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HIGH TEMPERATURE NICKEL-BASE ALLOY

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The present invention relates to a high temperature nickel base alloy. It is particularly concerned with a nickel base alloy adapted for use at elevated temperatures such as those encountered in the operation of gas turbines and the like.

A primary object of the present invention is to provide a high temperature nickel base alloy having a relatively low strategic alloy content and possessing optimum stress-rupture and fatigue strength, ductility and forgeability characteristics.

Heretofore for high temperature applications such as those encountered in the operation of gas turbines, as for example, gas turbine buckets, cobalt base alloys have ordinarily been used because of their desirable high temperature characteristics. However, the high cost of cobalt made such alloys unavoidably expensive and at the present time, cobalt is one of the more strategic elements so that it has become highly desirable to replace such alloys with suitable alloys having comparable high-temperature characteristics but lower and less expensive strategic alloy contents. Iron base alloys have not been found to meet these requirements due to their poorer oxidation resistance and strength characteristics. Heretofore nickel base alloys of various types have been considered because of their oxidation resistance but it has been found in general that the high temperature strength of such alloys has not been as satisfactory as that of similar cobalt base alloys.

In accordance with the present invention, there has been provided a nickel base alloy having a low critical alloy content and, in addition, possessing high temperature properties comparable to the best commercially available cobalt base alloys. In addition to the nickel base, the alloy of the present invention contains by weight, 0.1 to 0.2 percent carbon, 18 to 20 percent chromium, 6 to 11 percent molybdenum, 9 to 11 percent cobalt, 2.25 to 2.75 percent titanium, 0.25 to 1.25 percent aluminum and not over 5 percent iron. The alloy also contains the usual deoxidizing quantities of manganese and silicon in amounts ranging from about 0.5 to 1.5 percent manganese and 0.3 to 1 percent silicon. The iron content of the alloy results from the fact that it is present in certain of the essential elements employed in the fabrication of the alloy and is not deliberately added as such. This is also true of the aluminum which, however, is an essential ingredient of the alloy and is preferably present in an amount ranging from about 0.5 to 1.25 percent, by weight.

From the above analysis, it will be seen that the alloy of the present invention has a very low strategic alloy content when compared particularly with the cobalt base alloys ordinarily employed for gas turbine bucket applications and in which the cobalt, for example, is a major constituent. It is free from columbium which is an ingredient of a number of high temperature alloys and its cobalt content is relatively low. Its strength characteristics are obtained primarily through the molybdenum and titanium contents with the molybdenum tending to

strengthen the matrix of the alloy and the titanium forming intermetallic compounds which result in a high degree of precipitation hardening upon proper heat treatment of the alloy. Due to the absence of the columbium and the relatively low content of cobalt, the alloy is also characterized by the fact that it is comparatively inexpensive for a high temperature alloy.

The alloys of the present invention are forgeable and their forgeability characteristics are comparable to other high temperature alloys. Preferably the forging or working of these alloys is ordinarily carried out at temperatures in the neighborhood of about 2000° F. An acceptable forging technique comprises the preheating of the alloy at 1600° F. for a short time, for example, three hours, followed by an initial forging operation at a temperature of about 1950° F. until the dendric structure of the cast alloy is broken up. The forging temperature is then increased to a range of from 2050° F. to 2100° F. and the material forged to the desired shape. To obtain the optimum physical properties, the forged product is heat treated or aged at a temperature from about 1200° F. to 1700° F. followed by air cooling. A preferred heat treatment includes a solution treatment at a temperature of about 1950° F. followed by air cooling and an aging or precipitation hardening treatment at a temperature of from 1200 to 1700° F., preferably about 1400° F. for 15 hours followed by air cooling to room temperature. After solution treating at 1950° F. the material has a Rockwell C hardness of from 15 to 17 while the maximum hardness developed after precipitation hardening is 30 to 35 on the Rockwell C. scale.

The room and high temperature physical properties of the alloys of the present invention and a comparison thereof with the physical properties of comparable alloys containing more or less of certain of the alloying ingredients can be obtained from the following table in which the nickel content includes 1–1.5% manganese and 0.5 to 1% silicon.

In the table, alloys M–252, 607, 608 and 635 are examples of alloys within the scope of the present invention. Alloy M–252 is a preferred alloy in that it possesses a combination of good yield strength, room temperature and high temperature tensile strengths and stress rupture (Str. Rup.) characteristics at elevated temperatures. All of the alloys listed in the table were forged at a temperature in the neighborhood of 2,000° F. and the forged products were solution treated and age hardened as described hereinbefore.

A comparison of the properties of the first four alloys listed in the table with the remaining alloys will show that for optimum results it is essential that the alloying ingredients be kept within the proportions indicated hereinbefore. For example, alloy M–346 which has a carbon content of only 0.05% has poor stress rupture and tensile strength characteristics. Any substantial increase in the carbon content, such as that present in alloy M–430 markedly reduced the forgeability of the alloy to such an extent that stress rupture tests could not be performed on this alloy.

Alloys M–344 and P–841 respectively represent a decrease and an increase in the cobalt contents as compared with the preferred alloy M–252. Alloy M–344 was inferior to M–252 both as to tensile properties and rupture strength while alloy P–841 had very poor ductility characteristics as shown by the elongation and reduction in area results obtained in the various tensile strength tests.

In alloy P–841, the molybdenum content was increased to 14.9 percent. The resultant alloy had good tensile and yield strength characteristics but very poor ductility. The rupture strengths of alloy P–840 were inferior to M–252 at the 1500° F. temperature. The higher molyb-

denum alloy was also much harder to forge than the M–252 alloy.

tegic alloy content, cost, good forgeability, high tensile, rupture, and fatigue strengths and fair ductility, of any

Alloy No.	M–252	607	608	635	M–346	M–430	M–344	P–841	P–840	M–365	M–282	M–364	M–416
C	.17	.19	.17	.10	.05	.29	.19	.15	.14	.16	.19	.15	.19
Cr	19.0	19.4	19.4	19	19	19	19	19	19	19	19	19	19
Co	10	10.5	10.4	10	10	10	8.7	11	10	10	10	10	10
Mo	10	7.8	7.2	6.0	10	10	12.87	10	14.9	10	10	10	10
Ti	2.25	2.3	2.3	2.5	2.5	2.5	2.5	2.5	2.5	2.5	1.62	3.0	2.5
Al	.5	.7	.73	.65	.5	.5	.5	.5	.5	1.34	.5	.5	.5
Fe	3	4.2	4.2	2	3	3	3	3	3	3	3	3	12.75
Ni	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.
0.2% offset yield Str. at R. T.	85,750				74,480	98,000	68,600	100,450	121,520	108,290	73,900	83,300	80,850
R. T., T. S. (p. s. i.)	169,800	174,600	161,200	163,250	143,300	163,600	151,400	164,100	188,500	144,500	155,950	113,800	140,300
R. T., Percent Elong	14	26	29	28	19	12	20	6	1	4	26	2	5
R. T., Percent Red. in Area	11.6	24	27	35	16	7.7	16.7	5.5	1.4	7.7	25.9	3.8	5.5
1,200° F., T. S. (p. s. i.)	160,850	153,800	143,100	141,900	117,300	136,000	127,600	169,000	196,500	142,400	138,400	126,800	139,800
1,200° F., Percent Elong	15	24	16	24	11	7	13	6	3	3	19	3	12
1,200° F., Percent Red. in Area	13	25	15	24	13	13.8	16.1	5.5	6.9	4.6	19.5	8.5	10.8
1,500° F., T. S. (p. s. i.)	82,200	78,300	76,500	76,100	69,900	93,500	74,400	78,754	95,500	84,900	70,212	86,600	68,172
1,500° F., Percent Elong	16	39	37	36	18	6	9	29	28	4	30	5	37
1,500° F., Percent Red. in Area	15.3	55	52	50	23	9.3	13	32	43.4	6.9	32.6	8.5	39.7
100 Hr. Str. Rup. at 1,200° F. (p. s. i.)	80,000				70,000		74,000			74,000	79,000		
1,000 Hr. Str. Rup. at 1,200° F. (p. s. i)	59,000							65,000	68,000	63,000			
100 Hr. Str. Rup. at 1,500° F. (p. s. i.)	26,000	23,000	23,000	28,000	22,000		23,000	27,500	22,300	19,000	22,500		21,000
1,000 Hr. Str. Rup. at 1,500° F. (p. s. i.)								18,000					

As was pointed out hereinbefore, the aluminum is inherently present as part of the added titanium alloy employed in the manufacture of these alloys and is desirable in such amounts. However, when additional aluminum is added as, for example, in alloy M–365, the ductility characteristics of the alloy are not acceptable. Alloy M–282 has a lower titanium content and M–364 has a higher titanium content than the alloys of the present invention. From the consideration of the physical characteristics of these alloys, it will be noted that the lower titanium content alloy has generally poorer physical characteristics while the alloy M–364 having a higher titanium content has poor ductility characteristics. In fact the ductility characteristics were too low to permit satisfactory stress-rupture tests.

The iron present in the alloy of the present invention is part of the ferro alloy additions such as the ferro chrome employed for introducing the chromium content of the alloy. It should not exceed the indicated maximum of about 5 percent since a higher iron content is detrimental both to the short time stress rupture properties. This is illustrated by the test results on alloy M–416 where the iron content was deliberately increased to about 12.75 percent, by weight.

From the above results, it will be seen it is essential that the various alloying ingredients should be kept within the prescribed limits set forth hereinbefore. In addition to the properties set forth in the table for the alloys of the present invention, it has been found that these alloys also have exceptionally good fatigue strength. For example, the fatigue strength of alloy M–252 as measured on the Krouse rotating beam apparatus was 72,500 p. s. i. at 10^8 cycles of the test temperature of 1200° F. This is to be compared with the fatigue strength of 60,700 p. s. i. at 10^8 cycles and at 1200° F. for a standard cobalt base alloy presently employed extensively in the manufacture of gas turbine buckets. The same cobalt base alloy is also characterized by tensile strength of 67,000 p. s. i. at 1500° F. It will be seen, therefore, that the nickel base alloy of the present invention is superior both as to tensile strength and fatigue strength properties. Based on a comparison of the alloy of the present invention with a number of commercially available high temperature alloys it has been found that the present alloy represents the best all around balance of low strategic alloy content, cost, good forgeability, high tensile, rupture, and fatigue strengths and fair ductility, of any alloy tested. To obtain these properties, care should be exercised to maintain the various alloying ingredients within the prescribed limits, this being particularly true of the titanum and aluminum contents of the alloy.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A nickel base alloy for high temperature applications containing as essential alloying ingredients, by weight, from 0.1 to 0.2 percent carbon, 18 to 20 percent chromium, 6 to 11 percent molybdenum, 9 to 11 percent cobalt, 2.25 to 2.75 percent titanium, 0.25 to 1.25 percent aluminum, not over 5 percent iron, balance nickel except for deoxidizing quantities of manganese and silicon.

2. A high temperature nickel base alloy consisting of, by weight, about 0.17 percent carbon, 19 percent chromium, 10 percent cobalt, 10 percent molybdenum, 2.25 percent titanium, 0.5 percent aluminum, not over 3 percent iron, balance nickel except for deoxidizing quantities of manganese and silicon.

3. A high temperature nickel base alloy consisting essentially by weight of .17 percent carbon, 19 percent chromium, 10 percent cobalt, 6 percent molybdenum, 2.5 percent titanium, .65 percent aluminum, less than 5 percent iron, balance nickel except for deoxidizing quantities of manganese and silicon.

4. A high temperature nickel base alloy containing by weight about .19 percent carbon, 19.4 percent chromium, 10.5 percent cobalt from 7 to 8 percent molybdenum, 2.25 to 2.75 percent titanium, 0.5 to 1.25 percent aluminum, not over 5 percent iron, balance nickel except for deoxidizing quantities of manganese and silicon.

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