

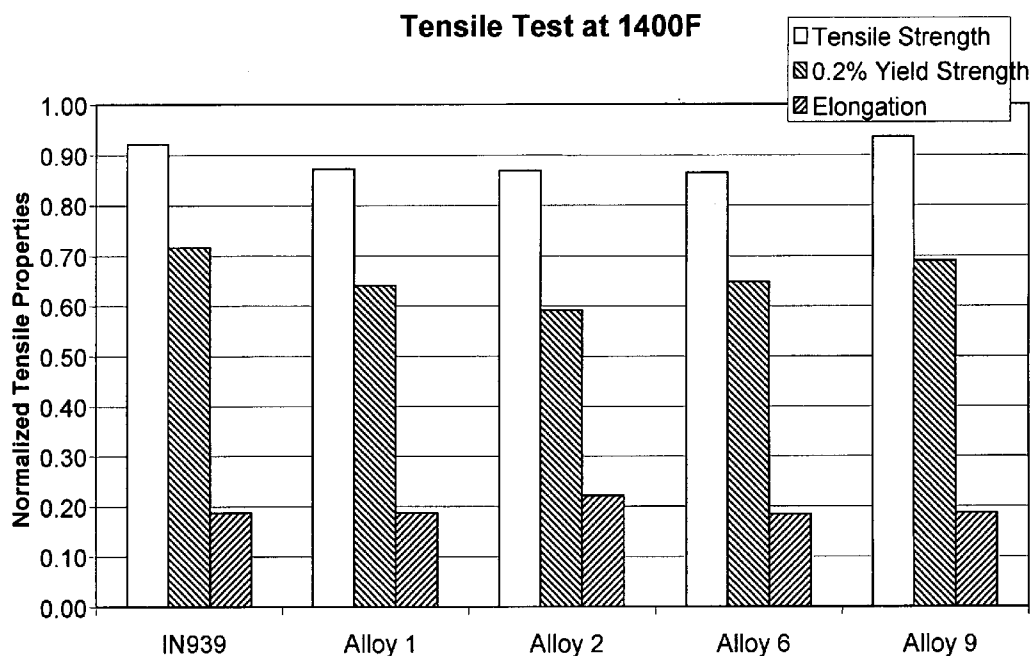


US 20070095441A1

(19) **United States**(12) **Patent Application Publication****Jiang et al.**(10) **Pub. No.: US 2007/0095441 A1**(43) **Pub. Date: May 3, 2007**(54) **NICKEL-BASE ALLOY, ARTICLES FORMED THEREFROM, AND PROCESS THEREFOR****Publication Classification**(75) Inventors: **Liang Jiang**, Schenectady, NY (US);
Ganjiang Feng, Greenville, SC (US);
Stephen Joseph Balsone, Simpsonville, SC (US)(51) **Int. Cl.**
C22C 19/05 (2006.01)(52) **U.S. Cl.** **148/410; 420/448**(57) **ABSTRACT**

A composition and process for a nickel-base alloy that exhibits a desirable balance of high-temperature strength and weldability, as well as other properties suitable for high temperature applications. These properties are achieved with an alloy in which the combined level of titanium, aluminum, niobium, and tantalum is carefully controlled. The alloy consists of, by weight, 10 to less than 20% chromium, 15 to 20% cobalt, less than 1.0% molybdenum, 2.5 to 5% tungsten, 1.1 to 1.5% niobium, less than 0.5% tantalum, 3.0 to 3.9% titanium, 2.5 to 3.4% aluminum, 0.07 to 0.15% carbon, less than 0.06% zirconium, less than 0.03% boron, the balance nickel and impurities.

Correspondence Address:

HARTMAN & HARTMAN, P.C.**552 EAST 700 NORTH****VALPARAISO, IN 46383 (US)**(73) Assignee: **GENERAL ELECTRIC COMPANY**,
Schenectady, NY (US)(21) Appl. No.: **11/163,847**(22) Filed: **Nov. 1, 2005**

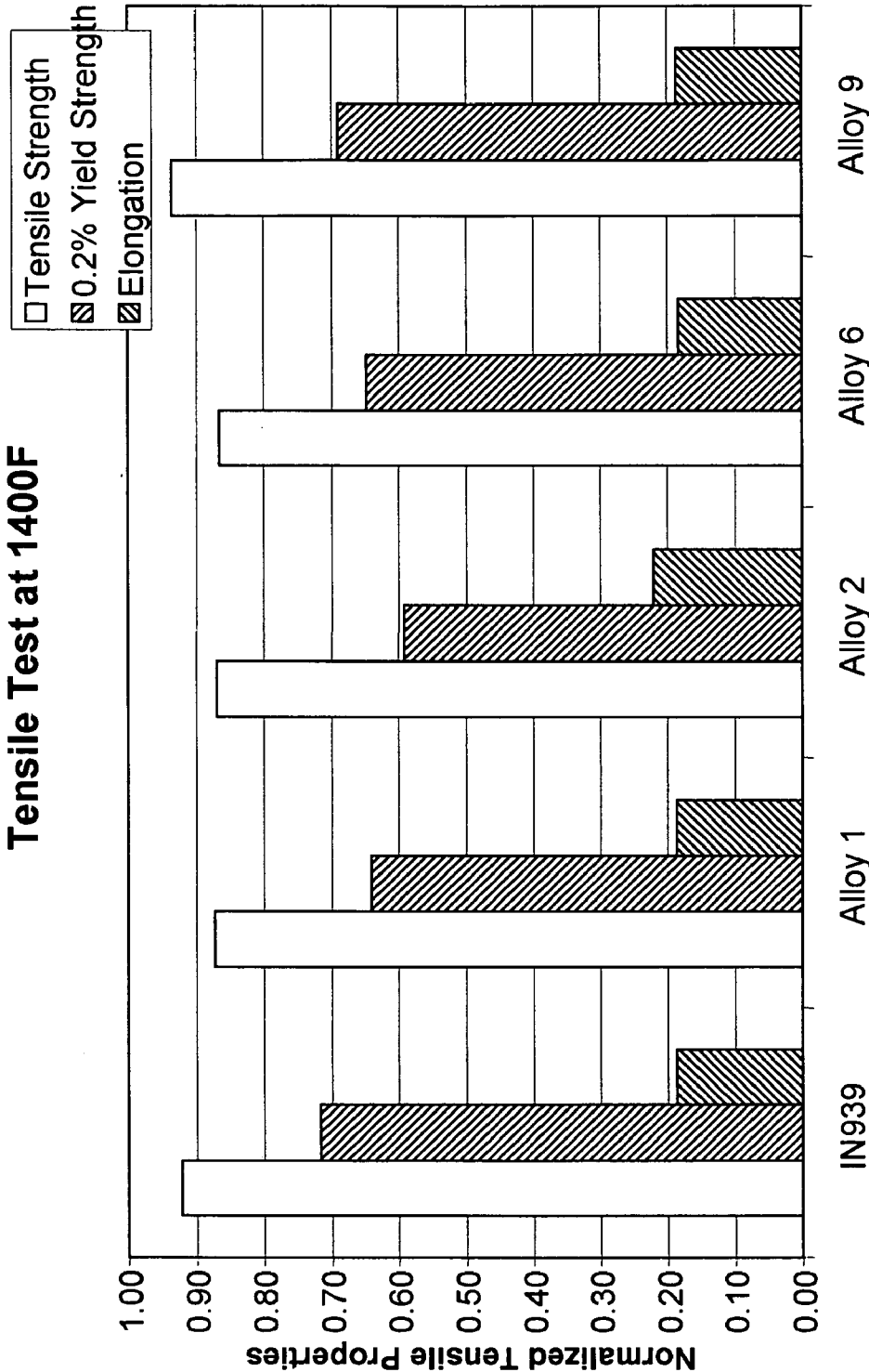


Fig. 1

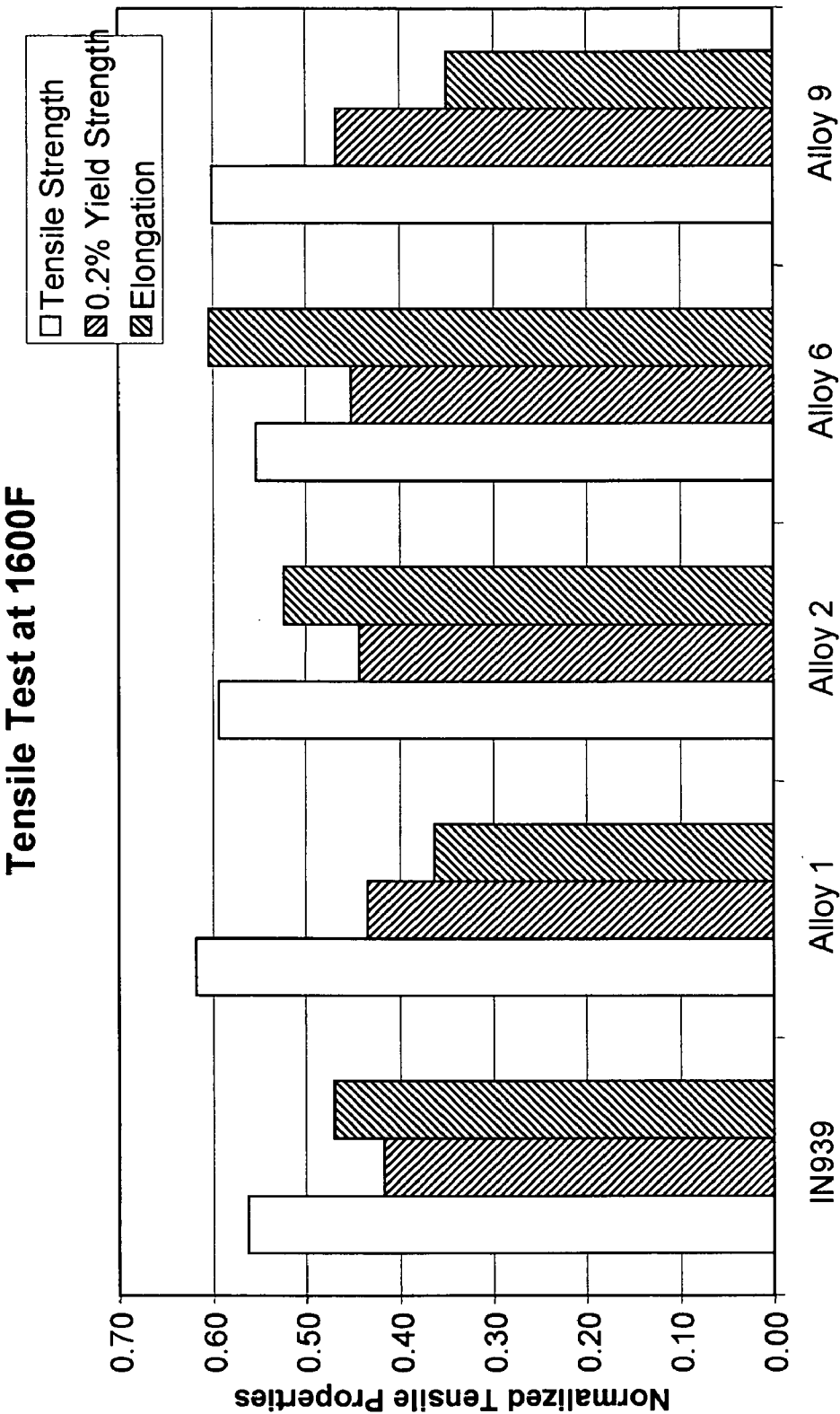


Fig. 2

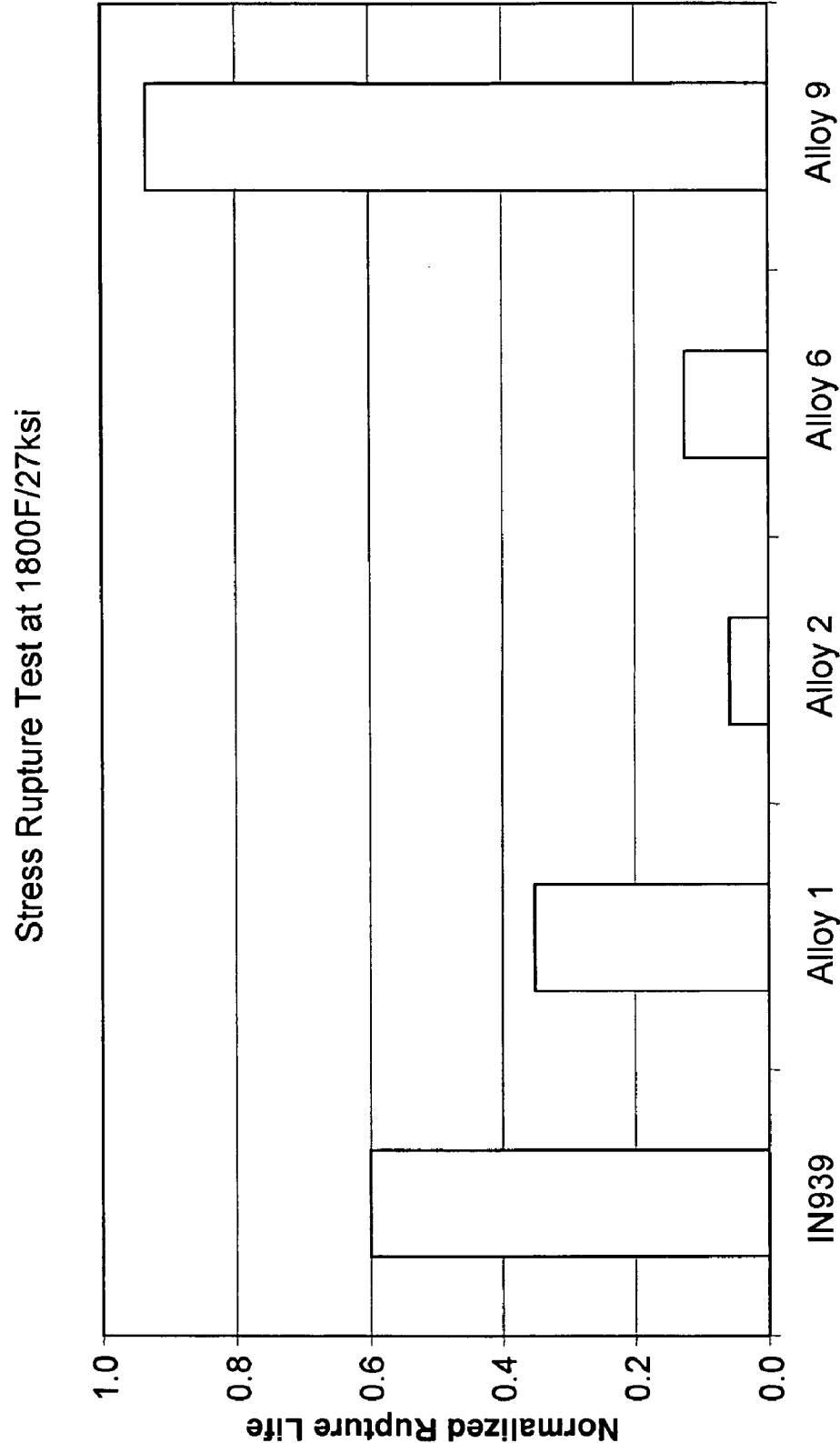


Fig. 3

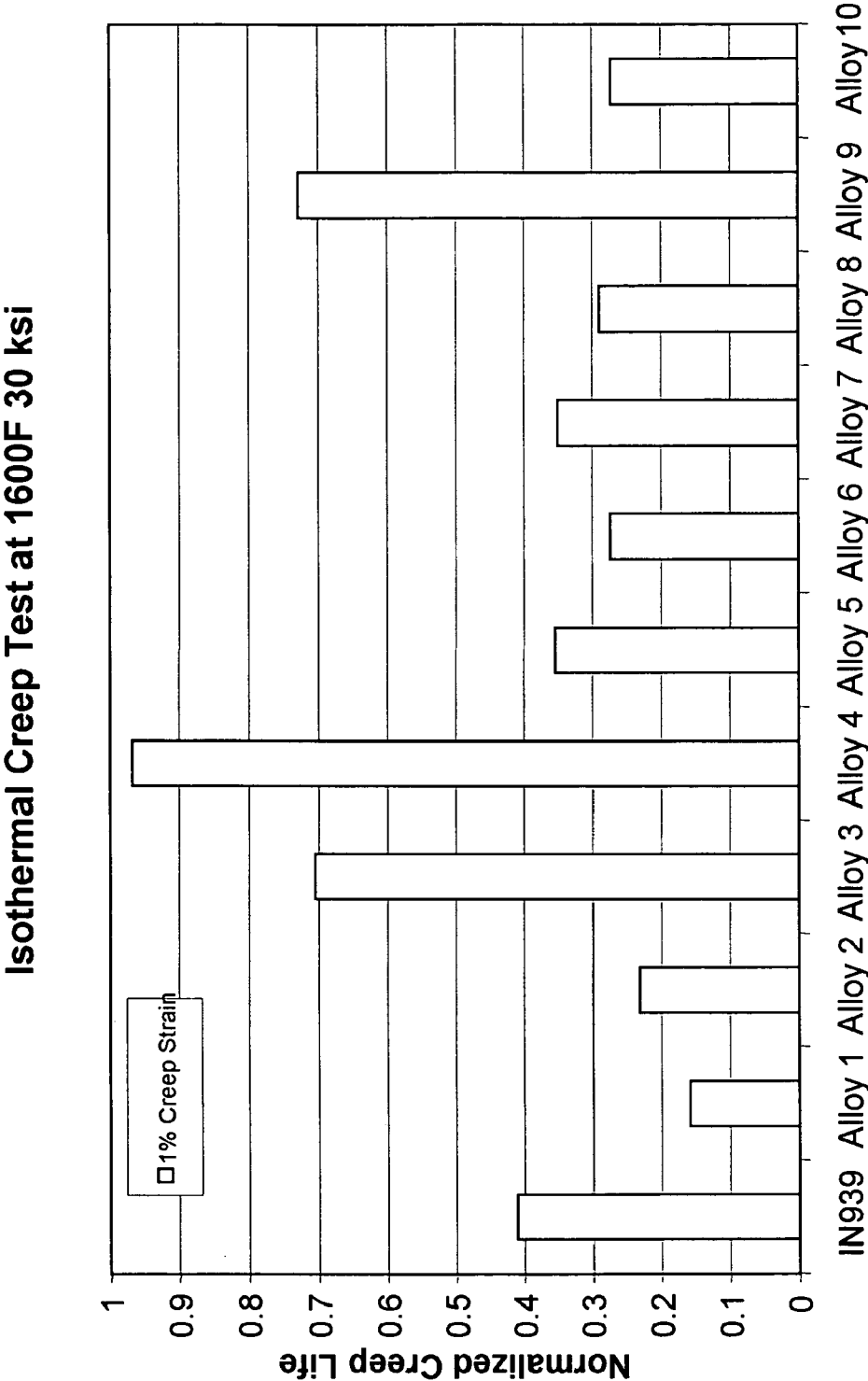


Fig. 4

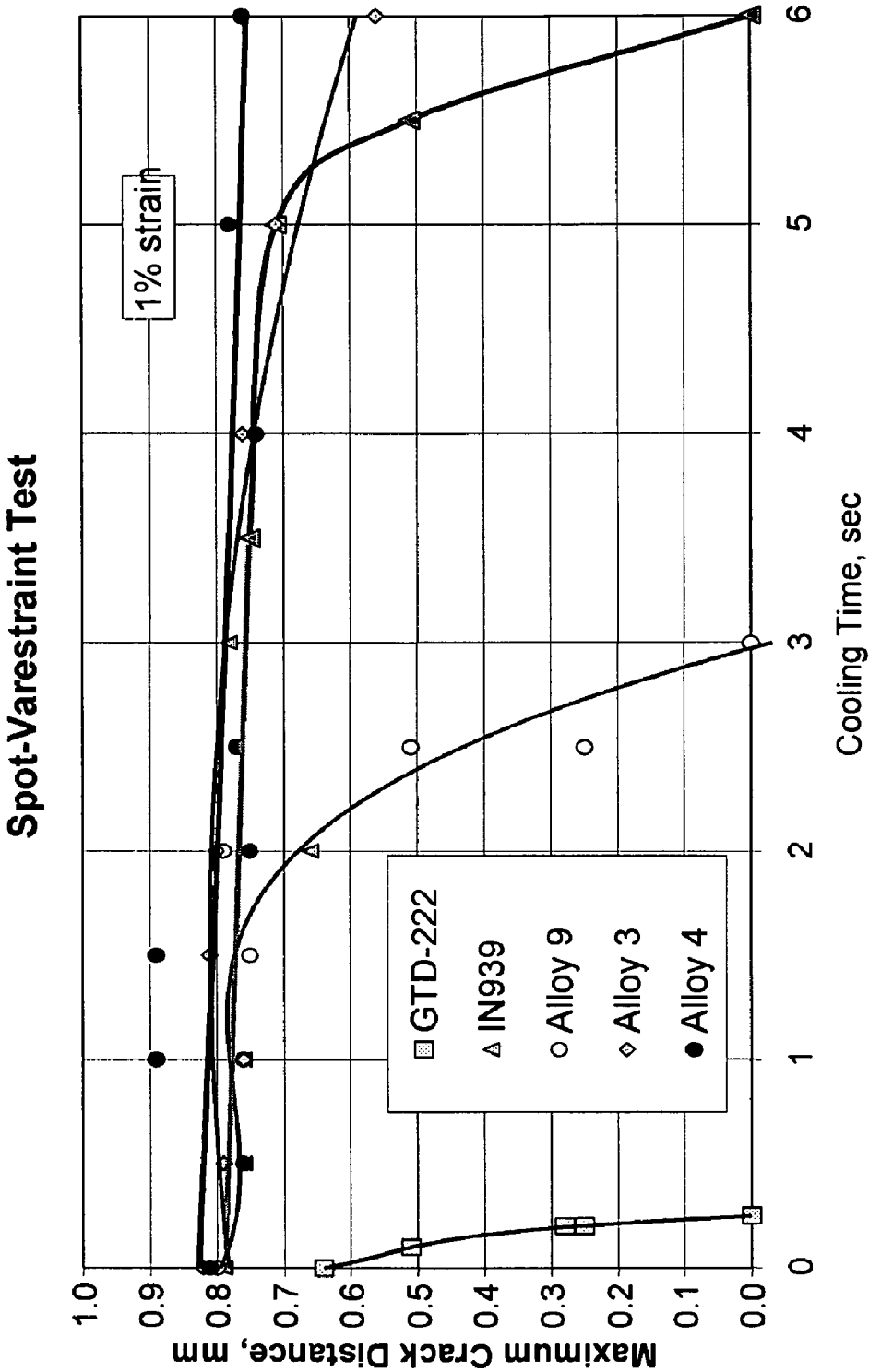


Fig. 5

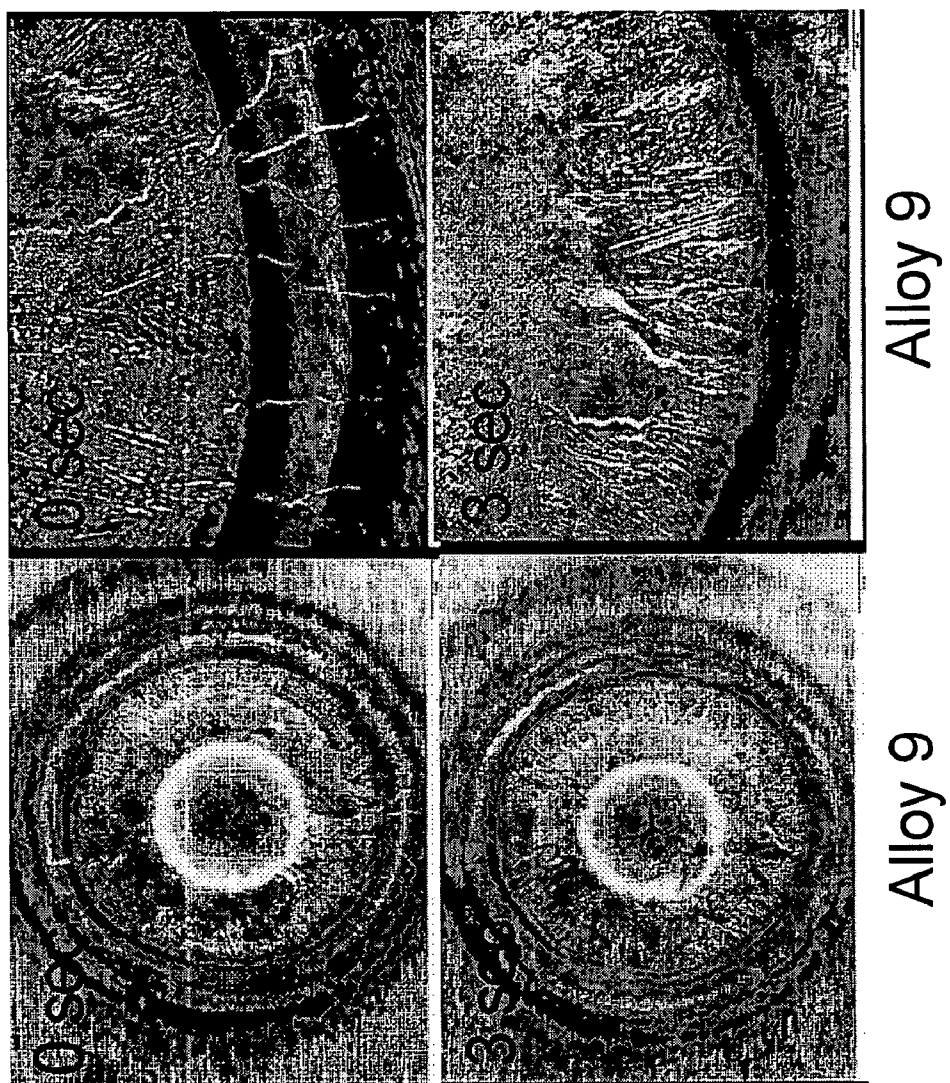


Fig. 6

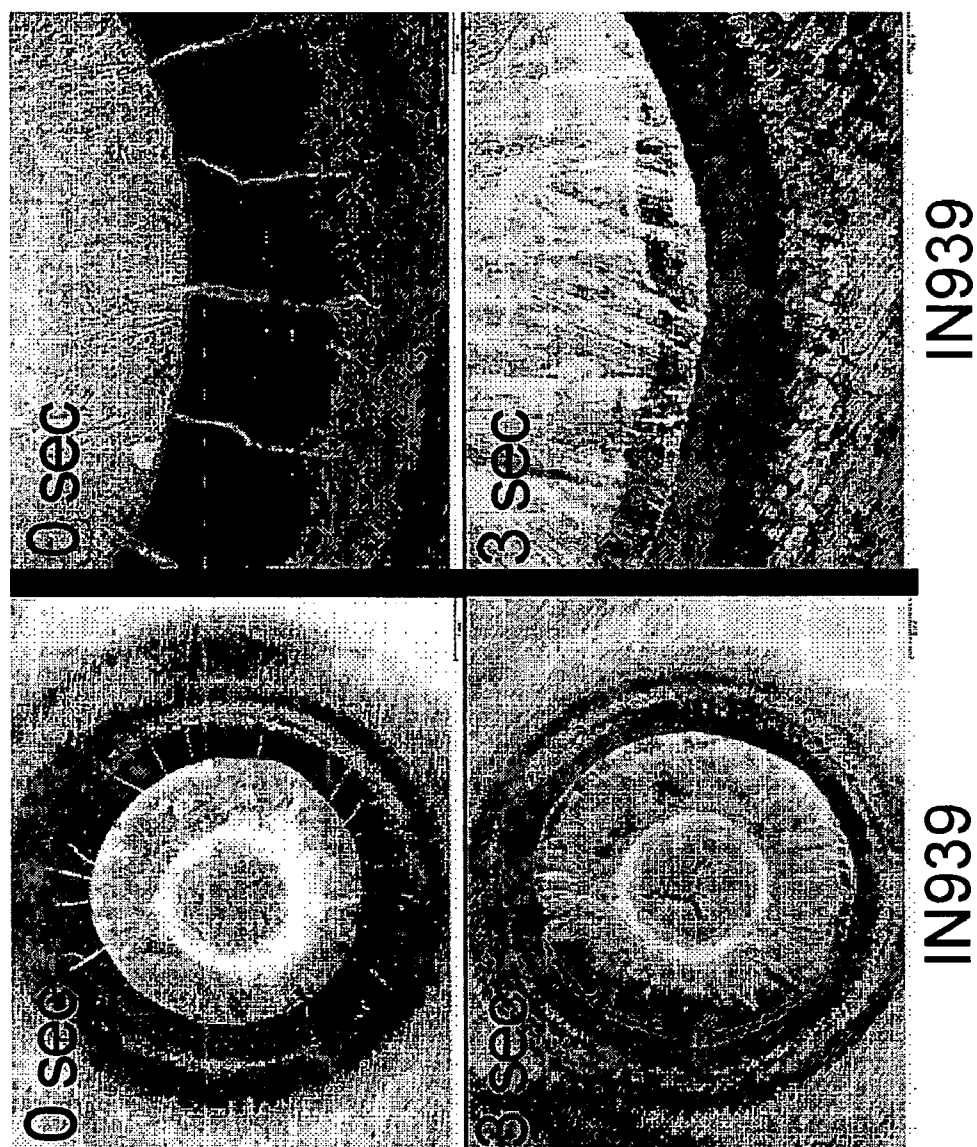


Fig. 7

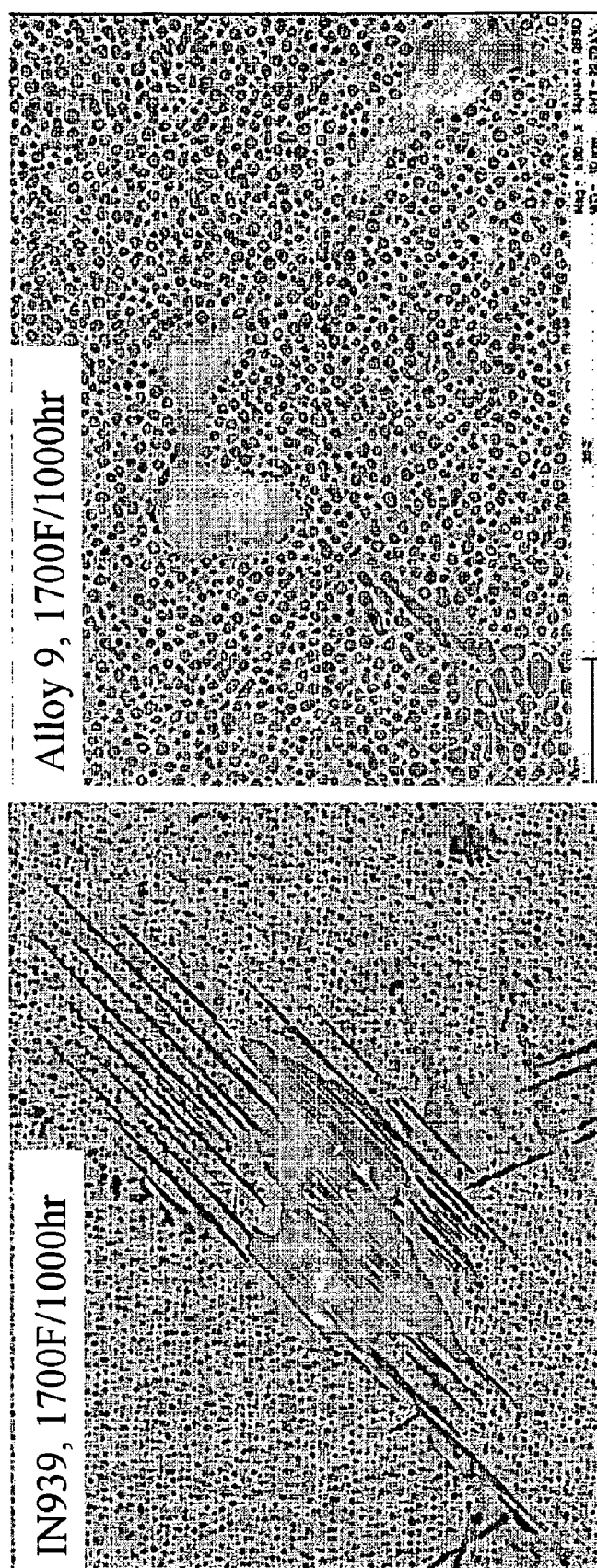


Fig. 8

NICKEL-BASE ALLOY, ARTICLES FORMED THEREFROM, AND PROCESS THEREFOR

BACKGROUND OF THE INVENTION

[0001] The present invention generally relates to nickel-base alloys. More particularly, this invention relates to a weldable nickel-base superalloy that exhibits desirable properties suitable for gas turbine engine applications.

[0002] Superalloys are used in the manufacture of components that must operate at high temperatures, such as buckets, nozzles, combustors, and transition pieces of industrial gas turbines. During the operation of such components under strenuous high temperature conditions, various types of damage or deterioration can occur, including wear and cracks. Because the cost of components formed from superalloys is relatively high, it is more desirable to repair these components than to replace them. For the same reason, new-make components that require repair due to manufacturing flaws are also preferably repaired instead of being scrapped. Methods for repairing nickel-base superalloys have included gas tungsten arc welding (GTAW) techniques, which typically entails the use of a filler and often a ductile filler to reduce the tendency for cracking in the weldment.

[0003] Compositions of nickel-base superalloys are characterized by controlled concentrations of certain critical alloying elements to achieve a desired mix of properties. For use in gas turbine applications, such properties include, in addition to weldability as noted above, high temperature creep strength, oxidation and corrosion resistance, resistance to low cycle fatigue, phase stability, and castability. If attempting to optimize any one of the desired properties of a superalloy, other properties are often adversely affected. A particular example is weldability and creep resistance, both of which are of great importance for rotating components of gas turbines. However, greater creep resistance results in an alloy that is more difficult to weld, which is necessary to allow for repairs by welding.

[0004] Precipitation-strengthened nickel-base superalloys containing high levels of principal gamma prime-forming elements (aluminum, titanium, tantalum, and niobium) have proven to be difficult to weld, with typical flaws including solidification shrinkage, hot tears, and cracking during and after the welding processes, and strain age cracking due to gamma prime (γ') precipitation (principally $\text{Ni}_3(\text{Al,Ti})$) during post-weld vacuum heat treatment. An example of such an alloy is the nickel-base alloy commercially known as IN-738. An improved gamma-prime strengthened nickel-base superalloy meeting the needs for various gas turbine components is disclosed in commonly-assigned U.S. Pat. No. 6,902,633 to King et al. The disclosed alloy contains, by weight, about 15.0 to about 17.0% chromium, about 7.0 to about 10.0% cobalt, about 1.0 to about 2.5% molybdenum, about 2.0 to about 3.2% tungsten, about 0.6 to about 2.5% columbium (niobium), less than 1.5% tantalum, about 3.0 to about 3.9% aluminum, about 3.0 to about 3.9% titanium, about 0.005 to about 0.060% zirconium, about 0.005 to about 0.030% boron, about 0.07 to about 0.15% carbon, and the balance nickel and impurities. The alloy is disclosed by King et al. as intended to have properties comparable to IN-738, but with a chemistry that allows for the reduction or complete elimination of tantalum.

[0005] Other gamma-prime strengthened superalloys, such as IN-939 (U.S. Pat. No. 4,039,330) and GTD-222

(disclosed in commonly-assigned U.S. Pat. No. 4,810,467), tend to be more readily weldable than IN-738. However, the high temperature capabilities of these weldable alloys are usually limited. Also, IN-939 tends to form Eta (η) phase, especially after long-term exposure at high temperature. Eta phase is known to cause cracking in castings, which detrimentally affects mechanical properties.

[0006] In view of the above, it can be appreciated that issues relating to existing alloys with high gamma prime contents include relatively poor weldability and castability, and in some instances microstructural instability after long-term exposure at high temperatures. Therefore, there is an ongoing need for alloys capable of exhibiting balanced high temperature mechanical properties and improved weldability and microstructural stability.

BRIEF SUMMARY OF THE INVENTION

[0007] The present invention provides a composition and process for a nickel-base alloy that exhibits a desirable balance of weldability, high-temperature strength (including creep resistance), microstructural (phase) stability, castability, and other properties that render the alloy particularly suitable for high temperature applications, including turbine nozzle and blade components of turbine engines. These properties are achieved with an alloy in which the combined level of titanium, aluminum, niobium, and tantalum is controlled to provide a desired level of weldability while maintaining acceptable properties such as strength and microstructural stability for high temperature applications.

[0008] According to the invention, the nickel-base alloy consists of, by weight, about 10 to less than 20% chromium, about 15 to about 20% cobalt, less than 1.0% molybdenum, about 2.5 to about 5% tungsten, about 1.1 to about 1.5% niobium, less than 0.5% tantalum, about 3.0 to about 3.9% titanium, about 2.5 to about 3.4% aluminum, about 0.07 to about 0.15% carbon, less than 0.06% zirconium, less than 0.03% boron, the balance nickel and impurities. Tantalum and molybdenum can be essentially absent from the alloy, i.e., only at impurity levels. The alloy of this invention is a gamma-prime precipitation-strengthened nickel-base alloy whose weldability characteristics are comparable to and potentially better than those of the IN-939 alloy, while exhibiting better mechanical properties and oxidation resistance. The alloy also has acceptable castability and develops little or no detrimental phases at elevated temperatures.

[0009] Other objects and advantages of this invention will be better appreciated from the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIGS. 1 and 2 are graphs comparing the tensile strength, yield strength, and elongation at 1400° F. and 1600° F., respectively, of nickel-base alloys within the scope of the present invention and the prior art nickel-base alloy IN-939.

[0011] FIG. 3 is a graph comparing the stress rupture lives at 1800° F. of the alloys represented in FIGS. 1 and 2.

[0012] FIG. 4 is a graph comparing the isothermal creep lives at 1600° F. of IN-939 and ten experimental alloys.

[0013] FIG. 5 is a graph plotting maximum crack distance (MCD) versus cooling time obtained from a weldability test performed on IN-939, GTD-222, and selected experimental alloys.

[0014] FIGS. 6 and 7 are micrographs of samples of Alloy 9 and IN-939, respectively, from the weldability test of FIG. 5.

[0015] FIG. 8 shows microstructure photos of samples of IN-939 and experimental Alloy 9 after thermal exposure at about 1700° F. for about 1000 hours.

DETAILED DESCRIPTION OF THE INVENTION

[0016] The present invention was the result of an investigation to develop a high temperature nickel-base alloy with enhanced weldability, generally equivalent to or better than existing weldable nickel-base alloys such as IN-939. As disclosed in U.S. Pat. No. 4,039,330, IN-939 may contain, by weight, 20 to 25% chromium, 5 to 25% cobalt, 0 to 3.5% molybdenum, 1 to 5% tungsten (with the value of % W +0.5 (% Mo) being from 1 to 5%), 0 to 3% niobium, 0.5 to 3% tantalum, about 1.7 to 5% titanium and 1 to 4% aluminum) with the sum of titanium and aluminum being 4 to 6 or 6.5% and the weight ratio of titanium to aluminum being 0.75:1 to 4:1, about 0.02 to 0.25% carbon, 0.005 to 1% zirconium, 0 to 2% hafnium (with the value of % Zr+0.5 (% Hf) being 0.01 to 1%), 0.001 to 0.05% boron, and 0 to 0.2% in total of yttrium and/or lanthanum, the balance being at least 30%

molybdenum, tungsten, and rhenium can have an effect on carbide morphology and gamma matrix strengthening. Based on these relationships, the amounts of these elements required to achieve a given strength level can be estimated. The compositions of the gamma-prime phase and other secondary phases such as carbides and borides, as well as the volume fraction of the gamma-prime phase, can also be estimated based on the starting chemistry of the alloy and some basic assumptions about the phases which form. However, other properties important to turbine nozzle and blade components, such as weldability, fatigue life, castability, microstructural stability and oxidation resistance, have not been predictable from the amounts of these and other elements present in the alloy.

[0018] In the investigation leading to this invention, ten alloys having the approximate chemistries set forth in Table I below were formulated (the balance of all alloys was nickel and incidental impurities). Test slabs with dimensions of about 0.875×5×9 inches (about 2×13×23 cm) were produced by investment casting and then solution heat treated at about 2100° F. (about 1150° C.) for about two hours, followed by aging at about 1150° F. (about 845° C.) for about four hours. The specimens were then sectioned by wire and machined from the castings in a conventional manner. To assess castability, bars were also cast from the alloys.

TABLE I

	Cr	Co	W	Mo	Nb	Ta	Ti	Al	C	Zr	B
1	14.3	9.5	3.9	1.5	1.45	0.00	2.8	3.5	0.1	0.00	0.01
2	14.3	9.5	3.9	1.5	1.45	0.50	2.3	3.0	0.1	0.00	0.01
3	14.3	9.5	3.9	1.5	1.45	0.25	2.3	4.0	0.1	0.00	0.01
4	14.3	9.5	3.9	1.5	1.45	0.50	3.3	4.0	0.1	0.00	0.01
5	14.3	9.5	3.9	1.5	1.45	0.25	3.3	3.0	0.1	0.00	0.01
6	20.3	13.5	3.7	0.0	1.34	0.00	2.8	2.6	0.1	0.01	0.01
7	20.3	15.0	3.7	0.0	1.10	0.00	3.1	2.6	0.1	0.01	0.01
8	20.3	15.0	3.7	0.0	1.60	0.00	2.6	2.6	0.1	0.01	0.01
9	14.8	17.2	3.0	0.0	1.30	0.00	3.2	2.8	0.1	0.01	0.01
10	20.3	17.0	3.7	0.0	1.10	0.00	2.6	2.6	0.1	0.01	0.01
939	22.5	19.0	2.0	0.0	1.0	1.4	3.7	1.9	0.15	0.1	0.01

nickel and impurities. The investigation resulted in the development of a gamma-prime precipitation-strengthened nickel-base alloy whose properties are particularly desirable for turbine nozzle and blade components of turbine engines, though other high-temperature applications are foreseeable. For the applications of particular interest, necessary properties include (in addition to weldability) high-temperature strength (including creep resistance), microstructural stability, oxidation and corrosion resistance, resistance to low cycle fatigue, and castability. The approach of the investigation resulted in the atomic ratio of Ti/Al and phase stability being identified as important factors in obtaining a desirable balance in creep resistance, weldability, and castability, and yielded an alloy with solidus and gamma-prime solvus temperatures also conducive to attaining these desirable properties.

[0017] The high-temperature strength of a nickel-base superalloy is directly related to the volume fraction of the gamma-prime phase, which in turn is directly related to the total amount of the principal gamma prime-forming elements (aluminum, titanium, tantalum and niobium) present. To some extent other elements such as chromium, cobalt,

[0019] In Table I all values are in weight percent. The nominal composition of IN-939 is also provided in Table I for comparison.

[0020] The above alloying levels were selected to evaluate the effects of using relatively low levels of the gamma-prime forming elements aluminum, titanium, niobium, and tantalum with certain levels of chromium, cobalt, tungsten, and molybdenum. The chromium levels tested were chosen for the purpose of achieving varying levels of high temperature corrosion resistance. Chromium levels below 20 weight percent are chosen with the intention of enhancing and stabilizing aluminum oxide formation at high temperature, thereby increasing oxidation resistance. The chromium levels tested were also for the purpose of improving high temperature strength and minimizing the formation of TCP phase. The tested levels for cobalt were chosen for the purpose of improving high temperature strength and weldability. The tested levels for tungsten were chosen as being believed necessary to achieve acceptable high temperature strength in view of the relatively low levels of the principal gamma-prime forming elements (Al, Ti, Nb, and Ta). The alloys were formulated to exclude rhenium, hafnium, and in

some instances molybdenum to promote microstructural (phase) stability during high temperature exposures, such as resistance to the formation of topologically close-packed (TCP) and Eta (η) phases. The carbon, zirconium, and boron levels were chosen to promote a balance of alloy properties and processing capabilities.

[0021] Tensile properties at about 1400° F. and about 1600° F. (about 760° C. and about 870° C., respectively) for the selected experimental alloys were determined with standard smooth bar specimens. The normalized data for four of the experimental alloys (Alloys 1, 2, 6, and 9) are summarized in FIGS. 1 and 2, along with data obtained with similar specimens of the prior art IN-939 alloy whose compositions coincided with the IN-939 composition set forth in Table I. The data indicated that the experimental alloys had comparable high temperature tensile properties as compared with IN-939. Stress rupture test were then conducted on specimens of the same four experimental alloys at about 1800° F. (about 982° C.) and about 27 ksi (about 186 MPa). FIG. 3 is a graph showing the resulting data, which indicated that Alloy 9 had a significantly better stress rupture life than the other alloys, including IN-939.

[0022] Stress rupture test results are useful to indicate the performance of a material under short-term high temperature and high stress conditions. Because long-term creep at a given strain level is an important consideration in the design of gas turbine components, particular rotating components such as blades, a long-term creep test was conducted with specimens of all ten experimental alloys of Table I, as well as the IN-939 alloy. The long-term creep test was conducted at about 1600° F. (about 870° C.) and about 30 ksi (about 207 MPa), with the results represented in FIG. 4. The data indicated that the 1% creep lives of Alloys 3, 4, and 9 were approximately two times or more longer than that of IN-939.

[0023] Based on the creep life results, Alloys 3, 4, and 9 underwent a weldability test known as Spot-Varestraint, which plots maximum crack distance (MCD) versus cooling time. Also tested were IN-939 and GTD-222. With this test, heat affected zone (HAZ) liquation cracking is induced by bending the sample to a given strain level at a given cooling time after a spot weld has been made on the surface of the sample. Weldability is then assessed by the minimum cooling time at which MCD equals zero. When MCD is plotted against cooling time, the area under the curve represents the weldability of the sample. The smaller the area, the better the weldability of an alloy. Plotted in FIG. 5, the data obtained with the Spot-Varestraint test indicated that Alloy 9 was about two times better than IN-939 in weldability. Alloys 3 and 4 showed much lower weldability, to the extent that they were concluded to be essentially as unweldable as IN-738. These results were believed to be caused by the relatively high levels of gamma-prime strengthening elements in Alloys 3 and 4. FIGS. 6 and 7 are micrographs of Spot-Varestraint samples for experimental Alloy 9 and prior art alloy IN-939, respectively.

[0024] Next, experimental Alloy 9 and IN-939 underwent thermal exposure at about 1700° F. (about 930° C.) for about 1000 hours to assess microstructural stability. FIG. 8 shows scanning electron microscope (SEM) photos of the microstructures of Alloy 9 and IN-939 specimens. The photos were taken at the same magnification, and evidence that the IN-939 sample contained coarse plate-like Eta phase, while

Alloy 9 mainly consisted of gamma prime and discrete carbide particles. The plate-like structure of the IN-939 sample is known to negatively affect mechanical properties.

[0025] Finally, the experimental alloys of Table I were cast to compare their castability to that of IN-939. The results indicated that all the experimental alloys had superior castability to IN-939 in terms of resistance to solidification shrinkage and hot tears.

[0026] On the basis of the above, an alloy having the broad, preferred and nominal compositions summarized in Table II is believed to have weldability better than IN-939, but with improved mechanical properties, castability, and phase stability suitable for use as turbine nozzle and blade components of an gas turbine engine, as well as other applications in which similar properties are required. All values are in weight percent except the Ti/Al ratio levels reported in atomic percent.

TABLE II

	Broad	Preferred	Nominal
Cr	10 to <20	14.0 to 15.6	14.8
Co	15 to 20	16.0 to 18.0	17.2
Mo	<1	<0.5	<0.25
W	2.5 to 5	2.75 to 3.25	3.0
Nb	1.1 to 1.5	1.2 to 1.4	1.3
Ta	<0.5	<0.25	<0.05
Ti	3.0 to 3.9	3.1 to 3.4	3.2
Al	2.5 to 3.4	2.6 to 3.0	2.8
Ti/Al	—	<1.0	<0.9
C	0.07 to 0.15	0.09 to 0.11	0.10
Zr	<0.06	<0.02	0.01
B	<0.03	<0.015	0.01
Ni	balance	balance	balance

[0027] From the above-reported test results, it appears the Ti+Al+Nb content in the alloy provides a sufficient volume fraction of the gamma-prime phase to achieve desirable high temperature strength levels while simultaneously providing for a level of weldability suitable for weld repair of castings formed of the alloy. On the basis of the performance of Alloy 9 compared to the other tested alloys, the tungsten level and Ti/Al ratio are both believed to be important to achieving the preferred properties for the alloy.

[0028] It is believed that the alloy identified above in Table II can be satisfactorily heat treated using the treatment described above, though conventional heat treatments adapted for nickel-base alloys could also be used. Though tested as an alloy for castability and particularly intended for production by investment casting as well as equiaxed, directionally-solidified, and single-crystal castings, it is also within the scope of this invention to use the alloy in powder form to produce powder metal products.

[0029] While the invention has been described in terms of a preferred embodiment, it is apparent that other forms could be adopted by one skilled in the art. Therefore, the scope of the invention is to be limited only by the following claims.

What is claimed is:

1. A castable weldable nickel-base alloy consisting of, by weight, 10 to less than 20% chromium, 15 to 20% cobalt, less than 1.0% molybdenum, 2.5 to 5% tungsten, 1.1 to 1.5% niobium, less than 0.5% tantalum, 3.0 to 3.9% titanium, 2.5

to 3.4% aluminum, 0.07 to 0.15% carbon, less than 0.06% zirconium, less than 0.03% boron, the balance nickel and impurities.

2. The alloy according to claim 1, wherein the chromium content in the alloy is, by weight, 14.0 to 15.6%.

3. The alloy according to claim 1, wherein the cobalt content in the alloy is, by weight, 16.0 to 18.0%.

4. The alloy according to claim 1, wherein the tungsten content in the alloy is, by weight, 2.75 to 3.25%.

5. The alloy according to claim 1, wherein the molybdenum content is, by weight, less than 0.5%.

6. The alloy according to claim 1, wherein the niobium content is, by weight, 1.2 to 1.4%.

7. The alloy according to claim 1, wherein the tantalum content is, by weight, less than 0.25%.

8. The alloy according to claim 1, wherein the titanium content is, by weight, 3.1 to 3.4%.

9. The alloy according to claim 1, wherein the aluminum content is, by weight, 2.6 to 3.0%.

10. The alloy according to claim 1, wherein the titanium, aluminum, niobium, and tantalum, contents are, by weight, 3.1 to 3.4%, 2.6 to 3.0%, 1.2 to 1.4%, and less than 0.25%, respectively.

11. The alloy according to claim 1, wherein the carbon, zirconium, and boron contents are, by weight, 0.09 to 0.11%, less than 0.02%, and less than 0.015%, respectively.

12. The alloy according to claim 1, wherein the atomic ratio of titanium to aluminum in the alloy is less than 1.0.

13. The alloy according to claim 1, wherein the alloy is in the form of a casting produced by a process chosen from the group consisting of investment casting, equiax casting, directional solidification, and single-crystal casting.

14. The alloy according to claim 1, wherein the alloy is in the form of a body formed of a compacted powder of the alloy.

15. The alloy according to claim 1, wherein the alloy is in the form of a gas turbine engine component chosen from the group consisting of blade and nozzle components.

16. A weldable nickel-base alloy casting consisting of, by weight, 14.0 to 15.6% chromium, 16.0 to 18.0% cobalt, less than 0.5% molybdenum, 2.75 to 3.25% tungsten, 1.2 to 1.4% niobium, less than 0.25% tantalum, 3.1 to 3.4% titanium, 2.6 to 3.0% aluminum, 0.09 to 0.11% carbon, less than 0.02% zirconium, less than 0.015% boron, the balance nickel and impurities, wherein the atomic ratio of titanium to aluminum is less than 0.9.

17. The weldable nickel-base alloy casting according to claim 16, wherein the casting has a composition of, by weight, about 14.8% chromium, about 17.2% cobalt, less than 0.25% molybdenum, about 3.0% tungsten, about 1.3% niobium, less than 0.05% tantalum, about 3.2% titanium, about 2.8% aluminum, about 0.10% carbon, about 0.01% zirconium, about 0.01% boron, the balance nickel and impurities.

18. The weldable nickel-base alloy casting according to claim 16, wherein the casting is a nozzle component of a gas turbine engine.

19. The weldable nickel-base alloy casting according to claim 16, wherein the casting is a blade component of a gas turbine engine.

20. A process for producing a weldable nickel-base alloy casting, the process comprising the steps of:

forming a melt consisting of, by weight, 10 to less than 20% chromium, 15 to 20% cobalt, less than 1.0% molybdenum, 2.5 to 5% tungsten, 1.1 to 1.5% niobium, less than 0.5% tantalum, 3.0 to 3.9% titanium, 2.5 to 3.4% aluminum, 0.07 to 0.15% carbon, less than 0.06% zirconium, less than 0.03% boron, the balance nickel and impurities; and

producing a casting from the melt by a process chosen from the group consisting of investment casting, equiax casting, directional solidification, and single-crystal casting.

* * * * *