybdenum matrix and a semi-continuous network of refractory carbides and borides. A combination of desirable properties is provided by these alloys, including elevated temperature strength, resistance to oxidation and hot corrosion, and a very low coefficient of thermal expansion.

**14 Claims, 4 Drawing Figures**

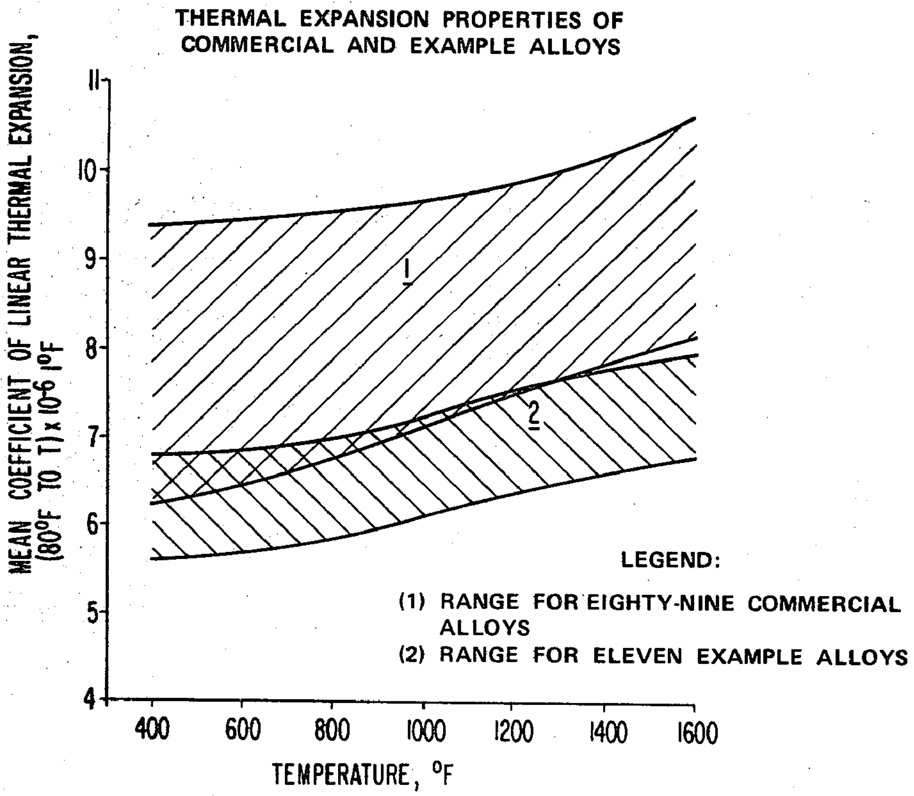


FIG. 1

THERMAL EXPANSION PROPERTIES
OF COMMERCIAL IRON, NICKEL AND
COBALT–BASE SUPERALLOYS

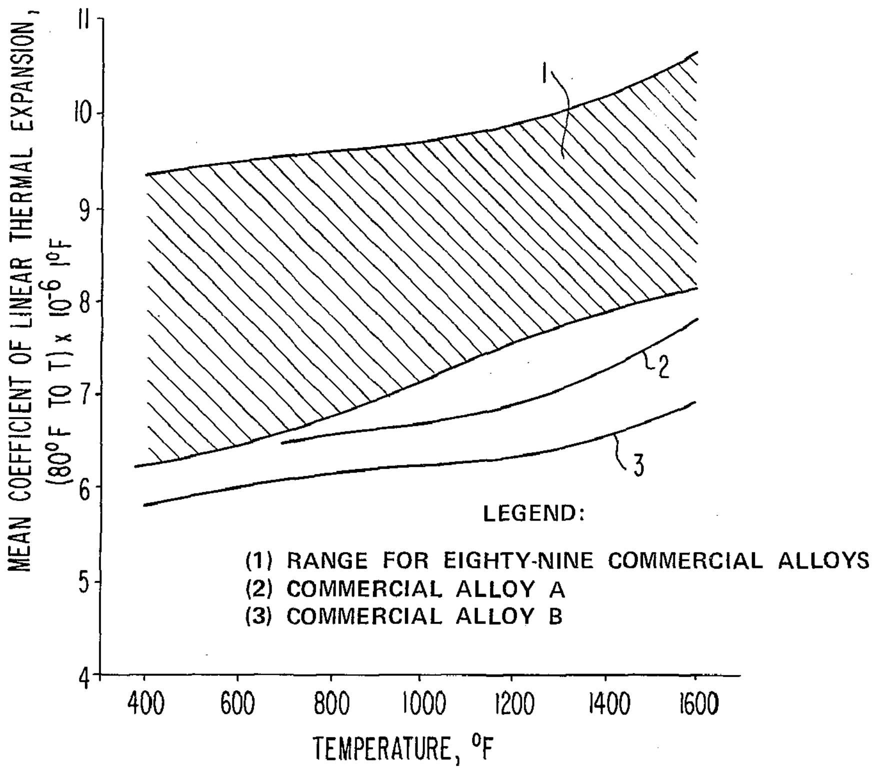


FIG. 2

100 HOUR CREEP RUPTURE LIFE
TEMPERATURE VS. STRESS
COMMERCIAL ALLOYS

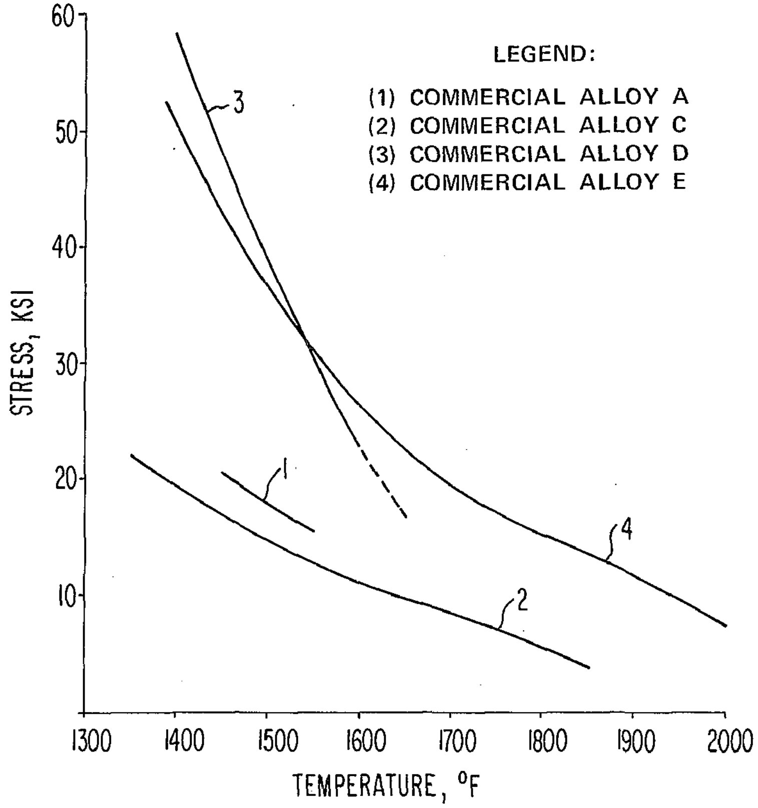


FIG.3

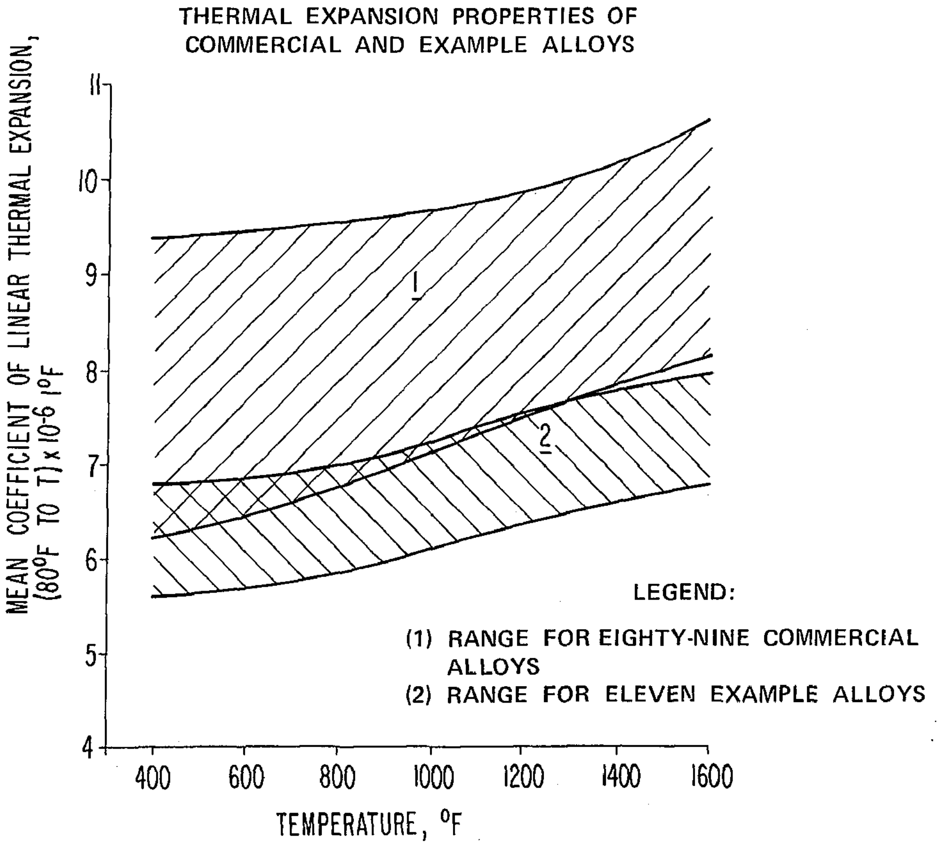
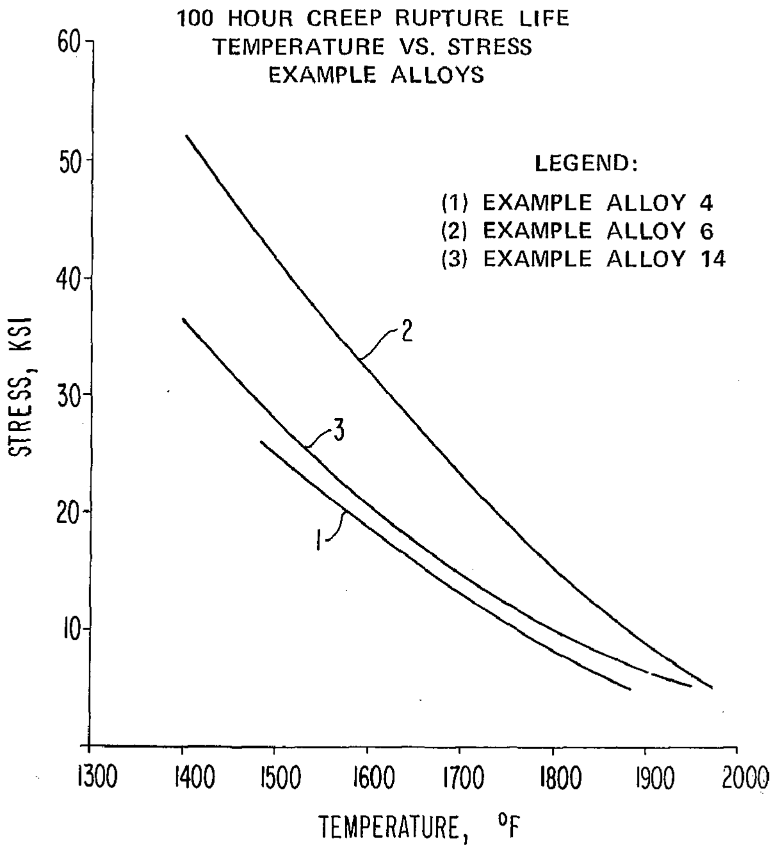

THERMAL EXPANSION PROPERTIES OF COMMERCIAL AND EXAMPLE ALLOYS
MEAN COEFFICIENT OF LINEAR THERMAL EXPANSION, (80°F TO T) x 10-6 /°F
11
10
9
8
7
6
5
4
400
600
800
1000
1200
1400
1600
TEMPERATURE, °F
1
2
LEGEND:
(1) RANGE FOR EIGHTY-NINE COMMERCIAL ALLOYS
(2) RANGE FOR ELEVEN EXAMPLE ALLOYS

FIG.4


100 HOUR CREEP RUPTURE LIFE TEMPERATURE VS. STRESS EXAMPLE ALLOYS
STRESS, KSI
60
50
40
30
20
10
1300
1400
1500
1600
1700
1800
1900
2000
TEMPERATURE, °F
LEGEND:
(1) EXAMPLE ALLOY 4
(2) EXAMPLE ALLOY 6
(3) EXAMPLE ALLOY 14
2
3
1

# NICKEL-BASE ALLOYS HAVING A LOW COEFFICIENT OF THERMAL EXPANSION

## FIELD OF INVENTION

The present invention pertains to nickel base alloy compositions consisting predominantly of nickel, chromium, molybdenum, and carbon. Preferably, the alloys also contain boron. The alloys of the present invention provide a unique, and previously unavailable combination of properties including elevated temperature strength, resistance to oxidation, resistance to corrosion at elevated temperatures, and a very low coefficient of thermal expansion. The nickel base alloys of this invention are particularly useful for making hard facing welding rods both in cast wire and powder form; components for use in the glass forming industry; and components for use in hot sections of gas turbine engines, such as integral wheels, turbine shrouds, cases, seals, and the like.

## BACKGROUND OF INVENTION

In recent years, there has developed a need for alloys having low thermal expansion characteristics coupled with elevated temperature capabilities. The need for such alloys, for the most part, has arisen in connection with gas turbine technology. With the growing demand for improved engine efficiency, attention has been focused upon increasingly sophisticated engine designs. Low thermal expansion characteristics of alloys from which gas turbine engine components are fabricated, is important if maximum engine efficiency is to be achieved under all modes and conditions of operation. Specifically, as adjacent engine components heat and cool, critical clearance dimensions change. In many cases, the ability to substantially maintain critical clearance dimensions throughout the full spectrum of engine operating conditions, will determine the success or failure of a particular engine design.

A typical situation is presented with respect to gas turbine engine shrouds. Gas turbine engine shrouds may be visualized as an open ended, thin-walled cylinder. Within the cylinder, a disk with radially attached blade air foils rotates about an axis which is common with the longitudinal axis of the cylinder. The clearance between the tips of the rotating blades and the inside surface of the cylinder will to a large extent, control the efficiency of the engine. If the shroud expands more than the blade air foils during engine operation, the clearance increases and the engine efficiency falls off sharply.

Gas turbine engine components fabricated from alloys having low coefficients of thermal expansion are advantageous for reasons other than maintaining critical clearance dimensions. It has been determined that a low coefficient of thermal expansion is an essential physical property for improving thermal fatigue or thermal shock cycling resistance in high temperature alloys.

Alloys suitable for fabricating objects such as components for gas turbine engines desirably possess a number of other properties in addition to low coefficients of thermal expansion. Such alloys must simultaneously possess a number of high temperature properties including resistance to oxidation, sulfidation, and other forms of environmental deterioration. In the past, exhaustive research has been conducted to develop alloys exhibiting resistance to oxidation and sulfidation. It is well recognized in the art that resistance to environmental deterioration in alloy compositions is controlled by the interaction of various alloying constituents. Chromium is by far the most influential solute element effecting resistance environmental deterioration. However, large amounts of chromium adversely affect high temperature creep rupture strength. For applications such as gas turbine components, high temperature creep rupture strength is also an important consideration.

The alloys currently used commercially for high temperature applications possess one, or in some instances two, of the three characteristics described heretofore (low coefficient of thermal expansion, high temperature corrosion resistance, and good creep rupture strength at elevated temperatures) that are desired in alloys useful for the fabrication of gas turbine components. For example, commercial nickel base alloys are available which exhibit remarkably low thermal expansion properties in comparison with typical high temperature alloys. However, the very low chromium content of such alloys renders them unacceptable for use in the uncoated condition at temperatures over about 1400°F. in sulfidizing environments. Such alloys deteriorate catastrophically at temperatures higher than 1,800°F. under sulfidizing conditions.

Other commercially available alloys exhibit excellent resistance to environmental deterioration, but typically such alloys are confined to low stress applications at temperatures over 1,600°F. More importantly, such alloys generally exhibit high thermal expansion properties typical of nickel base alloys.

There are a number of precipitation strengthened nickel base super alloys which, because of their strength for resisting creep deformation at elevated temperatures, are used as materials for fabricating components for use in high temperature sections of gas turbines. The conventional strengthening mechanism employed involved precipitation of an ordered intermetallic phase, generally referred to as gamma prime, having the generic formula $Ni_3(Al\ Ti)$. As amounts of aluminum and titanium have been increased, to increase the amount of precipitate formed and thereby increase strength, it is necessary to decrease the chromium content. The chromium content must be decreased in order to maintain an overall alloy composition that possesses microstructural stability and high temperature strength. As chromium content is decreased, the resistance to oxidation and sulfidization necessarily decreases.

Despite the apparent dilemma of being able to select either a strong alloy or one with good resistance to environmental deterioration, a few compositions have evolved with a relatively good balance of both properties. However, even these compositions are suitable for use only in gas turbine engines employing high grade aviation fuels and operating conditions whereby hot corrosion and sulfidization are minimized, unless an oxidation and sulfidization resistant coating is applied to components formulated from such alloys.

Furthermore, despite the good combination of strength and corrosion resistance, such alloys are not well suited for applications in which low thermal expansion is a primary concern. Such alloys have high thermal expansion properties typical of nickel base superalloys.

Cobalt based superalloys rely on solid solution strengthening and a dispersion of primary carbides for elevated temperature strength. For this reason, cobalt based alloys will accommodate a significantly greater percentage of chromium than nickel base alloys. As a general proposition, cobalt base superalloys may be categorized as weaker, but more corrosion resistant, than nickel base materials. The expansion properties of cobalt base alloys are generally higher than nickel base alloys, making cobalt base alloys even less attractive for applications which require low thermal expansion.

The present invention pertains to nickel base alloy compositions possessing a very low coefficient of linear thermal expansion and sulfidation resistance adequate to enable use of uncoated components fabricated from the alloys in corrosive environments. In addition, the alloys possess elevated temperature strength characteristics adequate to permit the alloys to be employed for numerous high temperature applications.

The alloys of the present invention contain unusually high levels of chromium and molybdenum. In the vast majority of cases, chromium and molybdenum containing commercial nickel base alloys contain concentrations of chromium and molybdenum which are below the respective solubility limit of each element in nickel. In the alloys of the present invention, the concentration of chromium and molybdenum far exceeds normal solubility limits in nickel.

Excess chromium and molybdenum in the alloys are prevented from forming deleterious embrittling phases through the addition of boron and carbon. Boron and carbon react with chromium and molybdenum to form borides and carbides. Unusual and unexpected strength improvements result from the boride and carbide dispersions so produced.

High concentrations of chromium in both the metallic matrix and the strengthening dispersoid result in unusually high resistance to sulfidation and corrosion at elevated temperatures. The presence of all four major alloying constituents (chromium, molybdenum, boron, and carbon) serve to lower the thermal expansion properties of the alloys. The expansivity of specific alloy compositions within the scope of the present invention is lower than any known commercial nickel, cobalt, or iron-base alloy.

The present invention provides a nickel-base alloy having a low coefficient of thermal expansion as well as elevated temperature strength and resistance to high temperature corrosion. In addition, the present invention provides a nickel base alloy composition having a high elevated temperature hardness and corrosion resistance suitable for use in high temperature hard facing applications. Furthermore, the present invention provides high strength nickel base alloys of sufficient chromium content to resist the fluxing action of molten oxides and thus is suitable for fabricating components useful in the manufacture of glass shapes.

## SUMMARY OF INVENTION

In general terms, the present invention pertains to nickel base alloy compositions consisting essentially of nickel, chromium, molybdenum, carbon and boron. These alloys have good elevated temperature strength, resistance to oxidation, and resistance to hot corrosion, as well as a very low coefficient of thermal expansion. The invention also concerns components for use in gas turbine engines and hard facing welding rod made from such alloys.

Table I sets forth a broad range, an intermediate range, and two different and narrower ranges, in terms of percent by weight, of elements employed in the alloys of the present invention. It should be understood that the tabulation in Table I relates to each element individually, and is not intended to solely define composites of broad and narrow ranges. Nevertheless, composites of the narrower ranges specified in Table I represent particularly preferred embodiments.

TABLE I

| Element | Broad Range | Intermediate Range | Narrower Ranges | |
|---|---|---|---|---|
| Cr | 24–42 | 28 – 42 | 38 – 42 | 33 – 37 |
| Mo | 8–22 | 12 – 20 | 12 – 16 | 16 – 20 |
| C | 0.1–1.4 | 0.15 – 1.2 | 0.5 – 1.2 | 0.3 – 1.2 |
| B | 0–0.8 | 0.04 – 0.7 | 0.2 – 0.7 | 0.15 – 0.5 |
| Ni | Balance | Balance | Balance | Balance |

In addition to the alloying constituents specifically set forth in Table I, the alloys of the present invention may contain minor amounts of other elements ordinarily included in nickel base alloys by those skilled in the art which will not substantially deleteriously affect the important characteristics of the alloy or which are inadvertently included in such alloys by virtue of impurity levels in commercial grades of alloying ingredients. Impurities and incidental elements which may be present include titanium, manganese and silicon in amounts normally employed to achieve castability and melt deoxidation. Typically, these elements would be present in amounts less than 1 percent and preferably manganese and silicon would each be present in amounts of not more than 0.5 percent while titanium would be present in amounts of not more than 0.2 percent. Other impurities and incidental elements which may be present in the alloys of the present invention include copper in amounts of not more than 0.5 percent, sulphur and phosphorous in amounts of not more than 0.20 percent and iron and cobalt in amounts of not more than 2.0 percent. Impurities such as nitrogen, hydrogen, tin, lead, bizmuth, calcium and magnesium should be held to as low a concentration as practical.

## BRIEF DESCRIPTION OF THE DRAWINGS:

FIG. 1 is a graphical plot of thermal expansion properties of commercial iron, nickel and cobalt-base superalloys.

FIG. 2 is a graphical plot depicting 100 hour creep rupture life for various commercial alloys.

FIG. 3 is a plot of thermal expansion properties for commercial iron, nickel and cobalt base superalloys and for example alloys of the present invention.

FIG. 4 is similar to FIG. 2 but represents example alloys of the present invention rather than commercial alloys.

## DESCRIPTION OF EXAMPLES AND PREFERRED EMBODIMENTS:

As previously noted, commercially available high temperature alloys may possess some of the characteristics desired in an alloy useful for fabricating components of gas turbine engines, but such alloys do not possess all of the desired characteristics. This may be illustrated with reference to several commercial alloys whose compositions are presented in Table II. As shown in FIG. 1, commercial alloys A and B of Table II show remarkably low thermal expansion properties in comparison with typical high temperature alloys. In FIG. **1**, the shaded area designated **1** represents a range of mean coefficients of linear thermal expansion at various temperatures for **89** commercial iron, nickel and cobalt-base superalloys. Curves **2** and **3** represent plots of mean coefficients of thermal expansion against temperature for, respectively, commercial alloys A and B.

In the case of both commercial alloy A and B, their low thermal expansion is attributed to the presence of unusually high levels of molybdenum, a refractory element with low expansivity. The total absence or very low chromium content in these alloys renders them unacceptable for service, in an uncoated condition, at temperatures over about 1,400°F. in a sulfidizing environment. Both alloys deteriorate catastrophically at temperatures of 1,800°F. and higher under sulfidizing conditions.

TABLE II

| Commercial Alloy | Ni | Co | Fe | Cr | Mo | W | Al | Ti | Cb | Ta | C | B | Zr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A* | (1) | 2.5 | 5 | 0.6 | 28 | — | — | — | — | — | 0.1 | — | — |
| B* | (1) | — | — | — | 18 | — | 8 | — | — | — | .04 | — | — |
| C | (1) | 1.5 | 19 | 22 | 9 | 0.6 | — | — | — | — | 0.1 | — | — |
| D** | (1) | 20 | — | 29 | — | — | 1.2 | 2.3 | 0.7 | — | .05 | .003 | .05 |
| E | 10 | (1) | — | 24 | — | 7 | — | 0.2 | — | 3.5 | 0.6 | — | 0.5 |

(1) Balance

*No sulfidation resistance unless coated

**Vacuum Melted

In addition to inadequate environmental corrosion resistance, the elevated temperature strength of commercial alloy A is so limited that it cannot be employed for components subjected to high stress at temperatures of above 1,600°F. This is illustrated in FIG. **2** which plots 100 hour creep rupture life in terms of temperature versus stress for a number of commercial alloys. Curve **1** of FIG. **2** represents commercial alloy A. As may be further seen from FIG. **2**, commercial alloy C (curve **2**) also lacks adequate elevated temperature strength. Commercial alloys D and E (curves **3** and **4**, respectively, of FIG. **2**) possess better high temperature strength characteristics, but not as high as desired at temperatures above about 1,600°F. Although the strength of commercial alloy B is excellent through about 2,200°F., the total lack of environmental corrosion resistance severely restricts its use.

Commercial alloys C, D and E possess exceptional resistance to environmental deterioration. However, the thermal expansion properties of all of these alloys are high, typical of nickel-base alloys falling within the shaded area of FIG. **1.** The high thermal expansion properties of these elements is a major drawback with respect to their use for fabrication of certain gas turbine engine components.

As shown by the formulations of Table II, the use of chromium and molybdenum as major alloying constituents in high temperature nickel-base alloys is relatively common. The advantages and effect of each element is known to those skilled in the art. However, in certain compositions, it has been observed that these elements, if present together in sufficient quantity will cause the precipitation of brittle phases in the form of needles or platelets. The resultant effect on high temperature strength and ductility can be severe.

In the high chromium, high-molybdenum alloys of the present invention, the amount of chromium available for brittle, acicular phase formation, is reduced through the addition of carbon and boron. Chromium

forms stable carbides and both chromium and molybdenum form stable borides.

Evaluation of cast alloys in accordance with the present invention shows a noticeable increase in alloy hardness in comparison to similar alloys which do not contain borides and carbides. Microstructural examination confirms that refractory carbides and borides are formed on solidification of the alloy. In addition microstructural examination shows that the carbide and boride constituents are rejected by the solidifying metallic dendrites. The continuity of the metallic phase on a microstructural scale can be controlled by varying the alloy composition, but the network of particulate carbides and borides remains fairly continuous.

It has further been found that in addition to an improvement in room temperature hardness, the elevated temperature-creep rupture strength of alloys in accordance with the present invention which contain only 0.5 to 1.0 percent carbon approaches the strength of several commercial cast cobalt base superalloys. The simultaneous addition of carbon and boron results in creep-rupture strength comparable to several widely used commercial cobaltbase cast alloys. The maximum creep rupture strength observed in alloys in accordance with the present invention containing both carbon and boron is 42,000 psi for rupture in 100 hours at 1,500° F. This value is approximately 10 percent higher than the strongest known cast cobalt-base superalloy.

A number of example alloy compositions in accordance with the present invention were studied, using material melted and cast in air in standard shell test bar and weld rod molds. Thirty to 50 lb. heats were produced for each composition studied. Response to heat treatment was determined by subjecting the test materials to a 24-hour aging exposure at 1,600° F. Alloys that demonstrated an aging response were given the 1,600°F. aging treatment prior to testing or were subjected to a 2,150°F. stress relief/solution anneal prior to aging and testing.

Creep rupture tests were conducted at temperatures between 1,400°F. and 2,000°F. under loads that would enable comparison of properties with those of commercial alloys. The measurements of thermal expansion properties were conducted on ground cylindrical specimens 2 inches in length and 0.200 inches in diameter using standard dialatometric methods.

Hot corrosion and resistance to sulfidization were studied by subjecting 1 inch long, 0.50 inch diameter, cylindrical specimens to a 300 hour partial exposure immersion in molten 90% $Na_2SO_4$ – 10% NaCl salt mixture at 1,600°F. Resistance was determined by the measurement of weight loss per unit area and by determination of surface recession rate by metallographic means.

Analysis of the example alloys is presented in Table III, in terms of percent by weight of alloying constituents. The results of thermal expansion studies are presented in Table IV and graphically represented FIG. **3**, in comparison with commerical alloys. In FIG. **3**, shaded area **1** represents the range of mean coefficient of linear thermal expansion over the temperature range between about 400°F. and 1,600°F. for 89 commercial high temperature alloys while shaded area **2** represents the same range for **11** example alloys. As shown in FIG. **3**, alloys within the scope of the present invention tend to have substantially lower thermal expansion properties than conventional commercial superalloys.

### TABLE III

| Example Alloy | Elements | | | | | | |
|---|---|---|---|---|---|---|---|
| | Ni | Cr | Mo | B | C | Mn | Si |
| 1 | (1) | 25 | 18 | — | 0.5 | — | — |
| 2 | (1) | 30 | 18 | — | 1.0 | — | — |
| 3 | (1) | 30 | 18 | 0.2 | 1.0 | — | — |
| 4 | (1) | 35 | 18 | 0.2 | 1.0 | — | — |
| 5 | (1) | 35 | 18 | 0.5 | 1.0 | — | — |
| 6 | (1) | 40 | 14 | 0.5 | 1.0 | — | — |
| 7 | (1) | 40 | 14 | 0.05 | 1.0 | — | — |
| 8 | (1) | 40 | 14 | 0.5 | 0.5 | — | — |
| 9 | (1) | 35 | 18 | 0.05 | 1.0 | — | — |
| 10 | (1) | 35 | 18 | 0.2 | 0.5 | — | — |
| 11 | (1) | 30 | 18 | 0.05 | 0.5 | — | — |
| 12 | (1) | 30 | 18 | 0.2 | 0.5 | — | — |
| 13 | (1) | 30 | 18 | 0.2 | 0.5 | 0.5 | 0.5 |
| 14 | (1) | 30 | 18 | 0.5 | 0.2 | — | — |
| 15 | (1) | 30 | 18 | 0.2 | 0.2 | — | — |

(1) Balance

### TABLE IV

| Example Alloy | Mean Coefficient Of Linear Thermal Expansion from 80°F to Indicated Temperature | | | |
|---|---|---|---|---|
| | 400°F. | 800°F. | 1200°F. | 1600°F. |
| 1 | 6.79 | 6.94 | 7.56 | 7.96 |
| 2 | 5.87 | 6.53 | 7.02 | 7.17 |
| 4 | 5.56 | 5.83 | 6.40 | 6.77 |
| 5 | 6.17 | 6.39 | 6.84 | 7.03 |
| 6 | 6.17 | 6.39 | 6.76 | 7.23 |
| 7 | 5.87 | 5.97 | 6.76 | 7.17 |
| 8 | 5.87 | 6.11 | 6.84 | 7.17 |
| 11 | 6.17 | 6.53 | 7.02 | 7.36 |
| 12 | 5.71 | 6.31 | 7.06 | 7.59 |
| 14 | 6.31 | 6.44 | 7.10 | 7.52 |
| 15 | 6.17 | 6.39 | 7.20 | 7.56 |

Creep rupture test results for various example alloys are set forth in Tables V and VI and in FIG. **4**. The data tabulated in Table V for each of the example alloys includes time to rupture in hours under various conditions of temperature and stress, the tolerated final total elongation or linear creep strain, the reduction in area of the specimen diameter in the area of fracture, and a calculated equivalent stress to produce rupture in 100 hours at 1,500°F. The temperature of 1,500°F. was selected because it would enable comparison with other alloys which are candidates for use in applications which require low expansion.

Table VI tabulates creep rupture test results for notched specimens. Time to rupture in hours at 1,600°F. under stress of 22,000 psi is given for a number of example alloys.

FIG. **4** represents a plot of 100 hour creep rupture life as temperature versus stress for a number of example alloys. In FIG. **4**, curves **1**, **2** and **3**, respectively, represent example alloys **4**, **6** and **14**.

### TABLE V

| Example Alloy | Creep-Rupture Properties Test Conditions Temp. °F. | Stress, psi | Life, Hrs. | % El. | % RA | 1500°F.-100 Hr. Rupture Stress |
|---|---|---|---|---|---|---|
| 1 | 1600 | 20,000 | 8.6 | 19.0 | 33.1 | — |
| | 1600 | 20,000 | 9.9 | 26.7 | 40.2 | — |
| | 2000 | 5,000 | 8.5 | 12.6 | 24.3 | — |
| | 2000 | 5,000 | 8.8 | 19.0 | 26.0 | — |
| | — | — | — | — | — | 20,000 |
| 2 | 1600 | 20,000 | 9.3 | 50.6 | 46.0 | — |
| | 1600 | 20,000 | 8.4 | 55.5 | 47.1 | — |
| | 2000 | 5,000 | 6.1 | 16.6 | 26.5 | — |
| | 2000 | 5,000 | 6.0 | 20.0 | 30.1 | — |
| | — | — | — | — | — | 20,000 |
| 3 | 1600 | 20,000 | 10.0 | 20.1 | 24.6 | — |
| | 1600 | 20,000 | 81.0 | 19.1 | 19.8 | — |
| | 2000 | 5,000 | 15.2 | 7.9 | 10.3 | — |
| | 2000 | 5,000 | 12.3 | 6.0 | 8.5 | — |
| | — | — | — | — | — | 26,500 |
| 4 | 1600 | 20,000 | 48.8 | 17.5 | 16.9 | — |
| | 1600 | 20,000 | 58.3 | 28.3 | 32.5 | — |
| | 2000 | 5,000 | 7.6 | 35.0 | 47.0 | — |
| | 2000 | 5,000 | 10.2 | 24.6 | 41.5 | — |
| | — | — | — | — | — | 25,500 |
| 5 | 1600 | 20,000 | 69.7 | 19.0 | 27.1 | — |
| | 1600 | 20,000 | 57.6 | 13.9 | 17.3 | — |
| | 2000 | 5,000 | 18.2 | 27.5 | 29.4 | — |
| | 2000 | 5,000 | 10.4 | 20.6 | 17.8 | — |
| | — | — | — | — | — | 26,000 |
| 6 | 1400 | 50,000 | 132.4 | 3.0 | — | — |
| | 1400 | 50,000 | 228.4 | 3.1 | 3.9 | — |
| | 1600 | 35,000 | 65.6 | 2.4 | 2.8 | — |
| | 1600 | 35,000 | 35.8 | 2.0 | 3.2 | — |
| | 1800 | 15,000 | 12.2 | 2.0 | 4.0 | — |
| | 1800 | 15,000 | 153.2 | 1.2 | 1.5 | — |
| | 2000 | 5,000 | 58.2 | 1.3 | 1.8 | — |
| | 2000 | 5,000 | 14.7 | 5.5 | 18.6 | — |
| | 2000 | 5,000 | 95.1 | 1.7 | 2.2 | — |
| | 2000 | 5,000 | 24.0 | 7.6 | 9.0 | — |
| | — | — | — | — | — | 42,000 |
| 7 | 1600 | 20,000 | 60.9 | 3.8 | 4.5 | — |
| | 1600 | 20,000 | 64.9 | 3.9 | 4.3 | — |
| | 2000 | 5,000 | 3.7 | 1.8 | 3.0 | — |
| | 2000 | 5,000 | 3.6 | 2.3 | 3.5 | — |
| | — | — | — | — | — | 25,500 |
| 8 | 1600 | 20,000 | 48.6 | 5.5 | 6.4 | — |
| | 1600 | 20,000 | 60.1 | 6.5 | 7.2 | — |
| | 2000 | 5,000 | 9.6 | 2.6 | 3.8 | — |
| | 2000 | 5,000 | 11.8 | 5.0 | 6.8 | — |
| | — | — | — | — | — | 25,000 |
| 9 | 1600 | 20,000 | 30.9 | 13.5 | 22.6 | — |
| | 1600 | 20,000 | 42.0 | 10.9 | 17.1 | — |
| | 2000 | 5,000 | 5.2 | 17.8 | 18.1 | — |
| | 2000 | 5,000 | 5.0 | 11.8 | 14.3 | — |
| | — | — | — | — | — | 24,000 |
| 10 | 1600 | 20,000 | 42.7 | 20.1 | 27.6 | — |
| | 1600 | 20,000 | 43.8 | 19.1 | 20.9 | — |
| | 2000 | 5,000 | 4.5 | 23.6 | 52.5 | — |
| | 2000 | 5,000 | 9.1 | 20.7 | 46.8 | — |
| | — | — | — | — | — | 24,000 |
| 11 | 1600 | 20,000 | 21.2 | 24.2 | 30.9 | — |
| | 1600 | 20,000 | 18.6 | 20.1 | 35.0 | — |
| | 2000 | 5,000 | 3.5 | 18.6 | 29.9 | — |
| | 2000 | 5,000 | 4.0 | 21.2 | 20.0 | — |
| | — | — | — | — | — | 22,500 |
| 12 | 1600 | 20,000 | 24.8 | 17.8 | 28.7 | — |
| | 1600 | 20,000 | 35.4 | 11.6 | 14.9 | — |
| | 2000 | 5,000 | 9.0 | 6.6 | 11.3 | — |
| | 2000 | 5,000 | 11.7 | 4.6 | 11.2 | — |
| | — | — | — | — | — | 23,000 |
| 13 | 1600 | 20,000 | 20.8 | 13.5 | 32.4 | — |
| | 1600 | 20,000 | 24.2 | 18.0 | 33.1 | — |
| | 2000 | 5,000 | 4.9 | 12.6 | 18.1 | — |
| | 2000 | 5,000 | 4.8 | 7.4 | 25.0 | — |
| | — | — | — | — | — | 23,000 |
| 14 | 1600 | 20,000 | 96.2 | 8.4 | 17.3 | — |
| | 1600 | 20,000 | 107.0 | 7.5 | 6.9 | — |
| | 2000 | 5,000 | 40.5 | 5.6 | 7.5 | — |
| | 2000 | 5,000 | 37.5 | 5.0 | 6.7 | — |
| | — | — | — | — | — | 27,500 |
| 15 | 1600 | 20,000 | 69.9 | 19.8 | 38.3 | — |
| | 1600 | 20,000 | 44.1 | 17.1 | 27.0 | — |
| | 2000 | 5,000 | 9.4 | 11.3 | 24.0 | — |
| | 2000 | 5,000 | 11.9 | 16.2 | 27.1 | — |
| | — | — | — | — | — | 24,500 |

## TABLE VI

| Example Alloy | Notch-Rupture Properties<br>Test Conditions<br>Temp. °F. | Stress, psi | Notch Factor<br>Kt | Life.Hrs. |
|---|---|---|---|---|
| 7 | 1600 | 20,000 | 3.5 | 49.6 |
| | 1600 | 20,000 | 3.5 | 350.0 (1) |
| 8 | 1600 | 20,000 | 3.5 | 209.7 |
| | 1600 | 20,000 | 3.5 | 250.0 |
| 11 | 1600 | 20,000 | 3.5 | 76.5 |
| | 1600 | 20,000 | 3.5 | 92.8 |
| 12 | 1600 | 20,000 | 3.5 | 23.6 |
| | 1600 | 20,000 | 3.5 | 193.8 |
| 13 | 1600 | 20,000 | 3.5 | 45.7 |
| | 1600 | 20,000 | 3.5 | 141.8 |
| 14 (2) | 1600 | 20,000 | 3.5 | 112.2 |
| | 1600 | 20,000 | 3.5 | 258.8 |
| 14 (3) | 1600 | 20,000 | 3.5 | 356.8 |
| | 1600 | 20,000 | 3.5 | 592.5 |

(1) No failure, Test discontinued

(2) As-cast Data

(3) Heat treated: 2150°F. for 1 hour, air cooled, 1600°F. for 24 hours and air cooled.

Example alloys **1** and **2** represent additions of relatively large percentages of carbon to ternary nickel-chromium-molybdenum alloys that would show, absent the relatively large amount of carbon, microstructural instability. Structurally, these alloys consist of primary metallic dendrites and primary "herring bone" eutectic chromium-molybdenum carbides. Example alloys **1** and **2** exhibited Rockwell hardness numbers C-scale, (Rc) of 33 and 42 respectively. Example alloy **2** showed a slight softening to Rc 38 upon aging. Rupture strength of both alloys is relatively low, but approaches that of cast cobalt-base superalloys.

Increasing chromium content of nickel base alloys generally results in a lowering of elevated temperature strength. However, as shown by the data in Table V with respect to example alloys **3, 4, 5,** and **6,** increasing chromium content while simultaneously adding relatively large percentages of carbon and boron results in sharp increases in strength. In the case of example alloy **6,** the stress to produce rupture in 100 hours at 1,500°F is more than doubled in comparison to example alloys **1** and **2.** Of course, this is an unusually large and unexpected increase in strength. By comparing FIGS. **2** and **4** it may be seen that the level of strength of example alloy **6** is approximately 10 percent above that of commercial alloy E. Alloy E is one of the strongest cobalt base alloys which has been developed.

Example alloy **4** not only has good strength, it possesses a lower mean coefficient of thermal expansion from 80°F. to 1,600°F. than any other known nickel-base alloy. The surprisingly low mean coefficient of thermal expansion of example alloy **4** from 80°F to 1,600°F. is shown in Table IV. A comparison of this data with the curves of FIG. **1** illustrates the low degree of thermal expansion of example alloy **4** compared to various commercially available superalloys.

Example alloys **4** and **6,** respectively, show a weight loss of 50.4 and 48.1 mg/cm$^2$ and surface recession rates of 0.0035 and 0.002 inches in 300 hours in the sulfidization test. This represents excellent resistance to the severe test conditions employed and demonstrates that these alloys may be categorized as hot corrosion resistant.

Despite the fact that example alloy **6** showed a remarkable increase in strength, example alloy **4** may be the more attractive material for certain types of use. The very low expansivity combined with excellent hot corrosion resistance and moderate strength makes example alloy **4** very attractive for fabricating components which require a very low degree of thermal expansion at elevated temperatures. Compositional modifications around example alloys **4** and **6** resulted in some strength improvement over alloy **4,** in example alloy **14,** but at some sacrifice in expansion properties.

In producing the alloys of the present invention, and objects prepared from the alloys of the present invention, no special skills or techniques are required other than normal conventional foundry practice. The alloys may be readily cast in sand, shell, or investment molds and melted and cast in air or under vacuum. Although the alloys were developed for use in the cast condition, several specific compositions within the ambit of the present invention may be employed in wrought form if produced by powder metallurgy techniques.

The alloys of the present invention may generally be described as a class of nickel-base alloys possessing a duplex structure consisting of a nickel-chromium-molybdenum matrix and a semi-continuous network of refractory carbides and borides. The alloy compositions possess a combination of physical and mechanical characteristics which have generally been considered mutually exclusive.

Although the present invention has been described in conjunction with preferred embodiments, it is to be understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention. Such modifications are considered to be within the purview and scope of the invention and appended claims.

What is claimed is:

**1.** A nickel base alloy having elevated temperature strength, resistance to oxidation and hot corrosion, and a low coefficient of thermal expansion, consisting essentially of the following elements in the weight percent ranges set forth:

| ELEMENTS | PERCENT |
|---|---|
| Chromium | 24–42 |
| Molybdenum | 8–22 |
| Carbon | 0.15–1.2 |
| Boron | 0.04–0.7 [0–0.8] |

the balance of the alloy being essentially nickel and minor amounts of impurities and incidental elements which do not detrimentally affect the basic characteristics of the alloy, the carbon and boron being effective to prevent the formation of deleterious embrittling phases through formation of chromium and molybdenum borides and carbides.

**2.** The nickel base alloy of claim **1** wherein the carbon content is about 0.5 to about 1.2 percent by weight.

**3.** A component for use in a gas turbine engine formed of the alloy of claim **1.**

**4.** A hard facing welding rod formed of the alloy of claim **1.**

**5.** The alloy of claim **1** which contains, on a weight basis, about 28 to about 42% chromium, and about 12 to about 20% molybdenum.

**6.** The alloy of claim **5** which contains, on a weight basis, about 16 to about 20 percent molybdenum and about 0.2% to about 0.7% boron.

**7.** A component for use in a gas turbine engine formed of the alloy of claim **5.**

**8.** A component for use in a gas turbine engine formed of the alloy of claim **6.**

**9.** A hard facing welding rod formed of the alloy of claim **5.**

**10.** A nickel base alloy having elevated temperature strength, resistance to oxidation and hot corrosion, and a low coefficient of thermal expansion consisting essentially of the following elements and the weight percentage ranges set forth:

| ELEMENTS | PERCENT |
|---|---|
| Chromium | 38–42 |
| Molybdenum | 12–16 |
| Carbon | 0.5–1.2 |
| Boron | 0.2–0.7 |

the balance of the alloy being essentially nickel and minor amounts of impurties and incidental elements which do not detrimentally affect the basic characteristics of the alloy, the carbon and boron being effective to prevent the formation of deleterious embrittling phases through formation of chromium and molybdenum borides and carbides.

**11.** A component for use in a gas turbine engine formed of the alloy of claim **10.**

**12.** A nickel base alloy having elevated temperature strength, resistance to oxidation and hot corrosion, and a low coefficient of thermal expansion consisting essentially of the following elements in the weight percentage ranges set forth:

| ELEMENTS | PERCENT |
|---|---|
| Chromium | 33–37 |
| Molybdenum | 16–20 |
| Carbon | 0.3–1.2 |
| Boron | 0.15–0.5 |

the balance of the alloy being essentially nickel and minor amounts of impurities and incidental elements which do not detrimentally affect the basic characteristics of the alloy, the carbon and boron being effective to prevent the formation of deleterious embrittling phases through formation of chromium and molybdenum borides and carbides.

**13.** A component for use in a gas turbine engine formed of the alloy of claim **12.**

**14.** The alloy of claim **1** which contains not more than 0.2% titanium.

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