United States Patent Office

2,766,156

Patented Oct. 9, 1956



2,766,156

# HEAT-TREATMENT OF NICKEL-CHROMIUM-COBALT ALLOYS

Walter Betteridge, Solihull, Arthur William Franklin, Quinton, Birmingham, and Ronald Alfred Smith, Smethwick, England, assignors to The International Nickel Company, Inc., New York, N. Y.

No Drawing. Application July 7, 1953, Serial No. 366,622

Claims priority, application Great Britain July 9, 1952

3 Claims. (Cl. 148—21.90)

This invention relates to articles which are subjected to prolonged stress at high temperatures. It is well known that the alloys of which these are made must not only possess resistance to corrosion at high temperatures and good general mechanical properties, but also by their nature must possess resistance to creep. The alloys commonly used for this purpose are of the kind in which the principal constituent is nickel or nickel + cobalt and which also contain chromium, aluminum and titanium, these last two elements forming a precipitable phase with some of the nickel. The precise composition of the alloy varies with the conditions under which it is to be used and the properties required under those conditions. In particular, the service temperature is important, and if good resistance to creep is needed at high service temperatures, e. g. 750 to 850° C., cobalt-containing alloys are used despite the high price of cobalt. The composition range of the alloys used at present for high service temperatures is from 18 to 21% chromium, from 15 to 21% cobalt, from 1.8 to 2.7% titanium, from 0.8 to 1.8% aluminum, from 0 to 0.10% carbon, from 0 to 1.0% manganese, from 0 to 1.5% silicon, 0 to 5% iron, and the balance nickel, except for residual de-oxidants, such as magnesium and calcium, and impurities.

To develop the good creep properties the alloys are heat-treated, and the treatment applied at present comprises heating the alloy for 8 to 12 hours at 1050° C. to 1180° C., cooling in air, and subsequently heating for from 12 to 16 hours at about 700° C. to bring about precipitation-hardening or ageing.

It is an object of this invention to provide an improved method of heat-treating fabricated articles of the kind referred to above.

Another object is to provide fabricated articles which possess increased resistance to creep as a result of a novel heat treatment.

The invention is based on the discovery that by variation of the heat treatment it is possible to improve the properties of articles fabricated from alloys of the kind in question. Even with alloys of the same nominal composition these properties vary from one case to another, and accordingly the properties of an article heat-treated according to the invention may not even be as good as those of another subjected to the usual heat-treatment, but those of an article of any given alloy will be improved.

The heat treatment used in the present invention comprises an initial heating at a temperature of from 1150 to 1250° C., the duration of the heating being from ½ to 12 hours at 1150° C. and from ¼ to 4 hours at 1250° C. with intermediate periods at intermediate temperatures, an intermediate heating for at least 4 hours at from 1000 to 1100° C. and finally a precipitation-hardening or



ageing heating which is not critical, but which may as usual be for 16 hours at 700° C. Between the initial and intermediate heatings, and between the intermediate and precipitation-hardening heatings, the alloys may be cooled in air or any other convenient rate, or the heatings may directly follow one another without any intermediate cooling. The duration of the initial or solution heating varies with the temperature because as the temperature rises the amount of scale formed becomes excessive if the heating is prolonged.

In the manufacture of articles from alloys of the kind in question hot working steps are usually employed, and these may involve heating the alloy to a temperature between 1150 and 1250° C. The working leaves the alloy in a state of stress, and this heating is not the equivalent of the initial or solution heating used in the present invention so far as the putting of the alloy into the desired physical state is concerned. When the solution heating of the invention has been carried out there must be no distortion of the alloy, though simple machining is permissible. Therefore, the alloy must have been fabricated into an article before the solution heating is applied. The term "article" is intended, however, to include not only a finished product or part (e. g. a turbine blade), but also a bar, strip, forging or stamping from which an article may be machined.

The alloys to which the heat treatment of the invention is applied are those which contain from 15 to 25% chromium, 5 to 40% cobalt, 0 to 0.2% carbon, 1.5 to 2.5% aluminum, 2.8 to 4.0% titanium, 0 to 10% iron, 0 to 1.0% manganese, 0 to 1.5% silicon, 0 to 5% molybdenum, 0 to 5 % tungsten, 0 to 1% in all of columbium or tantalum or both, 0 to 0.2% zirconium, and 0 to 0.01% boron, with the balance substantially all nickel, though of course there may be residual de-oxidants and impurities. It will be observed that the aluminum and titanium contents are higher than usual. The reason is that at high service temperatures, i. e. those over 815° C., the amount of the pricipitation-hardening complex of nickel, aluminum and titanium which is precipitable is not enough if the aluminum and titanium contents are the usual ones set forth above, since at these higher temperatures the alloy will hold more of the complex in solution. It is therefore desirable to increase both contents. Preferably the titanium content is from 2.8 to 3.2% and the aluminum content from 1.5 to 2.0%. Fabricated articles of alloys with these contents may be used with service temperatures of the order of 870° C.

Preferably the alloys differ from those at present in use (as set forth above) only by the increased aluminum and titanium contents and by the presence of very small amounts of both zirconium and boron.

The improvement in comparison with the properties obtained with the usual two-stage heat treatment referred to above is illustrated by the results of tests on alloys of the nominal composition 20.0% Cr, 17.0% Co, 3.0% Ti, 1.8% Al and 0.08% C, the balance being Ni; these alloys were tested under a stress of 9 tons per square inch at 870° C. Of each alloy, some specimens were initially heated for 8 hours at 1080° C., cooled in air and then heated for 16 hours at 700° C., i. e. were given the treatment customary hitherto; and other specimens of each alloy were heated for 1½ hours at 1200° C., transferred to another furnace and held in it for 8 hours at 1080° C., cooled in air and heated for 16 hours at 700° C., i. e. were treated according to the invention. The results obtained are given in Table 1 below, the actual composition of the alloys as determined by analysis being given.

*Table 1*

| Co | Cr | Ti | Al | C | 8 hrs. at 1,080° C., air cool, 16 hrs. at 700° C. | | 1½ hrs. at 1,200° C., transfer to 8 hrs. at 1,080° C., air cool, 16 hrs. at 700° C. | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Minimum creep rate (percent per hr.) | Time to fracture (hrs.) | Minimum creep rate (percent per hr.) | Time to fracture (hrs.) |
| 16.8 | 19.8 | 2.83 | 1.51 | 0.05 | 0.0068 | 68 | 0.0017 | 114 |
| 18.2 | 19.9 | 2.78 | 1.51 | 0.05 | 0.0056 | 76 | 0.0022 | 167 |
| 17.7 | 19.7 | 3.04 | 1.90 | 0.06 | 0.0074 | 89 | 0.0040 | 114 |
| 17.0 | 19.5 | 3.06 | 2.14 | 0.05 | 0.0067 | 110 | 0.0066 | 159 |
| 17.2 | 20.2 | 2.74 | 1.71 | 0.07 | 0.0054 | 69 | 0.0026 | 135 |

The use of an intermediate heating stage in the heat-treatment of nickel-chromium alloys is known per se, although it has not been used in practice in the treatment of the alloys used for gas turbine blades and other articles subjected to high service temperatures. In the present invention the high temperature range of 1000 to 1100° C. for the intermediate heating is critical, as is shown by the following table of results obtained under the same testing conditions of 9 tons per square inch at 870° C. with an alloy of the same nominal composition.

*Table 2*

| Intermediate treatment | Minimum creep rate (percent per hour) | Time to fracture (hours) |
|---|---|---|
| 8 hrs. at 1,080° C. | 0.0020 | 181 |
| 16 hrs. at 1,000° C. | 0.0034 | 134 |
| 16 hrs. at 950° C. | 0.0105 | 81 |
| 16 hrs. at 900° C. | 0.0100 | 44 |

The importance of the high temperature range for the initial heating is shown by the following table of results, also obtained with an alloy of the same nominal composition under the same testing conditions.

*Table 3*

| Initial treatment | Minimum creep rate (percent per hour) | Time to fracture (hours) |
|---|---|---|
| ½ hr. at 1,080° C. | 0.0068 | 72 |
| ½ hr. at 1,150° C. | 0.0031 | 151 |
| ½ hr. at 1,200° C. | 0.0020 | 181 |
| ½ hr. at 1,250° C. | 0.0007 | 234 |
| ½ hr. at 1,300° C. | 0.0035 | 31 |



It should be observed that if the carbon content exceeds 0.1% the alloy should either be transferred direct from the initial heating furnace to the intermediate heating furnace or should be cooled very rapidly through the range of temperature from just above to just below 950° C., say from 975 to 925° C.

Alloys heat-treated according to the invention are particularly valuable for use as gas turbine blades in airplane engines.

We claim:

1. A method for producing articles of manufacture having improved high temperature properties which comprises fabricating a wrought article subjected in use to prolonged stress at elevated temperatures from an alloy containing about 15% to 25% chromium, about 5% to 40% cobalt, not less than 1.5% and up to about 2.5% aluminum, not less than 2.8% and up to about 4% titanium, up to about 0.2% carbon, up to about 10% iron, up to about 1% manganese, up to about 1.5% silicon, up to about 5% molybdenum, up to about 5% tungsten, up to about 1% total of at least one metal selected from the group consisting of columbium and tantalum, up to about 0.2% zirconium, and up to about 0.01% boron, with the balance substantially all nickel; thereafter imparting to said wrought article an undistorted structure by initially heating said wrought article at a temperature within the range of about 1150° C. to 1250° C. for a period of time such that the heating is from about ½ to 12 hours at 1150° C. and from about ¼ to 4 hours at 1250° C. and is similarly correlated over said temperature range of about 1150° C. to 1250° C.; then intermediately heating said wrought article for at least 4 hours at a temperature not less than 1000° C. and up to about 1100° C.; and subsequently aging the thus-treated article having an undistorted structure.

2. A method according to claim 1 in which the alloy contains about 18% to 21% chromium, about 15% to 21% cobalt, not less than 1.5% and up to about 2% aluminum, not less than 2.8% and up to about 3.2% titanium, up to about 0.1% carbon, up to about 1% manganese, up to about 1.5% silicon, up to about 5% iron, small but effective amounts of zirconium and boron, and the balance substantially all nickel.

3. A fabricated wrought article produced in accordance with claim 1 characterized by high resistance to creep and having an undistorted structure.


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