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M. A. POHLMAN ET AL

3,457,066

NICKEL BASE ALLOY

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Fig 1

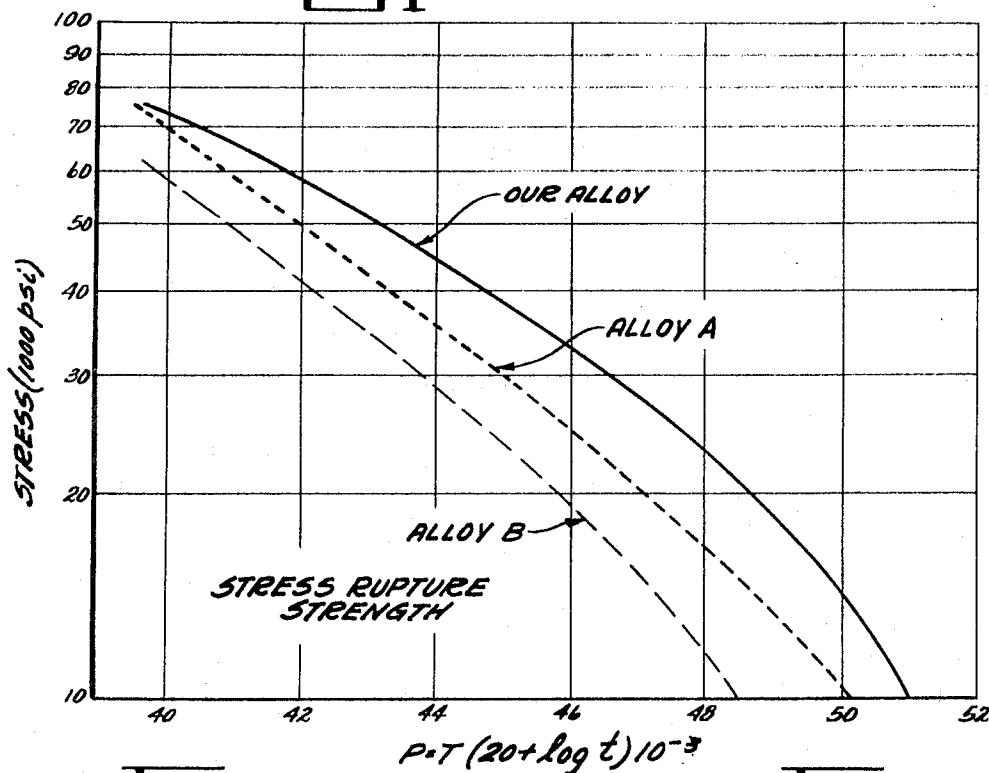


Fig 2

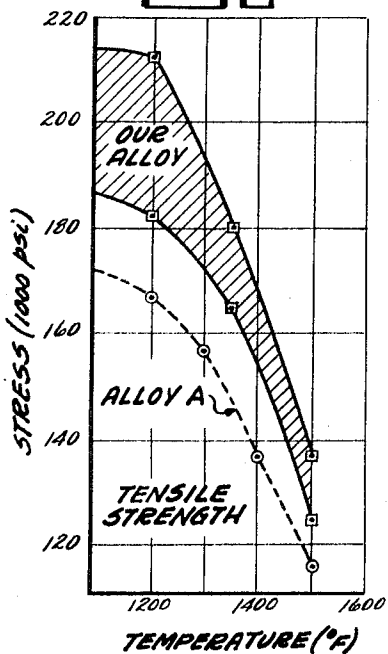
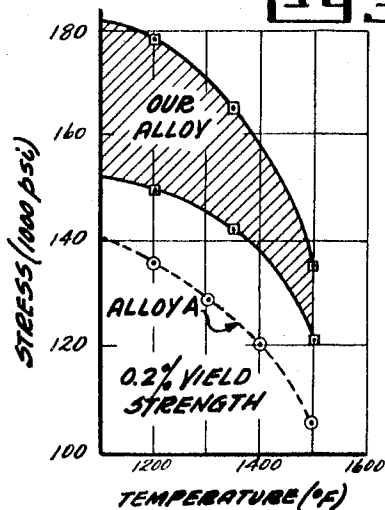


Fig 3



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3,457,066

NICKEL BASE ALLOY

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5 Claims

This invention relates to nickel base alloys suitable for elevated temperature operation and particularly useful as sheet material.

Nickel base alloys including relatively wide ranges of cobalt, chromium, molybdenum, titanium and aluminum as their principle alloying elements have been reported as suitable for high temperature use under conditions of relatively high stress. However, the unexpected advantages of a close balance between certain of these elements in narrower ranges had not been completely explored.

It is an object of this invention to provide a nickel base alloy having elevated temperature strength properties greater than presently known alloys for similar applications.

Another object is to provide a vacuum melted nickel base alloy which in sheet form exceeds the tensile and rupture strengths of known sheet alloys at elevated temperatures.

According to one form of our alloy, we provide a nickel base sheet alloy comprising in percent by weight up to about 0.08 carbon, about 14-17 chromium, about 0.01-0.05 boron, about 4-7 molybdenum, about 3-4 titanium, about 3.6-5 aluminum, about 5-20 cobalt with the balance essentially nickel, impurities and possibly the usual small amounts of silicon and manganese.

Although our alloy in its broad range has strength properties at elevated temperatures greater than those of other sheet alloys, we prefer our alloy in the range in the percent by weight of about 0.04-0.07 carbon, about 14.5-15.5 chromium, about 0.025-0.035 boron, about 14.5-15.5 cobalt, about 4.5-5.5 molybdenum, about 3.3-3.7 titanium, about 4.2-4.6 aluminum with the balance essentially nickel, impurities, up to about 0.1 each of manganese and silicon and a maximum of about 0.2 iron.

Our sheet alloy in its lower range of cobalt after a heat treatment, such as heating at about 2100° F. for about one half hour, air cooling, heating at about 1400° F. for about sixteen (16) hours and then air cooling, is characterized by particularly high elevated temperature tensile strength; in its upper range of cobalt it has exceptionally high elevated temperature stress rupture strength after that same type of heat treatment. We prefer about 14.5-15.5 percent by weight cobalt because that range results in the best balance at elevated temperatures between such properties as tensile and rupture strengths, oxidation resistance and the ability of the sheet material to be formed or worked.

Although the scope of our invention will be pointed out in the claims, our alloy will be better understood from our description taken in connection with the accompanying drawing in which:

FIG. 1 is a graph of the average stress rupture life of our preferred sheet alloy compared with the strongest of other available sheet alloys;

FIG. 2 is a graph of the ultimate tensile strength band of our alloy in its broad range;

FIG. 3 is a graph of the 0.2 percent yield strength and of our alloy in its broad range.

Three of the tests generally conducted on alloys to determine their physical properties are called "stress rupture", "ultimate tensile" and "yield" tests, the results of such tests being generally reported as "stress rupture strength", "ultimate tensile strength" and "yield strength". "Stress rupture strength" is the value of stress in pounds per square inch obtained by dividing the amount of an applied load by the area supporting that load initially while the test specimen is maintained at a selected temperature. The strength of material of a test specimen is also measured by the length of time it resists failure at a given stress and temperature. Such a length of time is called "stress rupture life" and the stress for such a time is called "stress rupture strength". By incorporating such values as temperature, initial applied load and stress rupture life into a special graph, later to be described in detail, that graph may be used to predict the life of the material or the time a material can be expected to be operable prior to failure under a specified stress and at a specified temperature.

"Ultimate tensile strength" is the value in pounds per square inch obtained when the maximum load recorded during the plastic straining of a specimen is divided by the cross sectional area of the specimen before straining.

The term "0.2% yield strength" shown in FIG. 3 is the stress at which a material exhibits 0.2% deviation from the proportionality of stress to strain. This figure, sometimes referred to as "0.2% offset" is commonly used as the basis of design strength of articles.

The nominal chemical compositions of alloy A referred to in FIGS. 1-3 and of alloy B referred to in FIG. 1 are given in the following table along with the composition range of our alloy all prepared by vacuum melting techniques.

TABLE I

Composition in percent by weight (sheet material)

	Our Alloy			
	Board range	Preferred range	Alloy A	Alloy B
C.....	1-08	.04-.07	.1	.1
Cr.....	14-17	14.5-15.5	.19	15.5
B.....	.01-.05	.025-.035	.003	1.005
Co.....	5-20	14.5-15.5		
Mo.....	4-7	4.5-5.5	10	5.5
Ti.....	3-4	3.3-3.7	3.1	2.5
Al.....	3.0-5	4.2-4.6	1.7	2
Fe.....	1-2	1-2	1.5	10
Ni.....	Bal.	Bal.	Bal.	Bal.
Si (max.).....	.1	.1	.5	.1
Mn (max.).....	.1	.1	.5	.1

¹ Max.

Referring to FIG. 1, the stress rupture strengths of the alloys after heat treatment are represented by the comparison of stress with a time-temperature parameter shown at the horizontal coordinate. This parameter, known as the Larson-Miller parameter, has been calculated from the Formula $P = T(20 + \log t) \times 10^{-3}$ in which P equals the time-temperature parameter number, T equals absolute temperature in degrees Rankine and t equals the time in hours. The curves of FIG. 1 have been prepared from a large amount of stress rupture test results and represent a compact summary of a wide range of data. Using this

special graph, it is possible to predict the stress rupture life of a material under a given load at a given temperature.

The curves of FIG. 1 show that the stress rupture strength of our vacuum melted sheet alloy in its preferred range is greater than that of the two strongest sheet alloys available, each after heat treatment.

The results of strength data represented by the graphs of FIGS. 2 and 3 show that our heat treated vacuum melted sheet alloy in its broad range has greater elevated temperature ultimate tensile strength and 0.2% yield strength than the next strongest available heat treated alloy represented by alloy A.

A comparison of the chemistry of alloy A with that of our alloy indicates that unexpected results have been achieved by our careful study and selection of elements previously reported in relatively broad ranges.

EXAMPLE 1

We vacuum melted an alloy including in percent by weight 0.06 carbon, 0.05 silicon, 0.05 manganese, 0.09 iron, 14.7 chromium, 0.031 boron, 14.8 cobalt, 5.07 molybdenum, 3.53 titanium, 4.47 aluminum, with the balance essentially nickel and impurities. This alloy was formed into a sheet material of about 0.065 inch thickness and then heat treated by first heating at 2100° F. for one half hour, air cooling, heating at 1400° F. for 16 hours, and then air cooling. Stress rupture testing gave the following results:

TABLE II

Temperature (° F.)	Stress (1,000 p.s.i.)	Stress rupture life (hours)
1,350.....	75	128
1,650.....	25	398
1,800.....	10	388

A Series of sheet materials of the compositions shown in Table III were to a thickness of about 0.065 inch and heat treated as in Example 1. The compositions are in percent by weight.

TABLE III

Example No. ...	2	3	4	5
C.....	.06	.06	.06	.06
Al.....	4.54	4.54	4.47	4.47
Ti.....	3.55	3.55	3.53	3.53
Mo.....	4.91	4.91	5.07	5.07
Cr.....	14.57	14.57	14.68	14.68
Co.....	4.6	9.4	14.8	19.0
Fe.....	0.12	0.12	0.09	0.09
Si.....	0.07	0.07	0.05	0.05
Mn.....	0.05	0.05	0.05	0.05
B.....	0.027	0.027	0.031	0.031
Ni.....	Bal.	Bal.	Bal.	Bal.

The results of tensile testing these materials, as tabulated in Table IV, show that although the entire range of our alloy as represented graphically in FIGS. 2 and 3 are higher in tensile strength than that of the strongest available alloy A, the range of cobalt between about 5-15 percent generally appears to be stronger.

TABLE IV

Temp. (° F.)	Example No.	Ultimate tensile strength (1,000 p.s.i.)	0.2% yield strength (1,000 p.s.i.)
5 1,200.....	2	212	179
	3	203	162
	4	202	162
1,350.....	5	182	149
	2	165	163
	3	169	161
10 1,500.....	4	180	166
	5	168	143
	2	125	121
	3	126	123
	4	137	136
	5	132	132

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

1. A wrought nickel base alloy consisting of in percent by weight about 0.04-0.07 carbon, about 14.5-15.5 chromium, about 0.025-0.035 boron about 14.5-15.5 cobalt, about 4.5-5.5 molybdenum, about 3.3-3.7 titanium, about 4.2-4.6 aluminum, with the balance nickel and impurities.

2. The alloy of claim 1 consisting in additions in percent by weight up to about 0.1 silicon and up to about 0.1 manganese.

3. A wrought nickel base alloy consisting of in percent by weight about 0.06 carbon, about 15 chromium, about 0.03 boron, about 15 cobalt, about 5 molybdenum, about 3.5 titanium, about 4.5 aluminum, with the balance nickel and impurities.

4. A nickel base alloy consisting of in percent by weight, 14.5-15.5 chromium, 14.5-15.5 cobalt, 3.3-3.7 titanium, 4.2-4.5 aluminum, .025-.035 boron, 4.5-5.5 molybdenum and the balance nickel.

5. A nickel base alloy consisting essentially of from 14.0% to 17.0% chromium, from 13.0% to 20.0% cobalt, from 3.25% to 3.75% titanium, from 4.0% to 4.5% aluminum, from 0.02% to 0.04% boron and from 4.50% to 5.50% molybdenum, the balance being essentially all nickel.

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RICHARD O. DEAN, Primary Examiner

Dedication

3,457,066.—*Marvin A. Pohlman*, Muskegon, Mich., and *Joseph B. Moore*, Tequesta, Fla. NICKEL BASE ALLOY. Patent dated July 22, 1969. Dedication filed June 26, 1970, by the assignee, *General Electric Company*.

Hereby dedicates the remaining term of said patent to the Public.
[*Official Gazette November 10, 1970.*]