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NICKEL ALLOY WITH GOOD STRESS-RUPTURE STRENGTH

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ABSTRACT OF THE DISCLOSURE

A hardenable nickel alloy containing special percentages of chromium, aluminum, titanium, hafnium, yttrium, molybdenum, tungsten, carbon, etc., offers enhanced stress rupture strength over the intermediate temperature range of 600° C.–900° C. while retaining a satisfactory level of ductility.

As is generally recognised in the art, over the past years considerable emphasis has been given to the development of the so-termed superalloys, notably those of the nickel-base precipitation hardenable type, capable of meeting the stringent requirements demanded by various commercial applications. As an example of this, mention might be made of the gas turbine engine, particularly such components as stator and rotor blades intended to operate over the intermediate temperature range of 600° C.–900° C. as well as at higher levels. A primary aim recently has been to overcome or minimize the "trough ductility" problem within this temperature range and thereby extend the overall usefulness of a given component. Tensile ductility remains an important consideration herein, but the subject invention is addressed principally to the task of also effecting over the 600° C.–900° C. range an improved level of stress rupture strength in respect of nickel alloys hereindescribed.

It has now been found that certain precipitation hardenable, nickel alloys containing special percentages of chromium, aluminum, titanium and other constituents as described herein, offer enhanced stress-rupture strengths in combination with adequate ductility, tensile strength, etc., when hafnium and yttrium are co-present in prescribed percentages.

Accordingly, alloys contemplated herein contain (by weight) up to 20%, e.g., 2% to 20%, chromium; from 3% to 8% aluminum, up to 8% titanium, the sum of the aluminum plus titanium being from 4% to 12%; from 0.25% to 3% hafnium; from 0.005% to 0.15% yttrium; up to 20% cobalt; up to 20% tungsten; up to 3% iron; up to 8% molybdenum; up to 9% tantalum; up to 4% niobium; up to 1.5% vanadium; up to 1.5%, e.g., 0.01% to 0.5%, zirconium; up to 0.3%, e.g., 0.001% to 0.1%, boron; up to 0.3% carbon; up to 0.5% manganese; up to 0.3% silicon, and the balance, other than impurities, being essentially nickel, the nickel being at least 30% and preferably at least 50%. Advantageously the chromium percentage does not exceed 14.5% and the yttrium content does not exceed 0.1%. Most advantageously, the percentages of hafnium and yttrium are from 0.3% to 1.5% and from 0.008% to 0.08%, respectively. The yttrium can, if desired, be partly or wholly replaced by a similar amount of lanthanum.

Within the ranges above given, preferred alloys of the invention are those in which one or more elements are maintained within the following ranges: 0.03% to 0.2% carbon; 5% to 13% chromium; up to 12% tungsten; up to 5% tantalum; up to 5% titanium; 4.5 to 7% aluminum; 0.02% to 0.7% zirconium, and up to 0.03% boron. A particularly preferred group of alloys contain from 0.03% to 0.2% carbon; from 5% to 13% chromium; up to 20% cobalt; up to 8%, e.g., 1% to 7%, molybdenum; up to 12% tungsten; up to 4% niobium, up to 5% tantalum; up to 5% titanium; from 4.5% to 7% aluminum; from 0.02% to 0.2% zirconium; up to 0.03%, e.g., 0.001% to 0.01%, boron; 0.008% to 0.08% yttrium; 0.3% to 1.5% hafnium; balance, apart from impurities, being nickel in an amount of at least 50%.

Further classes of preferred alloys of the invention are those of any of the above groups containing up to 4% molybdenum and from 6% to 12% tungsten and those containing from 2% to 7% molybdenum and up to 5% tungsten.

In carrying the invention into practice, the alloys in accordance herewith should normally be produced by vacuum melting, for example, in a vacuum induction furnace, followed by addition of the hafnium and yttrium (or lanthanum) and casting, either under vacuum or under an inert atmosphere. In striving for optimum characteristics, the alloys can be subjected to vacuum refining before the yttrium and hafnium additions are made, for example by vigorously agitating the molten alloy in a vacuum induction furnace for an extended period of time, e.g. from 15 to 60 minutes at a temperature of 1400 to 1600° C., preferably about 1500° C., and at a pressure not exceeding 100 microns, preferably not exceeding 10 microns and more preferably not exceeding 2 microns, adding the yttrium and hafnium, and casting the melt. A preferred vacuum refining operation is effected in a vacuum induction furnace for about 30 minutes under a pressure of about 1 micron with the crucible set wholly within the furnace induction coil and being between one and two thirds filled with melt so that the upper part of the coil is above the normal level of melt in the crucible. When the furnace is in operation, this arrangement increases the intensity of agitation to which the melt is subjected. If desired the yttrium and hafnium may be added under an inert atmosphere, e.g. argon, at a moderate pressure of, for example, 100 mm. of mercury.

The present invention results primarily in improvement in stress-rupture strength, although over generally the whole of the above-defined base composition range marked improvement is also obtained in the intermediate temperature tensile ductility.

To illustrate the improved properties obtained, yttrium and hafnium were incorporated, separately and together into two alloys of the following compositions:

Alloy	Composition (percent by wt.)											
	C	Cr	Co	Mo	W	Nb	Ta	Al	Ti	Zr	B	Ni
1	0.13	5.8	------	2.02	10.9	1.3	------	6.0	------	0.13	0.018	Bal.
2	0.14	9.1	9.7	------	9.6	------	1.9	5.5	1.5	0.16	0.02	Bal.

A 35 kg. heat of each alloy was made in a 55 kg. capacity 3 kc./s. vacuum induction furnace and cast as 10 kg. sticks which were cut into 4 kg. portions and remelted in a 4 kc./s. vacuum induction furnace of 10 kg. capacity. Various amounts of yttrium and hafnium singly and together were added to the 4 kg. melts under argon at a pressure of 100 mm. of mercury and each of the resulting melts was cast into a preheated refractory mould to provide suitably tapered test piece blanks. A blank melt with no addition was similarly cast to provide a reference sample.

Suitable test bars were machined from the tapered test blanks and were subjected to short-time tensile tests and to stress-rupture tests, all at 760° C. The results are set forth in the following Table I.

TABLE I

Alloy No.	Analysed contents		Tensile properties at 760° C.			Stress-rupture properties at 65 hbar/760° C.	
	Hf	Y	Elongation (percent)	R.A. (percent)	U.T.S. (hbar)	Life (h.)	Elongation (percent)
1	------	------	0.6	3	76	15	1.8
	------	0.04	2.8	9	89	74	4.0
	------	0.07	1.7	8	77	78	4.7
	0.75	------	2.5	6	89	20	1.4
	1.5	------	6.1	9	90	37	1.5
	0.80	0.02	4.1	10	86	160	5.3
	1.65	0.03	6.0	19	89	92	4.3
	1.08	0.01	2.4	8	98	311	3.7
2	------	------	2.0	9	89	93	2.2
	------	0.06	4.2	9	103	160	4.7
	0.66	------	4.7	8	100	119	3.7
	1.37	------	8.9	11	106	195	3.1
	0.80	0.08	5.7	12	96	218	5.9
	1.22	0.06	4.3	9	93	326	7.5

NOTE.—R.A.=Reduction in area; U.T.S.=Ultimate tensile stress.

It will be seen that while the separate additions of hafnium and yttrium improved the stress-rupture life and ductility of each of the alloys to some extent, a substantial and unexpected further increase in the stress-rupture life resulted from the combined addition. The tensile ductility of the alloys containing both yttrium and hafnium was also improved compared with the alloys with no additions.

The results in Table I also show that a very satisfactory combination of stress-rupture and tensile properties, including tensile ductility, is exhibited by alloys containing less than 1.5% hafnium, when yttrium is also present.

A further advantage of the co-presence of yttrium with hafnium is that it refines the grains of the castings. This is advantageous when making castings of heavy section, e.g. 2.5 cm. or more, and particularly in the case of castings having both thin and thick sections such as automobile gas turbine rotors with integrally cast blades. In such castings a fine grain structure can thus be obtained in the heavy centre section as well as the thin blade sections.

The compositions of other alloys of which the stress-rupture strength can be improved by the incorporation of yttrium and hafnium in accordance with the invention are given by way of example in the following Table II in percent by weight.

TABLE II

Alloy	C	Cr	Co	Mo	W	Nb	Ta	Ti	Al	Zr	B	Ni
3	0.08	5	15	3.5	8	------	8	------	6.0	0.05	0.10	Bal.
4	0.1	8.1	9.9	6.05	------	------	4.1	0.95	5.75	0.12	0.019	Bal.
5	0.1	10.1	10.0	4.05	------	------	------	3.65	5.8	0.14	0.015	Bal.
6	0.05	12	------	4.7	------	2	------	0.65	6.0	0.10	0.012	Bal.
7	0.10	12.1	------	4.2	------	2.3	------	0.8	6.3	0.12	0.018	Bal.
8	0.15	9.1	10.0	2.2	9.8	------	1.5	1.3	5.3	0.05	0.018	Bal.
9	0.1	3	12	------	19	------	3	------	5.75	0.35	0.03	Bal.
10	0.13	5.7	------	2	11	------	3	------	6.3	0.6	------	Bal.
11	0.17	16.0	8.5	1.75	2.6	0.9	1.75	3.4	3.4	0.1	0.01	Bal.

Castings produced from the alloys in accordance herewith can be employed in automotive and aircraft turbine engine blades, and also as dies, turbine rotors, etc., particularly within the temperature range of 600° C.–900° C. and particularly with regard to cast low chromium, highly precipitation hardened nickel superalloys.

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, as those skilled in the art will readily understand. Such modifications and variations are considered to be within the purview and scope of the invention and appended claims.

We claim:

1. A high nickel superalloy in the cast condition and characterized by good stress-rupture strength together with satisfactory ductility over the temperature range of 600° C.–900° C., the alloy consisting of up to 20% chromium, about 4.5% to 8% aluminum, up to 8% titanium, the sum of the aluminum plus titanium not exceeding 12%, about 0.25% to 3% hafnium, about 0.005% to 0.1% yttrium, up to 20% cobalt, up to 20% tungsten, up to 8% molybdenum, up to 3% iron, up to about 5% tantalum, up to 4% niobium, up to 1.5% vanadium, up to 1.5% zirconium, up to 0.3% boron, up to 0.3% carbon, up to 0.5% manganese, up to 0.3% silicon, and the balance essentially nickel, the nickel being present in an amount of at least about 30%, said casting being further characterized in that it exhibits grain refinement over the same alloy free of hafnium and yttrium whereby the casting is rendered more suitable for use in thick sections.

2. A cast nickel alloy in accordance with claim **1** containing about 0.3% to 1.5% hafnium and 0.008% to 0.08% yttrium.

3. A cast nickel alloy in accordance with claim **1** containing from 5% to 13% chromium, about .03% to 0.2% carbon, about 4.5% to 7% aluminum, up to about 0.03% boron, 0.66% to 1.65% hafnium, 0.01% to 0.08% yttrium, 2% to 7% molybdenum and up to 5% tungsten.

4. A cast nickel alloy in accordance with claim **1** containing up to 4% molybdenum and 6% to 12% tungsten.

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