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HEAT-TREATMENT OF COBALT BASE
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N. Y., a corporation of New JerseyNo Drawing. Application April 13, 1946,
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1

This invention pertains to improvements in the heat-treating of cobalt base alloys, and to the resulting heat-treated products.

The alloys in question may contain up to about 40% chromium, up to about 1% carbon, and up to about 20% molybdenum, with the balance substantially all cobalt, except for incidental impurities and small amounts of deoxidizing agents, such as manganese and silicon. Tungsten may be substituted for molybdenum in whole or in part. Up to about half the cobalt content may be replaced in whole or in part by nickel or iron, or both. In some cases, minor additions of columbium, tantalum, titanium, vanadium and zirconium, up to about 5% in aggregate, may be advantageous. Ordinarily, the alloys will contain about 15 to 25% chromium and about 0.1 to 0.5% carbon.

The excellent strength at elevated temperatures of cobalt base alloys, such as the above, has long been recognized. However, the brittleness evinced by these alloys at elevated temperatures has been a serious impediment to their extended use. Designing engineers naturally hesitate to specify a brittle alloy which may fail suddenly with little or no warning. Heretofore, this brittleness has been accepted as an inherent and unavoidable quality of these alloys, since no treatment was previously known which would overcome it. However, I have evolved a heat-treatment which gives a critically higher elevated temperature toughness and ductility than was thought possible with these alloys, while, at the same time, introducing only a slight decrease in the elevated temperature strength thereof.

In the past, it was considered that only two kinds of heat-treatments could be advantageously employed for these alloys, viz., a rapid cool from a high temperature substantially to room temperature; and, optionally, a subsequent precipitation-hardening treatment at a temperature around 1400° F. The rapid cool from a high temperature of approximately 2100 to 2400° F. was believed to place the alloy in the "fully annealed" or softest and toughest condition possible. The subsequent precipitation-hardening treatment at about 1400° F., where employed, was known to increase the hardness of the alloy appreciably, but generally at the expense of toughness.

I have discovered, however, in accordance with the present invention, that the toughness of these alloys may be remarkably increased over the results obtainable as aforesaid, either in the fully-annealed or in the precipitation-hardened condition, by subjecting the alloy to heat-treatment as follows: The alloy is first heated to a temperature between 2150° F. and its melting point, for a sufficient period to insure maximum homogenization of the alloy. It is then cooled to a temperature within the range of about 1650 to 2100° F., and

2

held at this temperature for a sufficient period, usually for about an hour or so, to permit the alloy to transform, whereupon it is air cooled to room temperature. This transformation is ordinarily effected isothermally at a particular temperature; although it is sometimes advantageous to permit the alloy to transform by cooling it slowly through the aforesaid temperature of 1650 to 2100° F., rather than by holding it at a specific temperature. Such slow cooling, where employed, should be at such rate as to hold the alloy within the aforesaid temperature range for about an hour or so, before permitting it to air cool to room temperature.

The optimum temperatures for the two steps of the heat-treatment aforesaid may vary within the ranges given, depending on the analysis of the particular alloy to be heat-treated, and the desired properties. Ordinarily, a minimum temperature of about 2150° F. is required for the homogenization treatment, i. e., to dissolve most of the secondary constituents present in the alloy "as rolled," "as forged" or "as cast." Naturally, the alloy should not be heated above its melting point, since this would destroy the as-rolled or as-forged structure. The homogenization treatment is usually best carried out in the temperature range of about 2150 to 2350° F., and for a period of from a few minutes up to fifteen to thirty minutes or so, but seldom exceeding an hour. The higher the temperature, the shorter the heating time within these intervals.

Numerous tests have shown that the improvement in elevated temperature strength and ductility is obtained only if the second step of the heat-treatment is carried out within the range of about 1650 to 2100° F. Transformation at temperatures under 1650° F. tends to have a deleterious effect on the elevated temperature strength as well as on the ductility; while transformation at temperatures over 2100° F. is ordinarily impossible. A preferred temperature range for the isothermal transformation of the alloy is about 1900 to 2000° F. The length of the isothermal treatment is a function of composition of alloy and temperature of transformation, but in most instances one hour at temperature is sufficient, although holding within the transformation period for longer periods, i. e., up to 16 hours or more, does no harm, but of course is uneconomical.

Generally, the product of the transformation is a lamellar constituent, although with some alloys, particularly those containing lower amounts of chromium, it may be more spheroidal in form. Usually, about one-third of the alloy transforms during the second or isothermal step of the heat-treatment according to the invention. The coarseness of the lamellar structure increases with an increase in the temperature at which it is formed. On the basis of a

long study of the microstructure of these alloys, I believe the lamellar structure is the result of an eutectoid reaction. I am not prepared to

treatments, while tests 3 and 4 present results for heat-treatments according to the present invention.

Table I

Analysis:						Per cent
Carbon						0.30
Manganese						0.63
Nickel						2.63
Chromium						27.40
Molybdenum						5.73
Balance: cobalt						

Test No.	Heat Treatment	1500° F. Stress Rupture Tests				Room Temperature, Rockwell C Hardness
		Applied stress, p. s. i.	Rupture time, hrs.	Elong., per cent in 2 in.	Reduction of area, per cent	
1	2250° F.; air cooled	40,000	2.87	9.2	15.5	31 -32.5
2	2250° F.; air cooled plus 1400° F. for 16 hrs., then air cooled.	40,000	3.77	13.9	22.5	38 -40
3	2250° F. followed by an isothermal trans. at 1800° F. for 1 hr., then air cooled.	40,000	2.02	25.1	34.5	35 -36.5
4	2250° F. followed by an isothermal trans. at 1900° F. for 1 hr., then air cooled.	40,000	2.70	24.9	34.7	35.5-36.5

state the composition of the constituents of the lamellar phase. However, it may be readily differentiated metallographically from the extremely fine precipitates formed during precipitation-hardening at temperatures from about 1100 to 1500° F. Moreover, precipitation-hardening always causes a significant increase in the hardness of the alloy over that obtainable by the heat-treatment of the present invention.

A short time stress rupture test has been found suitable to evaluate the strength and toughness at elevated temperatures of these alloys. In this test, the time for rupture is determined for a specimen heated to a specific temperature and subjected to a predetermined stress. Either the rupture time for a given stress or the stress required for a given rupture time may be used as the measure of the elevated temperature strength. I have found it most convenient in comparing the effects of various heat-treatments to determine the difference in rupture time of samples subjected to the same stress. The toughness is indicated by the reduction of area and the elongation of the failed specimen. The lower the reduction of area and elongation, the more brittle is the alloy. The stress rupture tests were made at 1500° F., as this is a common service temperature for cobalt base alloys.

An example of the benefits of the present invention is shown in Table I, wherein tests 1 and 2 represent the previously known types of heat-

Air cooling from 2250° F., per test 1, gives a rupture time of 2.87 hours under a load of 40,000 pounds per square inch at 1500° F., but the low elongation and reduction of area figures show that the material is very brittle in this condition. The precipitation-hardening treatment at 1400° F., per test 2, increases the elevated temperature strength, as indicated by the rupture time, and somewhat improves the elevated temperature ductility. It will be noted that the precipitation-hardening increases the room temperature hardness considerably. The effect of the two isothermal treatments in accordance with this invention, per tests 3 and 4, is startling. The strength at 1500° F. is slightly lower than for tests 1 and 2, but the ductility is much greater. The elongation values are about 80% higher for tests 3 and 4 according to the invention, than for the best of the prior treatments for tests 1 and 2, while the reduction of area figures are over 50% higher. The isothermal transformation at 1900° F. is to be preferred to the isothermal transformation at 1800° F. for this alloy, as it increases the strength with practically no sacrifice of ductility. The increase in toughness and ductility thus obtainable according to this invention will naturally greatly extend the possible uses of this alloy.

The following Table II gives the details of elevated temperature tests conducted on a similar alloy having a lower carbon content:

Table II

Analysis:						Per cent
Carbon						0.25
Manganese						0.66
Nickel						2.82
Chromium						27.35
Molybdenum						5.52
Balance: cobalt						

Test No.	Heat Treatment	1500° F. Stress Rupture Tests				Room Temperature, Rockwell C Hardness
		Stress, p. s. i.	Rupture Time, Hrs.	Elong., Per Cent in 2 in.	Reduction of Area, Per Cent	
1	2250° F., air cooled plus 1400° F. for 16 hrs., then air cooled.	45,000	1.95	4.1	4.3	39 -40.5
2	2250° F. followed by an isothermal trans. at 1700° F. for 1 hr., then air cooled.	45,000	1.48	17.1	23.7	33 -34
3	2250° F. followed by an isothermal trans. at 1900° F. for 1 hr., then air cooled.	45,000	1.32	20.9	28.4	31.5-32
4	2400° F., air cooled plus 1400° F. for 16 hrs., then air cooled.	40,000	3.87	2.4	2.9	39.5-40.5
5	2400° F. followed by an isothermal trans. at 1700° F. for 1 hr., then air cooled.	35,000	6.97	2.1	3.0	28.5-31
		40,000	2.50	13.4	18.6	
		35,000	4.40	13.3	19.7	

The beneficial effect of the isothermal treatment is thus even more outstanding with this alloy. In the case of the first three tests made on specimens initially heated to 2250° F., the ductility is improved 270 to 410% under this invention, tests 2 and 3, as judged on the basis of the elongation values, and 450 to 560% on the basis of the reduction of area figures, as compared with the results obtained on the specimen which had been precipitation-hardened at 1400° F., per test 1. In this particular case, the 1700° F. isothermal

tionally large increase in elevated temperature strength of 260 to 370%, as evidenced by comparison of the "rupture time" results at 38,000 pounds per square inch.

Table IV

Analysis:	Per cent
Carbon.....	0.23
Manganese.....	0.72
Nickel.....	9.90
Chromium.....	21.33
Molybdenum.....	5.82
Balance: cobalt.	

Test No.	Heat Treatment	1500° F. Stress Rupture Tests				Room Temperature, Rockwell C Hardness
		Stress, p. s. i.	Rupture Time, Hrs.	Elong., Per Cent in 2 in.	Reduction of Area, Per Cent	
1.....	2250° F., air cooled.....	45,000 38,000	1.37 3.58	7.1 4.2	8.9 4.3	24
2.....	2250° F., followed by an isothermal trans. at 1900° F. for 1 hr., then air cooled.	45,000 38,000	4.93 16.83	19.4 15.1	22.9 20.0	23.5

treatment, test 2, gives the better strength while the 1900° F. isothermal treatment, test 3, gives the better ductility. However, even the 1700° F. treatment gives much higher ductility values than the precipitation-hardening treatment, test 1. The specimens initially heated to 2400° F., viz., tests 4 and 5, show a marked difference in ductility between those isothermally transformed, test 5, and those precipitation-hardened, test 4. The improvement in ductility resulting from the isothermal treatment is about 500%, as compared to the precipitation-hardening treatment. While the 2400° F. treatments decrease the ductility relative to the corresponding 2250° F. treatments, nevertheless the specimens heated to 2400° F. and then isothermally transformed, test 5, still have better ductility than the samples heated only to 2250° F. and then precipitation-hardened, test 1.

Additional results are shown in Table III below, for a still lower carbon alloy. Here the increase in ductility is over 600% at the cost of a small drop in strength for a heat-treatment under the present invention, test 2, as compared to those of the known precipitation-hardening treatment, test 1.

Table III

Analysis:	Per cent
Carbon.....	0.09
Manganese.....	0.59
Nickel.....	2.90
Chromium.....	27.84
Molybdenum.....	5.58
Balance: cobalt.	

Test No.	Heat Treatment	1500° F. Stress Rupture Tests				Room Temperature, Rockwell C Hardness
		Stress, p. s. i.	Rupture Time, Hrs.	Elong., Per Cent in 2 in.	Reduction of Area, Per Cent	
1.....	2250° F., air cooled plus 1400° F. for 135 hrs., then air cooled.....	42,000	2.30	2.7	3.3	36-38
2.....	2250° F. followed by an isothermal trans. at 1700° F. for 1 hr., then air cooled.....	42,000	1.12	18.9	24.2	26-27

Table IV gives the elevated temperature properties for an alloy with about 10% nickel. The improved ductility resulting from the isothermal treatment, test 2, is 175 to 260% as evaluated on the basis of the elongation, and 175 to 365% on the basis of the reduction of area, as compared to the previously known treatment of test 1. Moreover, it is especially remarkable that this increased ductility is accompanied by an excep-

Cobalt base alloys of the above composition, and heat-treated in accordance with the present invention, have found successful elevated temperature applications for such uses as the buckets on turbine wheels of airplane superchargers, as well as on other forms of gas turbines. Numerous other applications suggest themselves where high strength, toughness and corrosion-resistance at elevated temperature are required.

I claim:

1. Process for heat-treating cobalt base alloys, which comprises: homogenizing at temperature above 2150° F. but below the melting point, and thereupon cooling to temperature within the range of about 1650 to 2100° F. and transforming within said range into a relatively soft, ductile and non-aged condition.

2. Process for heat-treating cobalt base alloys for increasing the elevated temperature toughness and ductility thereof, comprising the steps of: homogenizing at temperature above 2150° F. but below the melting point, and thereupon cooling to temperature within the range of about 1650 to 2100° F., holding and transforming the alloy within said range for at least one hour, and thereupon rapidly cooling substantially to room

temperature, thereby to provide a relatively soft and ductile, non-aged microstructure.

3. Process for heat-treating cobalt base alloys for increasing the elevated temperature toughness and ductility thereof, which comprises: homogenizing at temperature within the range of about 2150 to 2350° F. for about two to thirty minutes, thereupon cooling to temperature within the range of about 1650 to 2100° F. and hold-

ing and transforming therein for at least one hour, and thereupon cooling substantially to room temperature, thereby to provide a relatively soft and ductile, non-aged microstructure.

4. Process for heat-treating cobalt base alloys containing up to about 40% chromium, up to about 1% carbon, up to about 20% molybdenum, up to about 20% tungsten, nickel and iron up to about one-half the cobalt content, and the balance substantially all cobalt, said process comprising the steps of: homogenizing the alloy at temperature above 2150° F. but below the melting point thereof, thereupon cooling to temperature within the range of about 1650 to 2100° F. and holding therein for transformation into a relatively soft, ductile and non-aged state containing a microstructure of the group consisting of lamellar and spheroidal phases, and thereupon cooling said alloy substantially to room temperature.

5. Process for heat-treating cobalt base alloys containing up to about 40% chromium, up to about 1% carbon, up to about 20% molybdenum, up to about 20% tungsten, nickel and iron up to about one-half the cobalt content, and the balance substantially all cobalt, said process comprising the steps of: homogenizing at temperature above 2150° F. but below the melting point and thereupon cooling to within the temperature range of about 1650 to 2100° F., holding and transforming therein for at least one hour into a relatively soft, ductile and non-aged state containing a microstructure of the group consisting of lamellar and spheroidal phases, and thereupon rapidly cooling said alloy substantially to room temperature.

6. Process for heat-treating cobalt base alloys containing up to about 40% chromium, up to about 1% carbon, up to about 20% molybdenum, up to about 20% tungsten, nickel and iron up to about one-half the cobalt content, and the balance substantially all cobalt, said process comprising the steps of: homogenizing at temperature within the range of about 2150 to 2350° F. for about two to thirty minutes, thereupon cooling to temperature within the range of about 1650 to 2100° F. and holding and transforming therein for at least one hour into a relatively soft, ductile and non-aged state containing a microstructure of the group consisting of lamellar and spheroidal phases, and thereupon cooling said alloy substantially to room temperature.

7. A heat-treated cobalt base alloy, characterized by high elevated temperature toughness and ductility, said alloy being in the relatively soft non-age-hardened condition resulting from homogenizing at temperature above 2150° F., followed by transforming within the temperature range of about 1650 to 2100° F.

8. A heat-treated cobalt base alloy containing

chromium from an effective amount up to about 40%, and characterized by high toughness and ductility at elevated temperatures, said alloy being in the non-age-hardened, relatively soft condition resulting from homogenizing above 2150° F., followed by transforming in the temperature range of about 1650 to 2100° F.

9. A heat-treated cobalt base alloy, characterized by high toughness and ductility at elevated temperatures, and containing chromium in effective amounts up to 40%, carbon up to about 1%, metal of the group tungsten and molybdenum up to about 20%, metal of the group nickel and iron up to about one-half the cobalt content, and the balance substantially all cobalt, said alloy being in the non-age-hardened, relatively soft condition resulting from homogenizing at temperature above 2150° F., followed by transforming in the temperature range of about 1650 to 2100° F.

10. A heat-treated cobalt base alloy, characterized by high toughness and ductility at elevated temperatures, and containing about 15 to 25% chromium, about 0.1 to 0.5% carbon, metal of the group tungsten and molybdenum up to about 20%, metal of the group nickel and iron up to about one-half the cobalt content, and the balance substantially all cobalt, said alloy being in the non-age-hardened, relatively soft condition resulting from homogenizing at temperature above 2150° F., followed by transforming in the temperature range of about 1650 to 2100° F.

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