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AGE HARDENABLE NICKEL ALLOY

Clarence George Bieber and Mortimer Pierce Buck, Huntington, W. Va., assignors to The International Nickel Company, Inc., New York, N. Y., a corporation of Delaware

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The present invention relates to nickel alloys, and, more particularly, to age hardenable nickel alloys.

It is among the objects of our invention to produce nickel alloys capable of being hardened by heat treatment to any selected hardness over a broad hardness range; to provide nickel alloys having maximum hardness in the aged condition commensurate with satisfactory forgeability and good machining properties; and to produce nickel alloys having a broad range of hot malleability combined with high mechanical properties in the age hardened condition.

Other objects and advantages of the present invention will become apparent from the following description of the present invention.

Generally speaking, the present invention is based upon the surprising discovery made by us that nickel base alloys containing chromium, and optionally iron, having among other desirable properties an advantageous combination of hot malleability, good machining properties, good response to heat treatment, and high hardness in the heat treated condition can be produced by incorporating aluminum with titanium or silicon, or both titanium and silicon, in the alloy in critical amounts depending upon the nickel content, as hereinafter described. Response to heat treatment can be obtained in chromium-containing nickel base alloys by incorporating only one of the elements, aluminum, titanium or silicon in the alloy, but the amount necessary to produce maximum response to heat treatment is relatively large and this is accompanied by working difficulties. We have made the surprising discovery that by using at least two of the elements from the group aluminum, silicon and titanium, the response to heat treatment with a smaller total amount of hardening elements is as satisfactory or even better than in alloys containing only one of these hardening elements in effective amounts, and the new alloys are characterized by greatly improved hot malleability as compared with alloys of otherwise substantially the same composition containing only one of the hardening elements.

The nickel content of the alloys embodying the present invention in all cases will be at least 45% by weight of the alloy and usually will be 50% or substantially more than 50%. Chromium will be present within the range of about 5% to

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35% while iron may vary from 0 to about 45%.

The relative amounts of aluminum, silicon and titanium may vary over a range of several percent provided the ratio of nickel to the hardener content is maintained within the limits defined herein. Aluminum, and at least one of the elements of the group titanium and silicon must be present in the alloy in amounts greater than 0.25%. The third hardening element may be present in amounts more or less than 0.25%, the essential feature of this invention being that at least two of the hardening elements must be present in amounts greater than about 0.25%. Aluminum and silicon may be used in amounts up to about 8%, preferably not over 5% of either, while titanium should be less than 5% and preferably is employed in amounts less than 4%. Titanium exerts its greatest effect on age-hardenability within the range of about 0.25% to under 1%, in combination with proper amounts of aluminum and/or silicon.

We have discovered that the optimum combination of hot malleability, hardenability and high hardness in the heat-treated condition is obtained when the ratio of nickel to the weighted hardener content as obtained from the formula

$$\text{Weighted hardener content} = \text{Al} + 2\sqrt{\text{Ti}} + \text{Si}$$

is approximately 15, preferably within the range of 13 to 17, and always within the range of 11 to 20. Since the ratio is a quotient, it is immaterial what unit of weight is used to express the content of nickel, aluminum, titanium and silicon. Thus, for example, the amounts of these ingredients in any given alloy may be given in parts by weight, percentage by weight, etc., without changing the ratio.

In the commercial production of alloys embodying the present invention, the composition ordinarily will fall within the following ranges:

Element	Per cent
Cr	10 -22
Fe	0.1 -15
Al	0.25- 5
Ti	0.25- 4
Si	0.05- 2.0
C	0.00- 0.5
Mn	0.00- 2.0
Ni	Balance

The preferred ranges of the various ingredients are as follows:

Element	Per cent
Cr	11.00-15.0
Fe	5.00- 8.0
Al	0.25- 3.5
Ti	0.25- 3.0
Si	0.50- 1.0
C	0.02- 0.2
Mn	0.10- 0.5
Ni	Balance

For the purpose of giving those skilled in the art a better understanding of the present invention, the following specific examples are given of alloys that are typical of the preferred compositions:

Element	Per cent	Per cent	Per cent
Cr	13.43	14.40	21.45
Fe	6.08	6.17	0.79
Al	3.10	0.63	0.45
Ti	0.55	2.77	2.25
Si	0.82	0.52	0.84
C	0.03	0.03	0.04
Mn	0.15	0.53	0.50
S		0.007	0.009
Cu		0.10	0.05
Ni	75.67	74.82	73.60

Commercial alloys embodying the present invention may contain small amounts of other elements such as sulfur, copper, cobalt and phosphorus. The sulfur is preferably low, e. g., about 0.01%. The alloys may be substantially carbon-free or carbon may be present up to about 0.5%. Ordinarily the carbon will not exceed about 0.2% and preferably is maintained below about 0.1%. Ordinarily carbon will be present within the range of about 0.02 to 0.1%. Manganese ordinarily will not exceed about 2% and preferably will be within the range of about 0.1% to 0.5%.

The mechanical properties of the alloys embodying the present invention are substantially enhanced by age hardening and the alloys retain considerable strength even at the high temperature of about 1600° F. This property makes the alloys particularly suitable for fabricating metallic articles which are exposed in use to elevated temperatures under considerable stress.

The chromium-containing nickel alloys may be worked within the range of about 1900° F. to 2400° F., preferably within the range of about 2100° F. to 2300° F. This is a valuable novel result since the prior art had not been able to produce hot workable alloys of this type capable of being age hardened. It is surprising that the use of the hardening elements in combination makes it possible to produce age hardenable chromium-containing nickel alloys capable of being hot worked over as broad a range as indicated.

The alloys of the present invention may be softened by quenching or rapidly cooling from above 1700° F. The alloys may be age hardened by the conventional hardening treatment comprising a solution heat treatment, a rapid cooling and a precipitation heat treatment; or they may be hardened by a controlled cooling following the solution heat treatment as disclosed in our prior application Serial No. 253,350, filed January 28, 1939, now Patent No. 2,234,955, dated March 18, 1941; or they may be heat treated in accordance with the process disclosed in our copending application Serial No. 483,760 filed April 20, 1943, now abandoned. The controlled cooling for alloys of the present invention preferably comprises holding them within the range of about 1200° to 1400° F. for a period varying from about ½ hour to 16 hours, followed by slow cooling to a temperature within the range of about 1100° F. to 1000° F. at a rate not exceeding about 75° F. per hour, and preferably not over about 25° F. per hour. In the softened condition the alloys may be deformed cold, and in this condition the alloys lend themselves readily to machining operations. Where hardnesses higher than those obtainable by precipitation hardening of hot-worked material are desired, the material may be worked cold either before or after the age-hardening treatment. In the hardened condition the alloys, as those skilled in the art will readily appreciate, are machinable with greater difficulty than in the annealed condition but, if necessary, machining can be performed by the use of carbide type tools.

It will be seen from the foregoing description and the specific examples that we have provided nickel alloys combining optimum response to heat-treatment with hot malleability. These alloys may be used for various articles of manufacture including rollers and bearing balls, bearings and races therefor, roller chains, drop forgings and tie rods for airplane construction, valve seats and other valve parts, pump rods and the like, pump rod sleeves, pump pistons for high pressures and temperatures, plungers, turbine blades, turbine diaphragm blading, lock washers, screws and nuts, tools, cutting blades and the like, pins and needles, springs and other resilient elements, airplane instrument parts, nozzles for burners, rods, sheets, strip, wire, bars, rolled shapes, etc.

The present application is a continuation-in-part of our prior copending application Serial No. 374,208 filed January 13, 1941, which itself is a continuation-in-part of our prior application Serial No. 253,350 filed January 28, 1939, which latter application issued on March 18, 1941, as Patent No. 2,234,955.

Although the present invention has been described in conjunction with preferred embodiments, it is understood that modifications and variations may be resorted to without departing from the spirit and scope of the invention, as those skilled in the art will readily understand.

We claim:

1. An alloy containing 11% to 15% chromium, 5% to 8% iron, 0.25% to 3.5% aluminum, at least 0.25% and under 1% titanium, 0.5% to 1% silicon, 0.02% to 0.2% carbon, 0.1% to 0.5% manganese and the balance substantially all nickel, the ratio of the nickel content to the sum of the aluminum content, the silicon content, and two times the square root of the titanium content being between 13 and 17.

2. An alloy containing 10% to 22% chromium, 0.1% to 15% iron, 0.25% to 5% aluminum, at least 0.25% and under 1% titanium, 0.05% to 2% silicon, carbon in an amount not greater than 0.5%, manganese in an amount not greater than 2%, and the balance substantially all nickel, the ratio of the nickel content to the sum of the aluminum content, the silicon content, and two times the square root of the titanium content being between 13 and 17.

3. An alloy containing 0.25% to 5% aluminum, at least 0.25% and under 1% titanium, 0.05% to 2% silicon, 10% to 22% chromium, 0.1% to 15% iron, manganese in an amount not exceeding 2%, carbon in an amount not exceeding 0.5%, and the balance substantially all nickel, the nickel con-

tent being over 50% of the alloy, and the ratio of the nickel content to the sum of the aluminum content, the silicon content and two times the square root of the titanium content being between 11 and 20.

4. A wrought age hardened article of manufacture subjected in use to stress at elevated temperatures made of a nickel-base alloy containing 0.25% to 5% aluminum, at least 0.25% and under 1% titanium, 0.05% to 2% silicon, 10% to 22% chromium, 0.1% to 15% iron, manganese in an amount not exceeding 2%, carbon in an amount not exceeding 0.5%, and the balance substantially all nickel, the nickel content being over 50% of the alloy, and the ratio of the nickel content to the sum of the aluminum content, the silicon content and two times the square root of the titanium content being between 11 and 20.

CLARENCE GEORGE BIEBER.
MORTIMER PIERCE BUCK.

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