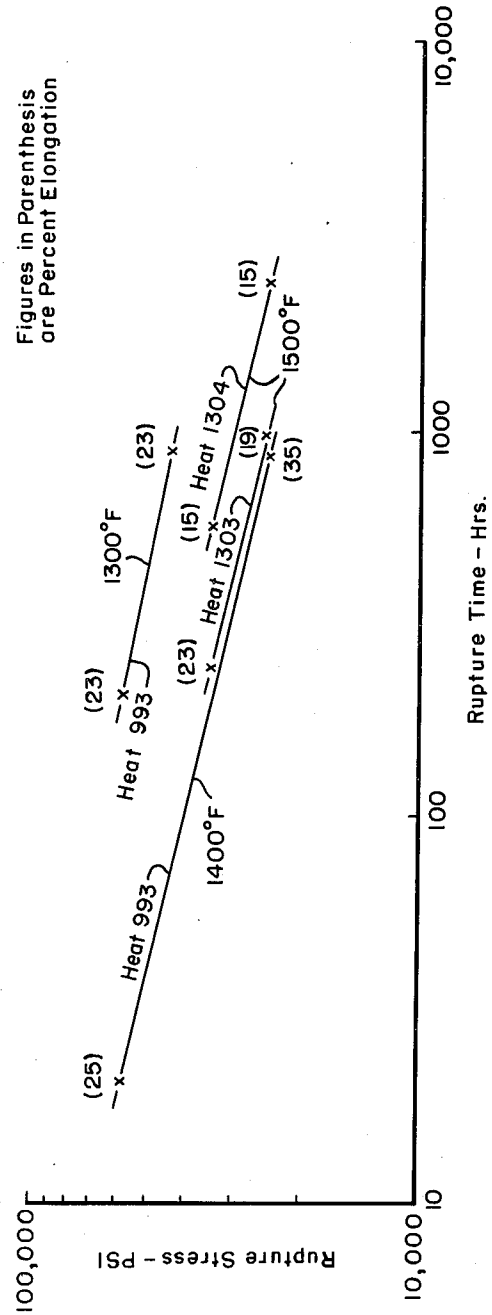
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STABILIZED AND PRECIPITATION-HARDENED NICKEL-BASE ALLOYS

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STABILIZED AND PRECIPITATION-HARDENED NICKEL-BASE ALLOYS

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The present invention is directed to a novel nickel-base alloy which can be forged into massive shapes from large ingots and a process for dually hardening the same.

Material problems connected with the development of aviation gas turbines, land gas turbines, and steam turbines include the need for an alloy for discs which must operate efficiently in the temperature range of from 1300° F. to 1500° F. and at the same time have relatively high ductility. Dependable operation is required for long times in steam turbines operating at the lower end of this temperature range and for shorter times for aviation gas turbines operating at the upper end of the temperature range. Another criteria for a good high temperature alloy is its ability to be economically fabricated from large ingots into various shapes of turbine discs.

Previously known alloys somewhat similar to that of the present invention, have been limited in production to small precision castings which are not worked and are put into use without any subsequent heat treatment.

An object of this invention is to provide a nickel-base alloy comprising predetermined proportions of chromium, molybdenum, aluminum, boron, vanadium, manganese, and iron, the alloy being characterized by its ability to be worked or forged from large igots into various massive shapes and then hardened to provide properties of high strength and ductility over a temperature range of from 1300° F. to 1500° F.

A further object of this invention is to provide a process for dually hardening a member of a nickel-base alloy comprising predetermined proportions of chromium, molybdenum, manganese, aluminum, boron, vanadium and iron, by first hot working an ingot of the alloy to disperse hardening components therein and thereafter solution treating the member at a temperature of from 1850° F. to 2250° F., cooling, and aging said member at a temperature of from 1200° F. to 1700° F. for a period of from five hours to 200 hours so that the desired properties of strength and ductility are retained in the wrought member when employed in the temperature range of from 1300° F. to 1500° F.

Other objects of the invention will be obvious and will in part appear hereinafter.

The figure is a graph of schematic curves illustrating the stress rupture properties of the different heats of the alloy.

The alloy of this invention is a nickel base alloy and contains a minimum of strategic materials. It combines exceptional stress rupture properties at temperatures up to 1500° F. with good ductility. It can be hot worked to desired shape. The alloy can be readily prepared to be notch insensitive.

The high temperature alloy in accordance with our invention consists essentially as follows:

	Percent
Chromium	12 to 28
Molybdenum	7 to 25
Iron	1 to 20
Vanadium	0.2 to 1
Manganese	0.2 to 2
Carbon	Maximum 0.08
Aluminum	1 to 6
Boron	0.2 to 0.8
Nickel	Balance

Tungsten can replace only up to ⅔ of the molybdenum, substituting for each two parts by weight of molybdenum one part by weight of tungsten. If the alloy is not vacuum melted, silicon will usually be added in a range of from 0.2% to 0.7%. However, this amount of silicon may be present in the vacuum melted alloy, and it usually is present as a component of the metals being melted.

One of the important elements used in the alloy of this invention is vanadium. When added in substantial amounts of from 0.2% to 1%, it aids in refining the grain structure of the ingot so that the ingot may be wrought into massive shapes. The reason for employing such relatively large percentages of molybdenum, from 7% to 25% alone, or in combination with tungsten, is to impart strength to the solid solution matrix whereby the full strength of the dually hardened alloy member may be attained. Manganese also adds to good hot working characteristics by combining with the extraneous sulfur and other impurities.

Boron is essential to provide the first stage of hardening of the dually hardenable alloy. When the solution treating temperature is attained, boron is dispersed in the matrix as a boride present as a finely dispersed stable second phase. The higher amounts of boron, that is from 0.4% up to 0.8%, increase the inherent matrix strength without decreasing ductility to an undesirable level. For example, in a heat of the alloy containing 0.78% boron, a specimen tested at 45,000 p.s.i. and 1400° F. lasted 108 hours and ruptured with 22% elongation.

The carbon content, on the other hand, is limited to a maximum value of 0.08% owing to the fact that carbides may be formed which are soluble in the solid solution matrix, therefore, imparting a loss of ductility. The iron, while it may be present in amounts up to 20%, need not be added in elemental form. Thus, iron may be added in combination with the other elements heretofore mentioned, such as ferrochromium and ferromanganese, etc. These last additions are more economical than the use of the pure separate elements.

Aluminum is employed as the primary precipitation hardening constituent in the second or aging stage of the dual hardening process. The aluminum precipitates at relatively high aging temperatures and enables the alloy to be used at higher temperatures than with other hardeners such as titanium. The invention further relates to a dual hardening process for members from ingots of a nickel-base alloy comprising essentially by weight from 12% to 28% chromium, from 7% to 25% molybdenum, from .2% to 1% vanadium, from .2% to 2% manganese, from 1 to 6% aluminum, from .2% to .8% boron, a maximum of .08% carbon, up to 20% iron and the balance substantially all nickel except for minor amounts of impurities. Ingots of the alloy are characterized by ability to be readily forged into large turbine discs, shafts and similar parts required for high temperature use. Wrought and dually hardened members exhibit properties of high strength and ductility in the temperature range of from 1300° F. to 1500° F. A preferred range of composition of said alloy which has given outstanding properties comprises by weight from 12% to 16% chromium, from 12% to 16% molybdenum, from .3% to .6% vanadium, from .7% to 1% manganese, from 2% to 5% aluminum from .4% to .8% boron, a maximum of .03% carbon, up to 13% iron, and the balance substantially all nickel except for minor amounts of impurities. The preferred alloy will usually contain from 0.2% to 0.4% silicon. Cobalt can replace a part of the nickel.

Particularly, the invention relates to a process for dually hardening the high temperature nickel-base alloy of this invention which comprises forging, swaging or otherwise hot working ingots of the alloy to produce a

finely dispersed boride in a matrix, then heating the wrought member to a solution treating temperature of from 1850° F. to 2250° F. for a period of time suitable to produce a matrix of a finely dispersed second phase, cooling the material to room temperature, then aging said alloy at a temperature of from 1200° F. to 1700° F. for a period of from five hours to 200 hours, and cooling in air to room temperature, said aged forgings having properties of high strength and ductility when used at a temperature range of from 1300° F. to 1500° F.

A convenient procedure for preparing alloy members in accordance with the teachings of the invention is the following. Predetermined proportions of the components of the alloy are preferably melted in a vacuum-cold hearth arc furnace at a temperature sufficient to melt the components. The alloy can be also melted in a vacuum induction furnace or in an open air induction furnace. The alloy melt is then cast in a large ingot mold. The alloy ingot is then heated in a soaking furnace and hot forged at a temperature of from 2000° F. to 2300° F. into the desired shape. Other hot working processes can be applied to produce massive wrought shapes. The forgings may then be machined or ground to specification. The forgings, or machined members, are solution treated in the temperature range of from 1850° F. to 2250° F. During the hot working operation, the boride phase is dispersed in the matrix and, a phenomenon called dispersion hardening results. This dispersion hardening comprises a fine dispersed stable second phase which increases the matrix hardness of the solution treated alloy from about 10 R"C" (Rockwell "C" scale) to about 25 R"C". The alloy members may be then further secondarily hardened by a precipitation hardening process. Precipitation hardening is obtained by aging the solution treated members at a temperature of from 1200° F. to 1700° F. for a period of from about five hours to 200 hours and longer, thereby increasing the hardness to a maximum of approximately 41 R"C". The aging can be carried out at a uniform temperature, or the temperature changed to a higher or lower value in the range of from 1200° F. to 1700° F.

A number of heats of the alloys of this invention as set forth in the following Table I, which gives the chemical analysis thereof were prepared.

Table I

Heat No.	Ni	Fe	Cr	Mo	V	C	B	Si	Mn	Al
993	54.2	12.0	15.0	14.9	.31	.04	.50	.30	.50	2.20
1181	53.0	12.2	15.2	15.6	.31	.012	.77	.31	.22	2.33
1182	53.3	11.7	15.2	15.5	.27	.019	.78	.35	.34	2.49
1303	51.2	14.1	16.0	13.3	.47	.02	.72	.36	.36	3.44
1304	51.3	14.4	14.0	14.8	.66	.01	.68	.36	.22	4.00

Table II sets forth tensile test data made on forged bars from heat number 993, while Table III sets forth the tensile tests made on forged bars produced from heat numbers 1303 and 1304.

Table II

Testing Temp., ° F.	Ultimate Strength	0.2% Yield Strength	Percent Elong. in 1.4"	Percent Reduction of Area	Dually Hardened Hardness, R"C"
R.T.	169,000	106,000	13	16	35
1,300	137,000	100,000	21	28	36
1,400	111,000	92,000	30	46	34
1,500	77,000	71,000	33	63	35

Heat Treatment: Solution treat, 2100° F. for one hour.
Age: One day, 1400° F.

Table III

Heat No.	Testing Temp., ° F.	0.2% Yield Strength	Ultimate Strength	Percent Elong. in 1.4"	Percent Reduction of Area	Dually Hardened Hardness R"C"
1303	R.T.	125,000	191,000	9	11	40
1304	R.T.	133,000	196,000	7	10	42
1303	1,200	111,000	159,000	6	18	--------
1304	1,200	139,000	182,000	10	12	--------
1303	1,400	104,000	115,000	19	30	--------
1304	1,400	----------	133,000	21	41	--------
1303	1,600	46,000	47,000	37	67	--------
1304	1,600	59,000	61,000	26	61	--------

Heat Treatment: Solution treat, 2100° F. for one hour.
Age: 48 hours, 1400° F.

Table IV gives the stress rupture results on combination (Notch and Plain) bars from heat number 1182.

Table IV

Testing Temp., ° F.	Stress (p.s.i.)	Plain Bar Rupture Time (Hrs.)	Percent Elong.	Notched Bar Rupture Time (Hrs.)	Hardness, R"C"
1,400	65,000	8	21	63	39-41
1,400	55,000	20	21	----------	36-38
1,400	45,000	103	22	311	39-40
1,400	35,000	227	41	----------	36-38

For a further showing of the excellent properties exhibited by the alloys of the present invention, reference may be made to Fig. 1. Forgings of alloys of Heats 993, 1303 and 1304 were subjected to rupture tests at 1300° F., 1400° F. and 1500° F. as indicated. The excellent ductility is indicated by the figures in the drawing in parentheses.

It will be obvious that the above description is illustrative and not limiting.

I claim as my invention:

1. A high strength high temperature nickel-base alloy comprising by weight from 12 to 28% chromium, from 7 to 25% molybdenum, from 1 to 6% aluminum, from 0.2 to 0.8% boron, from 0.2 to 1% vanadium, from 0.2 to 2% manganese, a maximum of 0.08% carbon, up to 20% iron, and the balance substantially all nickel except for minor amounts of impurities said alloy exhibiting good workability characteristics so that the final ingot casting may be forged or wrought into massive shapes at temperatures of from 2000° F. to 2300° F., and having properties of high strength and ductility in the temperature range of from 1300° F. to 1500° F.

2. The alloy of claim 1 wherein from .2 to .7% of silicon is present.

3. A high strength high temperature nickel-base alloy comprising by weight from 12% to 16% chromium, from 12% to 16% molybdenum, from 2 to 5% aluminum, from 0.4 to 0.8% boron, from 0.3 to 0.6% vanadium, from 0.7 to 1% manganese, a maximum of 0.03% carbon, up to 13% iron, and the balance substantially all nickel except for minor amounts of impurities, said alloy exhibiting good workability characteristics so that the final ingot casting may be forged or wrought into massive shapes at temperatures of from 2000° F. to 2300° F., and having properties of high strength and ductility in the temperature range of from 1300° F. to 1500° F.

4. The alloy of claim 3 wherein .2 to .4% silicon is used.

5. A wrought high strength, high temperature nickel-base alloy member comprising by weight 12 to 28% chromium, 7 to 25% molybdenum, from 1 to 6% aluminum, from .2 to .8% boron, from .2 to 1% vanadium, from .2 to 2% manganese, a maximum of .08% carbon, up to 20% iron, and a balance substantially all nickel except for minor amounts of impurities, said alloy member having been hot worked to shapes and dually hardened by dispersion hardening and precipitation harden-

ing to a hardness of at least a Rockwell "C" value of 20, so that the final wrought member exhibits properties of high strength and ductility within a temperature range of from 1300° F. to 1500° F.

6. A high strength, high temperature nickel-base alloy comprising by weight from 12 to 16% chromium, from 12 to 16% molybdenum, from 2 to 5% aluminum, from 0.4 to 0.8% boron, from 0.3 to 0.6% vanadium, from 0.7 to 1% manganese, a maximum of .03% carbon, up to 13% iron, and the balance substantially all nickel except for minor amounts of impurities, said alloy, having been hot worked to shape and, dually hardened by dispersion hardening and precipitation hardening to a hardness of at least a Rockwell "C" value of 20, so that the final wrought member exhibits properties of high strength and ductility within a temperature range of from 1300° F. to 1500° F.

7. In the process of dually hardening a nickel-base alloy forging comprising from 12 to 28% by weight of chromium, from 7 to 25% by weight of molybdenum, from 1 to 6% by weight of aluminum, from 0.2 to 0.8% by weight of boron, from 0.2 to 1% by weight of vanadium, from 0.2 to 2% by weight of manganese, from 0.2 to 0.7% by weight of silicon, a maximum of 0.8% carbon, up to 20% iron, and the balance substantially all nickel except for minor amounts of impurities, the forging having a first relatively uniform dispersion of hardening components, the step comprising heating the forging to a solution treating temperature of from 1350° F. to 2250° F. for a period of time suitable to produce a matrix of a finely dispersed second phase, cooling the material to room temperature, aging said alloy at a temperature of from 1200° F. to 1700° F. for a period of from about 5 hours to 200 hours and cooling in air to room temperature, said forgings having properties of high strength and ductility in the temperature range of from 1300° F. to 1500° F.

8. In the process of dually hardening a nickel-base alloy forging, comprising from 12 to 16% by weight of chromium, from 12 to 16% by weight of molybdenum, from 2 to 5% by weight of aluminum, from 0.4 to 0.8% by weight of boron, from 0.3 to 0.6% by weight of vanadium, from 0.7 to 1% by weight of manganese, from 0.2 to 0.4% by weight of silicon, a maximum of 0.03% carbon, up to 13% by weight of iron, and the balance substantially all nickel except for minor amounts of impurities, the forging having a first relatively uniform dispersion of hardening components, the steps comprising heating the forging to a solution treating temperature of from 1850° F. to 2250° F. for a period of time suitable to produce a matrix of a finely dispersed second phase, cooling the material to room temperature, aging said alloy at a temperature of from 1200° F. to 1700° F. for a period of from about 5 to 200 hours and cooling in air to room temperature, said forgings having properties of high strength and ductility in the temperature range of from 1300° F. to 1500° F.

9. The alloy of claim 5, wherein 0.2% to 0.7% of silicon is present.

10. The alloy of claim 6 wherein 0.2% to 0.4% of silicon is present.

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