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(54) **CAST NICKEL-IRON-BASE ALLOY
COMPONENT AND PROCESS OF FORMING
A CAST NICKEL-IRON-BASE ALLOY
COMPONENT**

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(57) **ABSTRACT**
A cast nickel-iron-base alloy component having by weight about 12.0% to about 16.5% Cr, about 1.0% to about 2.0% Al, about 2.0% to about 3.0% Ti, about 2.0% to about 3.0% W, about 3.0 to about 5.0% Mo, up to about 0.1% Nb, up to about 0.2% Mn, up to about 0.1% Si, about 0.05% to about 0.10% C, about 0.003 to about 0.010% B, about 35% to about 37% Fe, and balance essentially Ni and inevitable impurities. The nickel-iron-base alloy component has a creep rupture life greater than about 1000 hours at about 25 ksi to about 30 ksi at about 1400° F. A method for forming the cast nickel-iron-base alloy component is also disclosed.

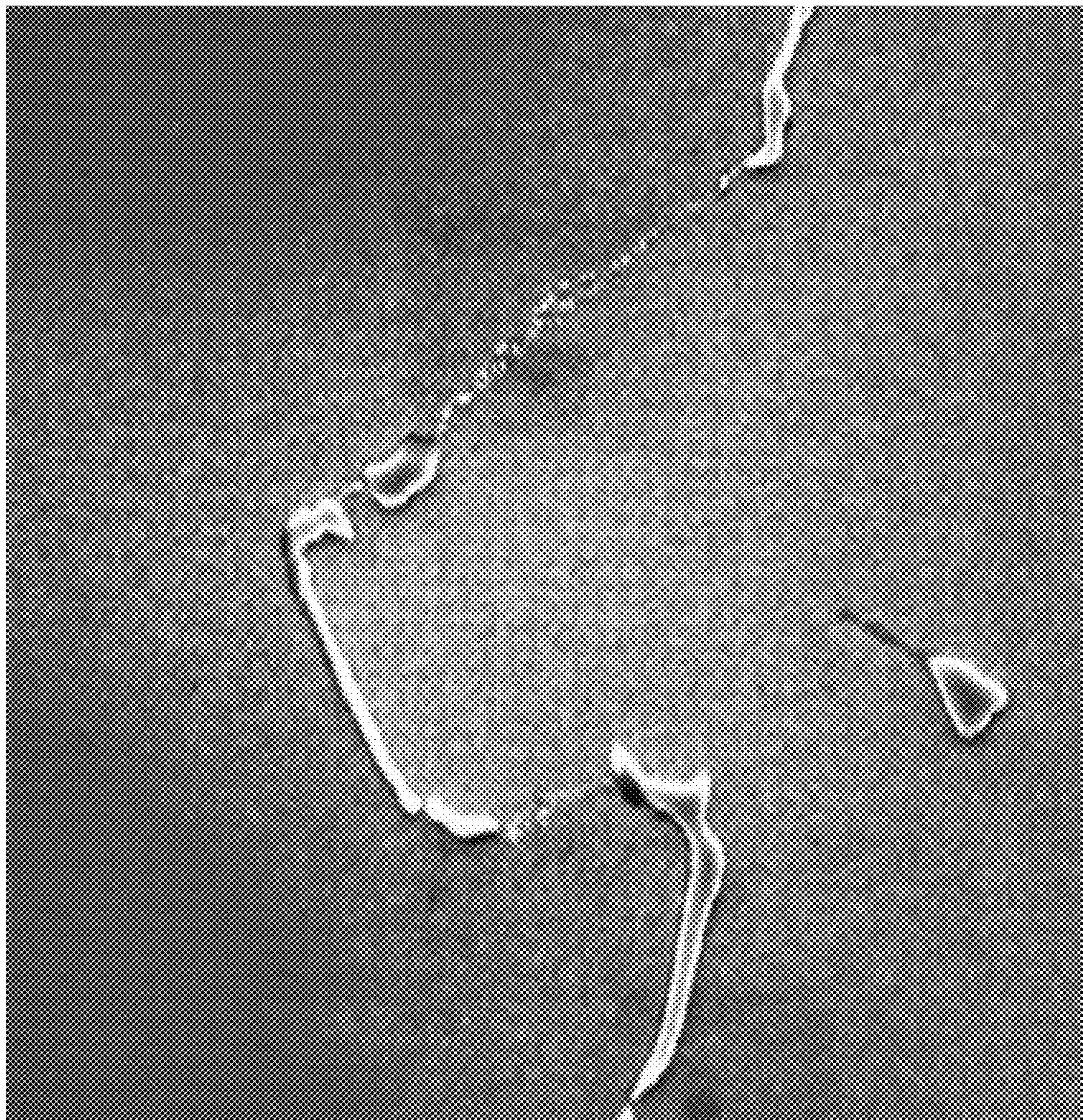


FIG. 1

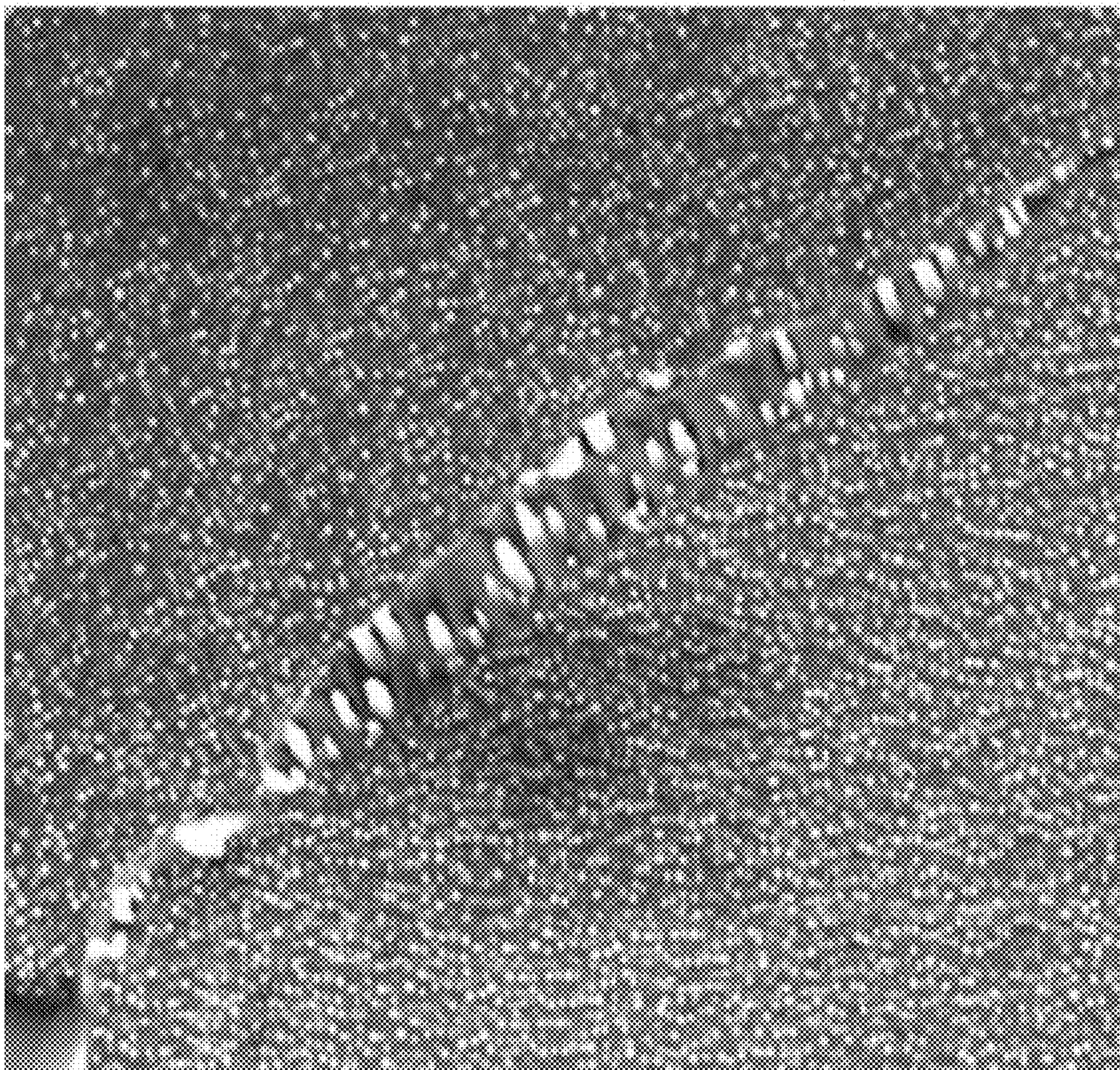


FIG. 2

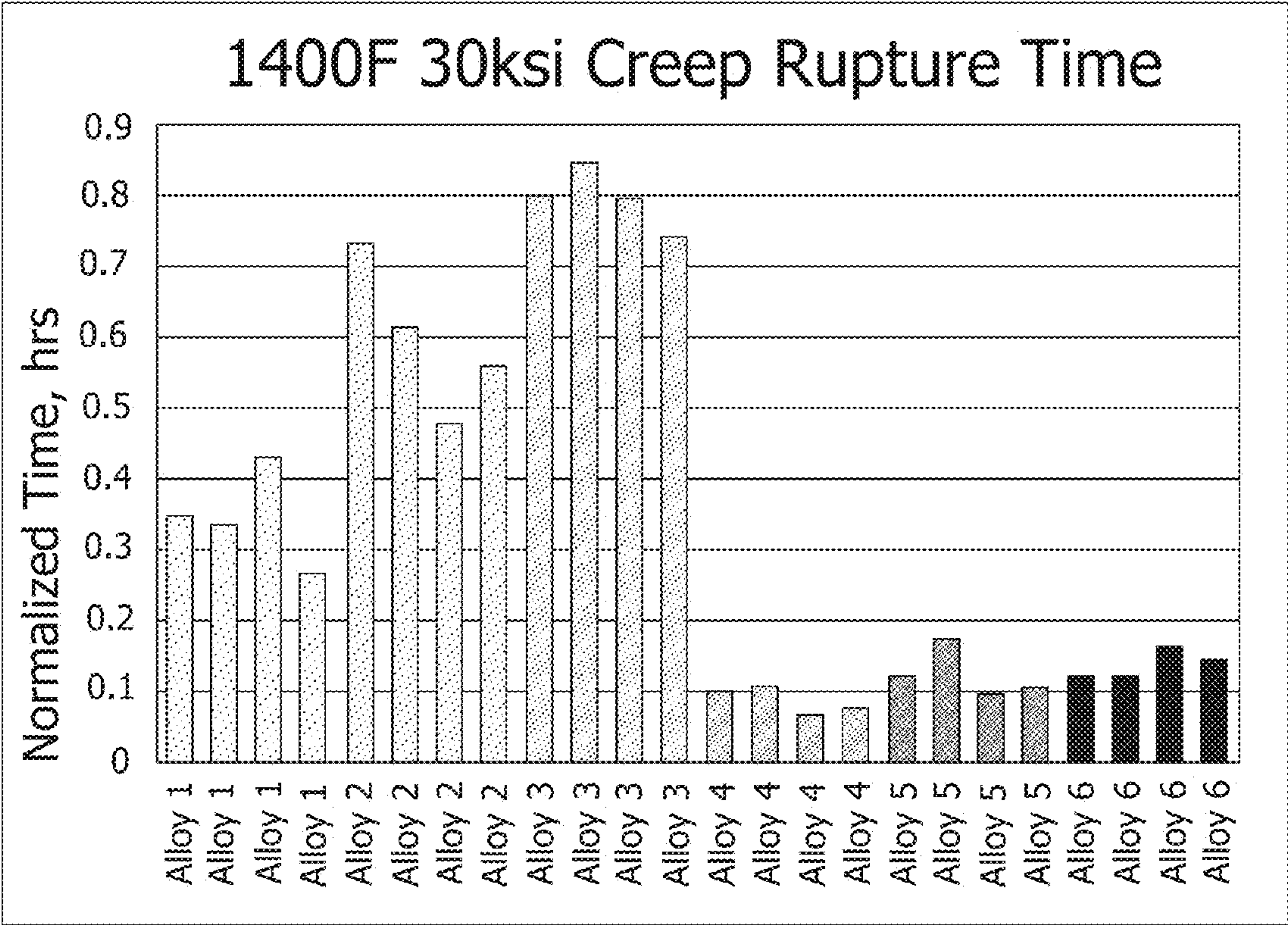


FIG. 3

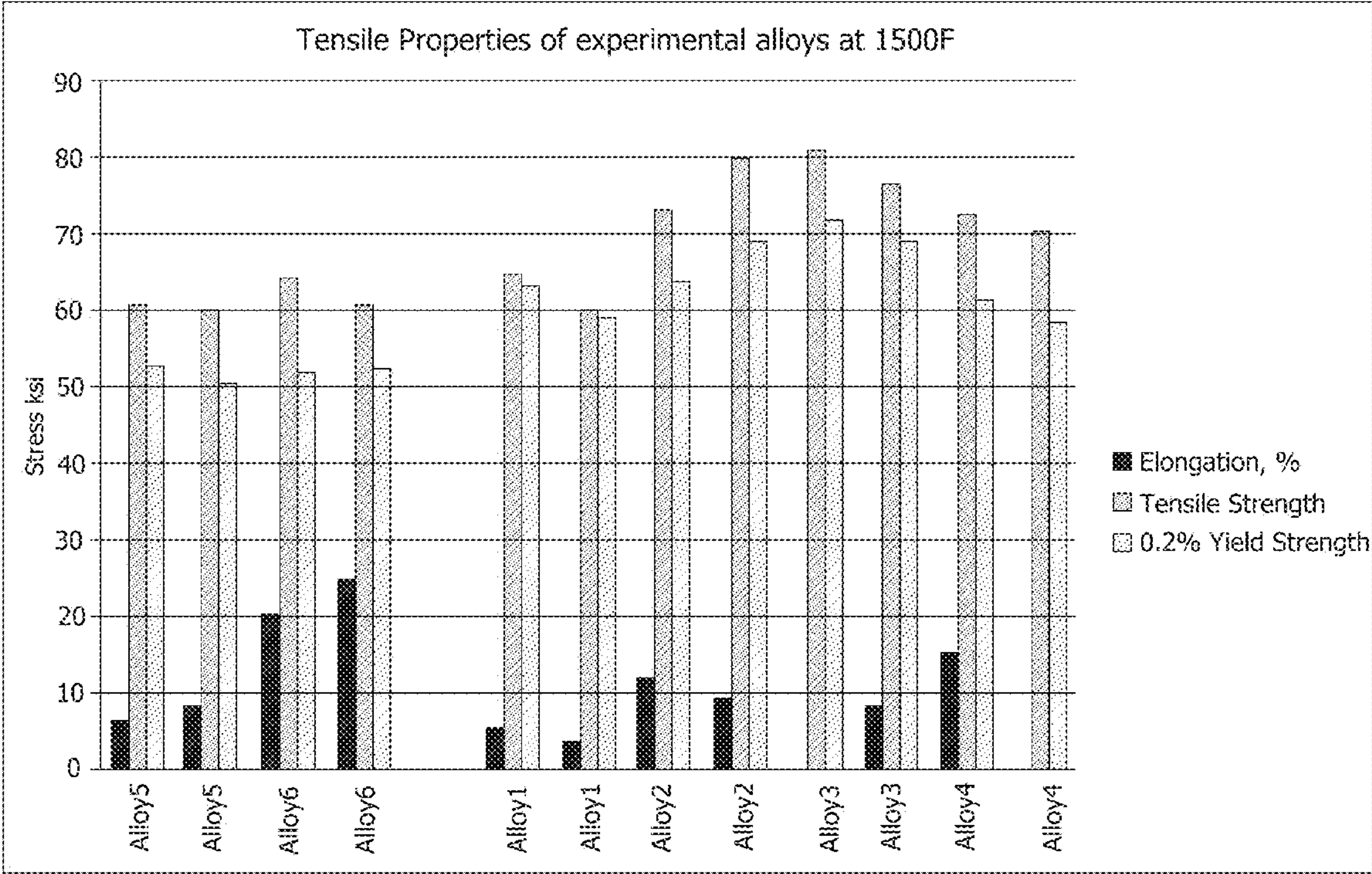


FIG. 4

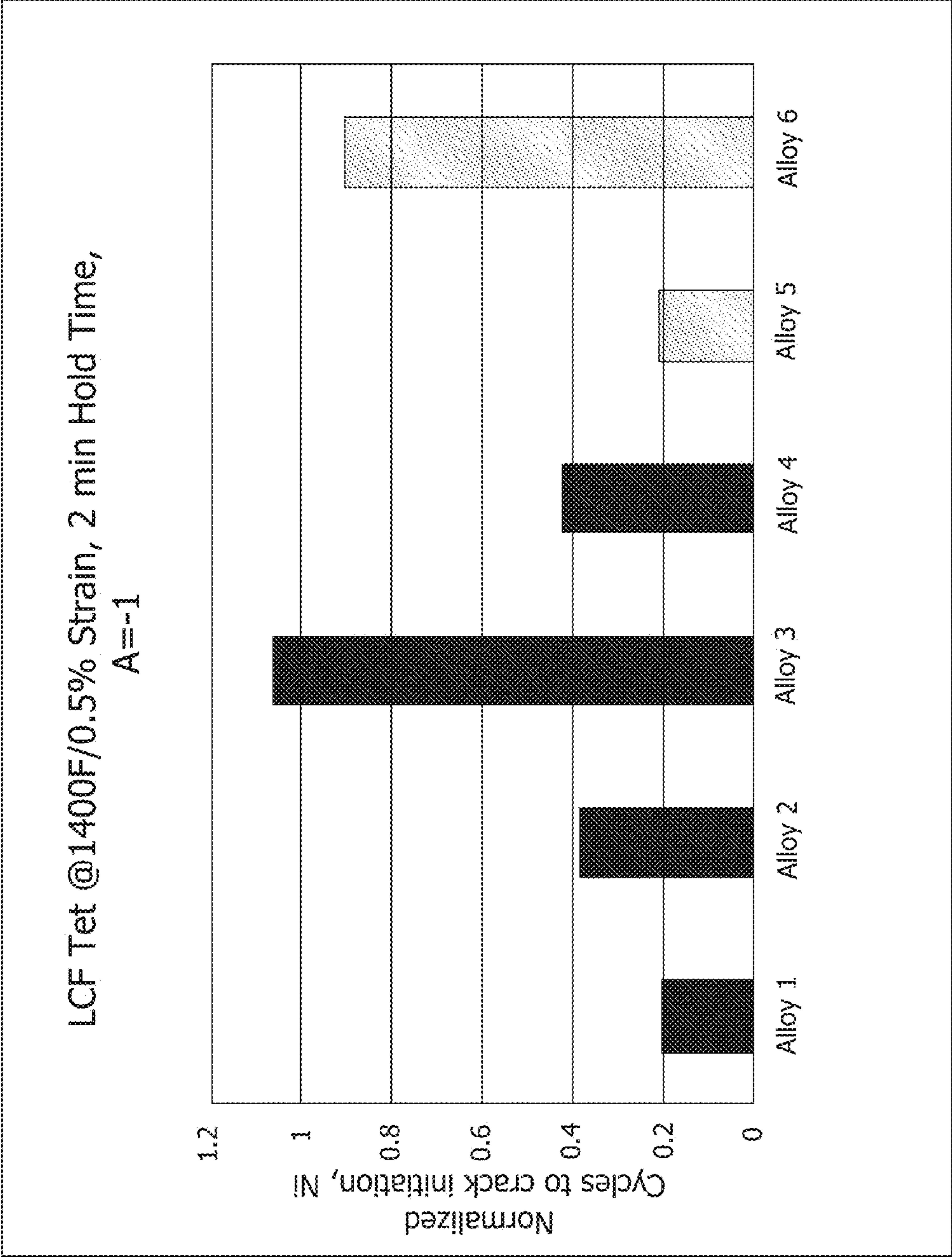


FIG. 5

CAST NICKEL-IRON-BASE ALLOY COMPONENT AND PROCESS OF FORMING A CAST NICKEL-IRON-BASE ALLOY COMPONENT

FIELD OF THE INVENTION

[0001] The present invention is directed to alloys, articles including alloys, and processes of forming alloys. More specifically, the present invention is directed to a nickel-iron-base alloy and a process of forming a nickel-iron-base alloy.

BACKGROUND OF THE INVENTION

[0002] The operating temperature within a gas turbine engine is both thermally and chemically hostile. Significant advances in high temperature capabilities have been achieved through the development of iron, nickel and cobalt-based superalloys and the use of environmental coatings capable of protecting superalloys from oxidation, hot corrosion, etc., but coating systems continue to be developed to improve the performance of the materials.

[0003] In the compressor portion of a gas turbine engine, atmospheric air is compressed to 10-25 times atmospheric pressure, and adiabatically heated to 800°-1250° F. (427° C.-677° C.) in the process. This heated and compressed air is directed into a combustor, where it is mixed with fuel. The fuel is ignited, and the combustion process heats the gases to very high temperatures, in excess of 3000° F. (1650° C.). These hot gases pass through the turbine, where airfoils fixed to rotating turbine disks extract energy to drive the fan and compressor of the engine, and the exhaust system, where the gases provide sufficient thrust to propel the aircraft. To improve the efficiency of operation of the engine, combustion temperatures have been raised. Of course, as the combustion temperature is raised, steps must be taken to prevent thermal degradation of the materials forming the flow path for these hot gases of combustion.

[0004] Demand for enhanced performance continues to increase. This demand for enhanced performance applies for newer engines and modifications of proven designs. Specifically, higher thrusts and better fuel economy are among the performance demands. To improve the performance of engines, the combustion temperatures have been raised to very high temperatures. This can result in higher thrusts and/or better fuel economy.

[0005] Stator components (nozzles and shrouds) are hot gas path components for gas turbines. It is desirable for the stator components to have oxidation resistance, thermal-mechanical fatigue capability and high temperature creep strength. Traditionally, the stator components are made of Ni-based or Co-based cast superalloys. These superalloys suffer from the drawback that they can have very high costs.

[0006] Known attempts to use different materials have been unsuccessful. For example, advanced stainless steels (for example Alumina-Forming Austenitic (AFA) alloys, developed by Oak Ridge National Laboratory) contain nano-precipitates and oxide-forming elements and demonstrate an outstanding heat-resistance. However, these advanced stainless steels have undesirably low creep strength for nozzles. Particularly, the creep strength of these advanced stainless steels only reaches about one half of design requirement for gas turbine nozzles.

[0007] Another group of low cost alternative materials, nickel-iron-base superalloys including A286, INCOLOY®

901, INCOLOY® 903 and INCONEL® 706, have been regarded as suffering from several drawbacks. "INCOLOY" and "INCONEL" are federally registered trademarks of alloy produced by Inco Alloys International, Inc., Huntington, W. Va. For example, INCOLOY® 901 has been regarded as lacking gamma prime phases (resulting in low creep strength), containing significant amounts of eta, sigma, and laves phases (resulting in low ductility and/or poor long-term mechanical properties), and having a wide solidification range and poor castability. The composition of INCOLOY® 901 is well-known and includes a composition of 40.0-45.0% Ni, up to 0.35% Al, 2.35-3.10% Ti, 11.0-14.0% Cr, 5.0-7.0% Mo, up to about 1.0% Co, up to 1.0% Mn, up to 0.03% S, up to 0.10% C, up to 0.60% Si, up to 0.03% P, up to 0.50% Cu, from 0.01 to 0.02% B, balance Fe. The composition of INCONEL® 706 is well-known and includes a composition of 39.0-44.0% Ni, 14.5-17.5% Cr, up to 0.40% Al, 1.5-2.0% Ti, 2.5-3.3% Nb+Ta, up to about 1.0% Co, up to 0.35% Mn, up to 0.015% S, up to 0.06% C, up to 0.35% Si, up to 0.020% P, up to 0.30% Cu, from up to 0.006% B, balance Fe.

[0008] Nickel-iron-base alloy components and processes of forming nickel-iron-base alloy components that do not suffer from the above drawbacks are desirable in the art.

SUMMARY OF THE INVENTION

[0009] According to an exemplary embodiment of the present disclosure, a cast nickel-iron-base alloy component having by weight:

- [0010]** about 12.0% to about 16.5% Cr;
- [0011]** about 1.0% to about 2.0% Al;
- [0012]** about 2.0% to about 3.0% Ti;
- [0013]** about 2.0% to about 3.0% W;
- [0014]** about 3.0 to about 5.0% Mo;
- [0015]** up to about 0.1% Nb;
- [0016]** up to about 0.2% Mn;
- [0017]** up to about 0.1% Si;
- [0018]** about 0.05% to about 0.10% C;
- [0019]** about 0.003 to about 0.010% B;
- [0020]** about 35% to about 37% Fe; and
- [0021]** balance essentially Ni and inevitable impurities;

The nickel-iron-base alloy component has a creep rupture life greater about 1000 hours at about 25 ksi to about 30 ksi at about 1400° F.

[0022] Another exemplary embodiment of the present disclosure includes a process of forming a cast nickel-iron-base alloy component. The process includes casting an alloy having by weight:

- [0023]** about 12.0% to about 16.5% Cr;
- [0024]** about 1.0% to about 2.0% Al;
- [0025]** about 2.0% to about 3.0% Ti;
- [0026]** about 2.0% to about 3.0% W;
- [0027]** about 3.0 to about 5.0% Mo;
- [0028]** up to about 0.1% Nb;
- [0029]** up to about 0.2% Mn;
- [0030]** up to about 0.1% Si;
- [0031]** about 0.05% to about 0.10% C;
- [0032]** about 0.003 to about 0.010% B;
- [0033]** about 35% to about 37% Fe; and
- [0034]** balance essentially Ni and inevitable impurities;

The cast ingot is homogenized at a temperature from about 2000° F. to about 2200° F. to form a homogenized ingot. The homogenized ingot is heat treated at a temperature from about 1700° F. to about 1850° F. to form a heat-treated ingot. The heat-treated ingot is then aged at a first aging temperature

from about 1200° F. to about 1500° F. and then aged at a second aging temperature from about 1000° F. to about 1200° F. to form an aged ingot. The aged ingot has a creep rupture life greater than about 1000 hours at about 25 ksi to about 30 ksi at about 1400° F.

[0035] Other features and advantages of the present invention will be apparent from the following more detailed description of the preferred embodiment, taken in conjunction with the accompanying drawings which illustrate, by way of example, the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0036] FIG. 1 is a photomicrograph of an alloy according to the present disclosure.

[0037] FIG. 2 is a photomicrograph of an alloy according to the present disclosure.

[0038] FIG. 3 is a graph showing creep rupture time data for Alloys 1-6.

[0039] FIG. 4 is a graph showing tensile property data for Alloys 1-6.

[0040] FIG. 5 is a graph showing low cycle fatigue (LCF) data for Alloys 1-6.

DETAILED DESCRIPTION OF THE INVENTION

[0041] Provided is a cast nickel-iron-base alloy component having a plurality of predetermined properties and a process of forming a nickel-iron-base alloy component having a plurality of predetermined properties. Embodiments of the present disclosure involve a nickel-iron-base alloy formed from one or more low-cost alloys previously regarded as unsuitable for hot gas path components such as engine turbine stators.

[0042] An embodiment of the present disclosure includes a high-temperature component, such as a turbine nozzle or shroud, having a desirable creep strength through casting and heat treatment according to the present disclosure. In addition, the nickel-iron-base alloy components, according to the present disclosure, having desirable long-term mechanical properties, are suitable for use in power generation systems.

[0043] One or more specific embodiments of the present invention will be described below. In an effort to provide a concise description of these embodiments, all features of an actual implementation may not be described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure. Specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a basis for the claims as a representative basis for teaching one skilled in the art to variously employ the present invention. Any modifications or variations in the depicted systems and methods, and such further applications of the principles of the invention as illustrated herein, as would normally occur to one skilled in the art, are considered to be within the spirit of this invention.

[0044] When introducing elements of various embodiments of the present invention, the articles "a," "an," "the," and "said" are intended to mean that there are one or more of the elements. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements.

[0045] Power generation systems include, but are not limited to, gas turbines, steam turbines, and other turbine assemblies. In certain applications, power generation systems, including the turbomachinery therein (e.g., turbines, compressors, and pumps) and other machinery may include components that are exposed to extreme environments and heavy wear conditions. For example, certain power generation system components, such as blades, casings, rotor wheels, shafts, nozzles, and so forth, may operate in high heat and high revolution environments. As a result of the extreme environmental operating conditions, cracks, gouges, cavities, or gaps may develop on the surface of the components.

[0046] Embodiments of the present disclosure include nickel-iron-base alloys having the following broad, preferred and nominal compositions:

TABLE 1

wt %	Broad Range	Preferred Range	Nominal
Chromium	12.0-16.5	12.0-14.0	12.5
Aluminum	1.0-2.0	1.35-1.65	1.5
Titanium	2.0-3.0	2.25-2.75	2.5
Tungsten	2.0-3.0	2.0-2.7	2.5
Molybdenum	3.0-5.0	3.2-4.0	3.5
Niobium	<0.1	<0.1	<0.1
Manganese	<0.2	<0.2	<0.2
Silicon	<0.1	<0.1	<0.1
Carbon	0.05-0.10	0.07-0.09	0.08
Boron	0.003-0.010	0.005-0.008	0.006
Iron	35-37	35-37	36
Nickel	Balance	Balance	Balance

[0047] In one embodiment, the nickel-iron-base alloy has a creep rupture life of greater than about 1000 hours, or greater than about 1400 hours, or greater than about 1800 hours at about 1400° F. and at about 25 ksi to about 30 ksi of loading. In one embodiment, the nickel-iron-base alloy is resistant to oxidation for 48,000 hours or more. In one embodiment, hold time low cycle fatigue of the nickel-iron-base alloy at 1400° F. is substantially the same or exceeds typical cobalt-base or nickel-base alloys for gas turbine nozzle castings, such as FSX414 alloy or GTD-222 alloy, respectively. For example, the nickel-iron-base alloy hold time (2 minutes) low cycle fatigue life at 1400° F. and 5% total strain may reach 2000 cycles or more.

[0048] In one embodiment, the component according to the present disclosure can be formed using a casting method, such as, but not limited to, investment casting. Investment casting or lost wax casting can prepare articles or components having intricate shapes while maintaining accuracy of features. Generally, investment casting comprises the following steps: forming a wax form of the part to be cast; building a shell around the wax form; de-waxing to leave a shell; filling the shell with molten metal; and removing the shell around the cast part. One important characteristic of casting alloy is the solidification range. It is the temperature range between the liquidus and solidus, which is often used to evaluate the castability of an alloy. The greater the solidification range is, the easier the shrinkage formation is. In one embodiment, the

nickel-iron-base alloy has a solidification range less than about 110° F. This solidification range provides good castability of the alloy. Other steps and processing may also be utilized to provide the cast ingot or component. In addition subsequent machining or other processes may be utilized to form the ingot or component into its final form.

[0049] Once the ingot or component has been cast, the ingot or component is subjected to heat treatment. The heat treatment includes homogenization, heat treatment and aging at temperatures and conditions that provide fine precipitates allowing the alloy to have strength and creep rupture resistance greater than known nickel-iron-base alloys, such as INCOLOY® 903 and INCONEL® 706. In one embodiment, the homogenizing includes homogenizing the cast ingot at a temperature from about 2000° F. to about 2200° F. or 2050° F. to about 2150° F. or about 2100° F. to form a homogenized ingot where the precipitates are put into solution and essentially only MC precipitates remain. The heat treating includes heat treating the homogenized ingot to a temperature from about 1700° F. to about 1850° F. for 2 hours or 1750° F. to about 1800° F. for 2 hours or about 1775° F. for 2 hours to form fine discrete carbides and an eta-phase microstructure along the grain boundaries (see, for example, FIG. 1). After the heat treatment, an aging process is provided. In one exemplary aging process, a multi-step aging is utilized, including aging the heat treated ingot at a first aging temperature from about 1200° F. to about 1500° F. for 8 hours or about 1300° F. to about 1400° F. for 8 hours or about 1350° F. for 8 hours and then at a second aging temperature from about 1000° F. to about 1200° F. for 8 hours or 1050° F. to about 1150° F. for 8 hours or about 1100° F. for 8 hours to form an aged ingot having fine precipitates in matrix of the alloy (see, for example, FIG. 2). Depending on the application and the desired mechanical properties, a 3rd step of age may be applied.

[0050] In one embodiment, the component is a power generation system component. For example, the component may be a turbine stator component including, but not limited to, a nozzle, a shroud, other suitable portions, or combinations thereof.

EXAMPLES

[0051]

TABLE 2

	Wt % EXAMPLES		
	Alloy 1	Alloy 2	Alloy 3
Chromium	16.0	14.0	12.5
Aluminum	1.5	1.5	1.5
Titanium	2.5	2.5	2.5
Tungsten	2.0	2.0	2.5
Molybdenum	1.0	4.0	3.5
Niobium	<0.1	<0.1	<0.1
Manganese	<0.2	<0.2	<0.2
Silicon	<0.1	<0.1	<0.1
Carbon	0.08	0.08	0.08
Boron	0.006	0.006	0.006
Iron	36	36	36
Nickel	Balance	Balance	Balance

TABLE 2-continued

	Wt % COMPARATIVE EXAMPLES		
	Alloy 4	Alloy 5	Alloy 6
Chromium	12.5	16.0	16.0
Aluminum	0.2	1.50	0.20
Titanium	2.8	1.75	1.75
Tungsten	0.1	2.00	<0.12
Molybdenum	5.7	<0.12	<0.12
Niobium	<0.1	0.50	2.90
Manganese	<0.2	<0.2	<0.2
Silicon	<0.1	<0.1	<0.1
Carbon	0.05	0.070	0.020
Boron	0.01	<0.006	0.006
Iron	36	37	37
Nickel	Balance	Balance	Balance

[0052] Alloys 1-3, as shown in Table 2, are alloys according to the present disclosure. Comparative Alloy 4 is an INCONEL® 706 alloy and Comparative Alloy 6 is an INCOLOY® 901 alloy. All of the alloys shown in Table 2 are investment cast alloys according to the indicated composition. In addition, the alloys in Table 2 were heat treated by homogenization, heat treatment and double aging.

[0053] FIG. 3 shows the creep rupture time for Alloys 1-6. FIG. 4 shows the tensile properties, including the % elongation, tensile strength and 0.2% yield strength of Alloys 1-6. FIG. 5 shows low cycle fatigue (LCF) values at 1400° F. with 0.5% strain and 2 min hold for Alloys 1-6. Alloys 1-3 according to the present disclosure showed about 5-10 times improvement in 1400° F. creep over the Alloy 6, INCOLOY® 901 alloy and the Alloy 4, INCONEL® 706 alloy baseline. LCF capability at the given condition (1400° F., 0.5% total strain, 2 minutes hold time) reached 2000 cycles, which is substantially the same as that of a nickel-base alloy, GTD-222. Alloys 1-3, according to the present disclosure, showed excellent castability, and heat treatment feasibility, which is evidenced by microstructure and mechanical properties.

[0054] While the invention has been described with reference to a preferred embodiment, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

1. A cast nickel-iron-base alloy component comprising by weight:

- about 12.0% to about 16.5% Cr;
- about 1.0% to about 2.0% Al;
- about 2.0% to about 3.0% Ti;
- about 2.0% to about 3.0% W;
- about 3.0 to about 5.0% Mo;
- up to about 0.1% Nb;
- up to about 0.2% Mn;
- up to about 0.1% Si;
- about 0.05% to about 0.10% C;
- about 0.003 to about 0.010% B;
- about 35% to about 37% Fe; and

balance essentially Ni and inevitable impurities;
wherein the component has a creep rupture life greater
about 1000 hours at about 25 ksi to about 30 ksi at about
1400° F.

2. The cast nickel-iron-base alloy component of claim 1, comprising about 12.0% to about 14% Cr, about 1.35% to about 1.65% Al, about 2.25% to about 2.75% Ti, about 2.0% to about 2.7% W, about 3.2 to about 4.0% Mo, up to about 0.1% Nb, up to about 0.2% Mn, up to about 0.1% Si, about 0.07% to about 0.09% C, about 0.005 to about 0.008% B, about 35% to about 37% Fe, and balance essentially Ni and inevitable impurities.

3. The cast nickel-iron-base alloy component of claim 1, comprising about 12.5% Cr, about 1.5% Al, about 2.5% Ti, about 2.5% W, about 3.5% Mo, up to about 0.1% Nb, up to about 0.2% Mn, up to about 0.1% Si, about 0.08% C, about 0.006% B, about 36% Fe, and balance essentially Ni and inevitable impurities.

4. The cast nickel-iron-base alloy component of claim 1, wherein the composition is devoid of Co.

5. The cast nickel-iron-base alloy component of claim 1, wherein the nickel-iron-base alloy component has a creep rupture life of greater than about 1400 hours at about 25 ksi to about 30 ksi at about 1400° F.

6. The cast nickel-iron-base alloy component of claim 1, wherein the nickel-iron-base alloy component has a creep rupture life of greater than about 1800 hours at about 25 ksi to about 30 ksi at about 1400° F.

7. The cast nickel-iron-base alloy component of claim 1, wherein the nickel-iron-base alloy component has a resistance to oxidation of greater than about 48,000 hours.

8. The cast nickel-iron-base alloy component of claim 1, wherein the nickel-iron-base alloy component is a nozzle.

9. The cast nickel-iron-base alloy component of claim 1, wherein the nickel-iron-base alloy component is a shroud.

10. A process of forming a cast nickel-iron-base alloy component, the process comprising:

casting an alloy comprising by weight:
about 12.0% to about 16.5% Cr;
about 1.0% to about 2.0% Al;
about 2.0% to about 3.0% Ti;
about 2.0% to about 3.0% W;
about 3.0 to about 5.0% Mo;
up to about 0.1% Nb;
up to about 0.2% Mn;
up to about 0.1% Si;
about 0.05% to about 0.10% C;
about 0.003 to about 0.010% B;
about 35% to about 37% Fe; and

balance essentially Ni and inevitable impurities to form a cast ingot;

homogenizing the cast ingot at a temperature from about 2000° F. to about 2200° F. to form a homogenized ingot;
heat treating the homogenized ingot at a temperature from about 1700° F. to about 1850° F. to form a heat treated ingot; and

aging the heat treated ingot at a first aging temperature from about 1200° F. to about 1500° F. and then at a second aging temperature from about 1000° F. to about 1200° F. to form an aged ingot;

wherein the aged ingot has a creep rupture life greater than about 1000 hours at about 25 ksi to about 30 ksi at about 1400° F.

11. The process of claim 10, wherein the alloy comprises about 12.0% to about 14% Cr, about 1.35% to about 1.65% Al, about 2.25% to about 2.75% Ti, about 2.0% to about 2.7% W, about 3.2 to about 4.0% Mo, up to about 0.1% Nb, up to about 0.2% Mn, up to about 0.1% Si, about 0.07% to about 0.09% C, about 0.005 to about 0.008% B, about 35% to about 37% Fe, and balance essentially Ni and inevitable impurities.

12. The process of claim 10, wherein the alloy comprises about 12.5% Cr, about 1.5% Al, about 2.5% Ti, about 2.5% W, about 3.5% Mo, up to about 0.1% Nb, up to about 0.2% Mn, up to about 0.1% Si, about 0.08% C, about 0.006% B, about 36% Fe, and balance essentially Ni and inevitable impurities.

13. The process of claim 10, wherein the alloy is devoid of Co.

14. The process of claim 10, wherein the homogenizing includes heating the cast ingot to a temperature of from about 2050° F. to about 2150° F.

15. The process of claim 10, wherein the heat treating includes heating the homogenized ingot to a temperature of from about 1750° F. to about 1800° F.

16. The process of claim 10, wherein the aging includes heating the heat-treated ingot to a first temperature of from about 1300° F. to about 1400° F. and a second temperature of from about 1050° F. to about 1150° F.

17. The process of claim 10, wherein the aged ingot has a creep rupture life greater than about 1400 hours at about 25 ksi to about 30 ksi at about 1400° F.

18. The process of claim 10, wherein the aged ingot has a creep rupture life greater than about 1800 hours at about 25 ksi to about 30 ksi at about 1400° F.

19. The process of claim 10, wherein the nickel-iron-base alloy component is a nozzle.

20. The process of claim 10, wherein the nickel-iron-base alloy component is a shroud.

* * * * *