United States Patent Office

2,975,051

Patented Mar. 14, 1961

2,975,051

NICKEL BASE ALLOY

James E. Wilson, Loveland, and Eugene L. Dunn, Batavia, Ohio, assignors to General Electric Company, a corporation of New York

No Drawing. Filed Sept. 29, 1959, Ser. No. 843,056

5 Claims. (Cl. 75—171)

This invention relates to nickel base alloys particularly useful at elevated temperatures in cast form and, more particularly, to such alloys including chromium, aluminum, titanium, molybdenum, boron and tungsten.

Following the advance of technology in the field of power producing apparatus is a companion effort by materials specialists to force the materials thermal barrier up the temperature scale. At temperatures greater than about 2000° F. and under stress conditions of more than 3000 p.s.i., there were few, if any cast alloys, prior to that of this invention, which were practical. The specified mechanical properties of alloys useful within that range include those of good tensile ductility along with adequate life under stress conditions at temperatures of about 2000° F. or above.

A principal object of this invention is to provide an alloy suitable for casting which has high strength and ductility for practical use at about 2100° F.

Another object is to provide a nickel base alloy including a relatively critical range of such elements as boron, iron, aluminum titanium, molybdenum and tungsten in order to assure sufficient strength and ductility in an article for elevated temperature operation.

A further object is to provide a nickel base alloy having a balance of molybdenum and tungsten which results in an alloy of unusual stress rupture life.

These and other objects and advantages of this invention will be more readily understood when viewed in connection with the following more detailed description. The scope of the invention will be pointed out in the appended claims.

Briefly stated, this invention in one form provides a nickel base castable alloy comprising in percent by weight up to about 0.08 carbon, 0–6 iron, 0.05–0.10 boron, 14–16 chromium, 4.3–5.0 aluminum, 3.25–3.75 titanium, 3.5–4.0 molybdenum, 1.4–4.1 tungsten, 0–0.1 zirconium with the balance essentially nickel, impurities and the usual small amounts of silicon and manganese normally found in this type of alloy.

The elements aluminum, titanium and molybdenum have been combined in various amounts to produce precipitated phases or solid solutions in order to strengthen and harden high temperature nickel base alloys. Although tungsten has been included in some nickel base alloys as an alloying element, usually tungsten and molybdenum have not been components of the same nickel base alloy along with the elements aluminum and titanium. Through this invention it has been found that the inclusion of all such elements within a relatively narrow range of composition and the low iron content in some forms results in an alloy having unexpectedly high stress rupture strength along with good tensile ductility especially in the 2000–2150° F. operation range.

In its cast form, the alloy of this invention has the strength of a cast alloy and an unusual high tensile ductility generally found only in wrought alloys. Such properties expand the possible uses of the alloy of this invention over those of other cast alloys to include applications

under high impact and stress conditions by insuring better stress distribution.

Initial studies of the inter-relationship of aluminum, molybdenum and tungsten in nickel base alloys in connection with this invention are represented by the compositions of Table I. The composition of the alloys shown included in addition to the elements of Table I, in percent by weight up to 0.08 C, 3.5–6 Fe, 0.07–0.09 B, 14–16 Cr, 3.25–3.75 Ti, a maximum of 0.01 Mn, a maximum of 0.03 Si, with the balance essentially Ni and impurities.

TABLE I

Alloy	Elements (percent by weight)		
	Al	Mo	W
W-2	4.8	4.1	1.4
W-3	4.3	3.7	2.5
W-6	4.7	0	7.1
W-8	3.6	3.9	1.5
W-9	3.6	3.4	2.9
W-10	2.9	0	4.1

It can be seen in Table II that the tensile ductility and stress rupture lives of alloys W–2 and W–3 were very much gerater than the other "W" series alloys of approximately the same ultimate tensile strengths. The test bars which were used to obtain the values in Table II were standard 0.160 inch diameter, one inch gauge length bars.

TABLE II

Alloy	Tensile Properties @ 1,200° F.			Rupture Life @ 1,800° F. and 15,000 p.s.i. (hrs.)
	UTS, 1,000 p.s.i.	El, Percent	RA, Percent	
W-2	164	6.3	11.0	530
W-3				459
W-6	188	2.1	1.5	198
W-8	169	2.8	2.5	242
W-9	173	2.2	5.0	217
W-10	167	1.5	1.0	77

The alloys of Table I were heat treated by heating first to 2100° F. for one hour, air cooling, heating to 1950° F. for two hours, air cooling, heating to 1550° F. for four hours and then air cooling prior to testing the results of which are shown in Table II.

As used herein "UTS" means "Ultimate Tensile Strength," the value in pounds per square inch obtained when the maximum load recorded during the straining of a specimen is divided by the cross-sectional area of the specimen before straining; "El," which means "Tensile Elongation," is the amount of permanent extension in the fracture area in a tension test and is a measure of the permanent deformation before fracture by stress in tension; "RA" which means "Reduction in Area" is another measure of the ductility of an alloy; and "Rupture Life" is a measure of the length of time an alloy resists failure at a given stress and temperature.

By comparing W–2 with W–6, it is to be noted that molybdenum and tungsten are not interchangeable in this alloy nor do they have the same results on the mechanical properties as are sometimes shown to have in other cases. A comparison of W–3 with W–9 alloys shows the effect of a slight change of the amount of aluminum on the rupture life of this type of alloy. Alloy W–10 shows that tungsten alone cannot bring about the desired results without molybdenum and without an adequate amount of aluminum.

Additional alloy studies and recognition of the effects of a judicious selection of iron, carbon and tungsten within the selected ranges for titanium, aluminum and molybdenum are represented by the alloys of Table III.

TABLE III

Elements	Alloys (percent by weight)						
	B	C	D	F	G	H	T
C	.08 max.	.08 max.	.08 max.	.04 max.	.04 max.	.04 max.	.05-.12
Fe	4-6	4-6	4-6	.2 max.	.2 max.	.2 max.	.1
B	.05-.10	.07-.10	.05-.10	.07-.10	.07-.10	.07-.10	.05-.10
Cr	14-16	14-16	14-17	14-16	14-16	14-16	12-14
Al	4.3-5.0	4.3-5.0	3.6-5	4.3-5.0	5.5-6.5	5.5-6.5	5.5-6.25
Ti	3.25-3.75	3.25-3.75	3-4	3.25-3.75	.3-1	.3-1	.3-1
Mo	3.5-4.0	3.5-4.0	4-7	3.5-4.0	3.5-4.0	3.5-4.0	0
W	2.0-2.5	3.5-4.0	0	2.5-3.0	2.5-3.0	2.5-3.0	8-10
Zr	0	0	0	.05-.10	.05-.10	.05-.10	.05-.10
Cb	0	0	0	0	0	1.5-2.5	1-3
Ni	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.	Bal.

Alloys B, C and F have been shown to have unusual stress rupture life and tensile ductility as shown by the comparison of data in Tables IV and V below.

TABLE IV

Stress rupture life (like grain size)

Alloy	Temp. (° F.)	Stress (1,000 p.s.i.)	Life (hrs.)
F	2,130	3.3	35
T	2,130	3.3	23
*	*	*	*
F	1,900	15.0	45
G	1,900	15.0	28
H	1,900	15.0	26
*	*	*	*
B	1,850	15.0	245
D	1,850	15.0	196
*	*	*	*
B	1,800	15.0	530
C	1,800	15.0	459
D	1,800	15.0	410

TABLE V

Tensile reduction in area

[Percent @ 1,300° F.]

Alloy	Grain Size	
	1/32"-1/8"	1/4"-1/2"
F	8-11	17-19
T	2-5	6.5-11

From a study of the compositions of the above listed alloys and their resulting rupture lives, it has been recognized that molybdenum and tungsten complement each other. This invention recognizes that in percent by weight and times the Mo content added to one-half times the tungsten content lies in the range of about 4–6. Thus, numerically

$$\left(Mo+\frac{W}{2}\right)=4\text{–}6$$

the W and Mo being weight percents.

Prior to the testing of the specimens the data for which is shown in Tables IV and V, the specimens were solution heat treated at about 2100° F. for one hour before air cooling.

The alloys from which representative examples are shown in tables herein were prepared by induction vacuum melting and vacuum induction investment casting to specified grain sizes for control of testing. Grain sizes were measured at the face of the ingot adjacent the test bar section.

Although this invention has been described in connection with specific examples, it will be understood by those skilled in the art of metallurgy the modifications and variations of which this invention is capable.

What is claimed is:

1. A nickel base alloy suitable for casting comprising in percent by weight up to about 0.08 carbon, up to 6 iron, 0.05–0.10 boron, 14–16 chromium, 4.3–5.0 aluminum, 3.25–3.75 titanium, 3.5–4.0 molybdenum, 1.4–4.1 tungsten, up to 0.1 zirconium, with the balance essentially nickel and impurities.

2. A nickel base alloy suitable for casting comprising in percent by weight up to about 0.08 carbon, 4–6 iron, 0.05–0.10 boron, 14–16 chromium, 4.3–5.0 aluminum, 3.25–3.75 titanium, 3.5–4.0 molybdenum, 2.0–2.5 tungsten, with the balance essentially nickel and impurities.

3. A nickel base alloy suitable for casting comprising in percent by weight up to about 0.08 carbon, 4–6 iron, 0.07–0.10 boron, 14–16 chromium, 4.3–5.0 aluminum, 3.25–3.75 titanium, 3.5–4.0 molybdenum, 3.5–4.0 tungsten, with the balance essentially nickel and impurities.

4. A nickel base alloy suitable for casting comprising in percent by weight up to about 0.04 carbon, up to about 0.2 iron, 0.07–0.10 boron, 14–16 chromium, 4.3–5.0 aluminum, 3.25–3.75 titanium, 3.5–4.0 molybdenum, 2.5–3.0 tungsten, 0.05–0.10 zirconium, with the balance essentially nickel and impurities.

5. A nickel base alloy suitable for casting comprising in percent by weight up to about 0.08 carbon; up to 6 iron, 0.05–0.10 boron, 14–16 chromium, 4.3–5.0 aluminum, 3.25–3.75 titanium, 3.5–4.0 molybdenum, 1.4–4.1 tungsten, up to 0.1 zirconium, with the balance essentially nickel and impurities, the sum of the weight percentages of molybdenum and one-half of tungsten being 4–6.

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