



Europäisches Patentamt
European Patent Office
Office européen des brevets



(11)

EP 1 420 074 A2

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:

19.05.2004 Bulletin 2004/21

(51) Int Cl.7: **C22C 19/00**

(21) Application number: **03256701.8**

(22) Date of filing: **23.10.2003**

(84) Designated Contracting States:

**AT BE BG CH CY CZ DE DK EE ES FI FR GB GR
HU IE IT LI LU MC NL PT RO SE SI SK TR**

Designated Extension States:

AL LT LV MK

(30) Priority: **25.10.2002 US 280391**

(71) Applicant: **GENERAL ELECTRIC COMPANY
Schenectady, NY 12345 (US)**

(72) Inventors:

- **Groh, John Raymond
Loveland, Ohio 45150 (US)**
- **Gambone, Michael Joseph
Mason, Ohio 45040 (US)**

(74) Representative: **Goode, Ian Roy et al
London Patent Operation
General Electric International, Inc.
15 John Adam Street
London WC2N 6LU (GB)**

(54) **Nickel-base alloy and its use in casting and welding operations**

(57) An alloy has a composition of, in weight percent, from about 16 percent to about 21 percent chromium, from about 6 percent to about 12 percent iron, from about 6 percent to about 12 percent cobalt, from about 2.8 percent to about 3.3 percent molybdenum, from about 5 percent to about 5.4 percent niobium, from 0 to about 2 percent tantalum, from about 0.65 percent to about 1.15 percent titanium, from about 0.2 percent

to about 0.8 percent aluminum, from about 0.01 percent to about 0.05 percent carbon, from about 0.005 percent to about 0.01 percent boron, less than about 0.1 percent zirconium, balance nickel and impurities. A molten mass of this composition may be cast into a mold for solidification. The solid material may be welded either in a re-work/repair process or to join it to a second article.

EP 1 420 074 A2

Description

[0001] This invention relates to a nickel-base alloy and its use in the production of castings and welded articles.

[0002] The higher the operating temperature of a gas turbine engine, the greater is its efficiency. There is consequently an ongoing effort to raise the operating temperature, with the result that many of the components of the gas turbine engine, including cast components, are pushed to ever-higher service temperatures. The metallic alloy selected for each cast component must be both castable to the required configuration in a commercially acceptable manner and also exhibit suitable mechanical properties at elevated service temperatures.

[0003] The nickel-base Alloy 718 is widely employed in aerospace and other applications to produce castings that are used at elevated service temperatures of up to about 1150°F-1200°F, and for a time which is a function of the service temperature. The primary strengthening mechanism of Alloy 718 is based upon delta (δ)-phase (Ni_3Nb) and body-centered tetragonal gamma double prime (γ'')-phase ($\text{Ni}_3(\text{Nb}, \text{Ta}, \text{Al}, \text{Ti})$) precipitation. A minor amount of ordered gamma prime (γ')-phase ($\text{Ni}_3(\text{Al}, \text{Ti})$) also precipitates, but contributes little to the mechanical properties. Alloy 718 does not have sufficient mechanical properties and microstructural stability for many higher-temperature service applications.

[0004] In conventional practice, if the cast article is to be used at higher service temperatures, alloys strengthened by a substantial amount of ordered face centered cubic gamma prime (γ')-phase precipitate are used. Examples of such alloys are Rene™ 77, Rene™ 80, Rene™ 220C, and Rene™ 125 alloys. These high-gamma-prime strengthened alloys have the necessary high-temperature mechanical performance, but they are difficult to cast in a commercially acceptable manner. The gamma-prime strengthened alloys are susceptible to surface cracking during the casting operation. The surface cracks may be removed by grinding after the casting operation, but such rework procedures are costly in the labor required and also because the casting must be made oversize and a considerable amount of material wasted. These alloys are quite expensive to purchase, and the wasted material may be a substantial fraction of the cost of the final cast article. In addition, the repair of casting defects by welding is difficult in gamma-prime-strengthened alloys due to strain age cracking. Rene™ 220C alloy is primarily γ'' strengthened, similar to Alloy 718, and capable of service at temperatures above 1200°F. However, its elemental cost is high due to the high tantalum content of about 3.2 weight percent.

[0005] In summary, alloys such as Alloy 718 exhibit good casting and welding properties but have insufficient mechanical properties and stability at service temperatures above about 1150°F-1200°F. Alloys such as Rene™ 220C, Rene™ 77, Rene™ 80, and Rene™ 125

are difficult and expensive to cast and weld, but have acceptable mechanical properties at higher service temperatures.

[0006] There is a need for an affordable nickel-base alloy that is both castable and weldable in commercial-scale production without the need for expensive rework operations during casting, and also exhibits acceptable mechanical properties at elevated service temperatures. The present invention fulfills this need, and further provides related advantages.

[0007] The present invention provides an affordable gamma double prime (γ'')-strengthened nickel-base alloy that is readily castable in commercial operations. The result is substantially lower production costs for cast articles than is possible with the gamma-prime-phase strengthened cast articles. The alloy material is also readily welded, both for repair of casting defects and for joining. The material, when processed to a cast article, exhibits excellent stability and mechanical properties at elevated service temperatures up to about 1300°F.

[0008] A composition of matter has a composition consisting essentially of, in weight percent, from about 16 percent to about 21 percent chromium, from about 6 percent to about 12 percent iron (more preferably from about 8 percent to about 9.5 percent iron, and most preferably about 9 percent iron), from about 6 percent to about 12 percent cobalt (and preferably with the total of iron and cobalt from about 17 to about 19 percent), from about 2.8 percent to about 3.3 percent molybdenum, from about 5 percent to about 5.4 percent niobium, from 0 to about 2 percent tantalum (more preferably less than about 1 percent tantalum, and most preferably less than about 0.1 percent tantalum), from about 0.65 percent to about 1.15 percent titanium, from about 0.2 percent to about 0.8 percent aluminum, from about 0.01 percent to about 0.05 percent carbon, from about 0.005 percent to about 0.01 percent boron, less than about 0.1 percent zirconium, balance nickel and impurities. In a preferred embodiment, the composition consists essentially of, in weight percent, about 18 percent chromium, about 9 percent iron, about 9 percent cobalt, about 3 percent molybdenum, about 5 percent niobium, about 0.01 percent tantalum, about 1 percent titanium, about 0.5 percent aluminum, about 0.03 percent carbon, about 0.007 percent boron, balance nickel and impurities.

[0009] A cast article is provided by first providing a molten mass of metal having this composition, and casting the molten mass of metal into a mold. The casting may be hot isostatically pressed, and post-processed as needed by approaches such as heat treating and/or machining. The casting may be weld repaired as needed, so that material wastage is reduced as compared with that experienced in other alloys that would be suitable for applications at the high service temperatures. The cast article is operable over a wide range of service temperatures, but it achieves its greatest benefits over other alloys when placed into service at a maximum service temperature of from about 1100°F to about

1300°F, inasmuch as this alloy demonstrates better metallurgical stability than Alloy 718 in this temperature range.

[0010] The castability of the present alloy is similar to that of Alloy 718 and Rene™ 220C alloy.

[0011] 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, and in which:

Figure 1 is a schematic fragmented longitudinal sectional view of a portion of a static structure of a gas turbine engine;

Figure 2 is a block flow diagram of a preferred approach for practicing the invention by casting;

Figure 3 is a block flow diagram of a preferred approach for practicing the invention by welding;

Figure 4 is a schematic sectional view of a cast and surface-welded article;

Figure 5 is a schematic sectional view of two articles welded together;

Figure 6 is a graph of ultimate tensile strength of three cast-and-wrought alloys at 1000°F and 1300°F;

Figure 7 is an idealized microstructure of cast-and-wrought Alloy 718 after stability testing; and

Figure 8 is an idealized microstructure of cast-and-wrought Alloy 991 after stability testing.

[0012] Figure 1 is a sectional view of a cast article of manufacture, illustrated as a static structure 20 in the high-pressure turbine of a gas turbine engine. The use of the present invention is not limited to this cast article of manufacture, which is presented by way of illustration and not limitation. The static structure 20 is a relatively thin-walled cast article. The static structure 20 experiences a maximum service temperature of about 1300°F, which is too high a temperature to use Alloy 718 as its material of construction. Under conventional practice the static structure 20 would be cast of a higher-temperature alloy such as Waspaloy or Rene™ 220C. However, these latter higher-temperature alloys are difficult and expensive to cast and weld, leading to excessive cost for the static structure 20.

[0013] In the present approach, the article has a composition consisting essentially of, in weight percent, from about 16 percent to about 21 percent chromium, from about 6 percent to about 12 percent iron (more preferably from about 8 percent to about 9.5 percent iron, and

most preferably about 9 percent iron), from about 6 percent to about 12 percent cobalt (but preferably with the total of iron and cobalt about 18 percent), from about 2.8 percent to about 3.3 percent molybdenum, from about 5 percent to about 5.4 percent niobium, from 0 to about 2 percent tantalum (more preferably less than about 1 percent tantalum, and most preferably less than about 0.1 percent tantalum), from about 0.65 percent to about 1.15 percent titanium, from about 0.2 percent to about 0.8 percent aluminum, from about 0.01 percent to about 0.05 percent carbon, from about 0.005 percent to about 0.01 percent boron, less than about 0.1 percent zirconium, balance nickel and impurities. In a preferred embodiment, the composition consists essentially of, in weight percent, about 18 percent chromium, about 9 percent iron, about 9 percent cobalt, about 3 percent molybdenum, about 5 percent niobium, about 0.01 percent tantalum, about 1 percent titanium, about 0.5 percent aluminum, about 0.03 percent carbon, about 0.007 percent boron, balance nickel and impurities.

[0014] These elements function cooperatively to achieve the required balance of properties and may not be individually altered without affecting the properties of the alloy as a whole.

[0015] This alloy is nickel base, having more nickel than any other element. After processing, the alloy has a microstructure including body centered tetragonal gamma double prime ($\text{Ni}_3(\text{Nb}, \text{Ta}, \text{Al}, \text{Ti})$) precipitates, which harden the nickel-base solid-solution alloy matrix.

[0016] The chromium, iron, cobalt, and molybdenum partition primarily to the nickel-base alloy matrix.

[0017] Chromium imparts oxidation and corrosion resistance to the matrix. If the chromium content is greater than the indicated maximum, alpha-chromium and sigma phase may be present to cause embrittlement. If the chromium content is less than the indicated minimum, oxidation resistance is reduced with an associated increase in time-dependent crack growth rates.

[0018] Iron is present in the matrix as a solid solution strengthening element. However, a high iron content also causes incipient melting of the alloy and accelerates the precipitation kinetics of the body centered tetragonal gamma double prime phase at elevated temperature. The reduction in iron as compared with Alloy 718 increases the solidus temperature so that the alloy is workable at a higher service temperature than Alloy 718. The iron also reduces surface cracking of the alloy by improving ductility. If the iron content is greater than the indicated maximum, incipient melting may occur with the precipitation of brittle Laves phases. Minimizing incipient melting improves the as-cast homogeneity of the cast article and also after subsequent homogenization heat treatment at a higher temperature. The result is a component with a more uniform microstructure and mechanical properties. If the iron content is less than the indicated minimum, the elemental cost increases.

[0019] Cobalt substitutes for iron in the matrix, without significantly affecting the morphology of the body cen-

tered tetragonal gamma double prime precipitate. The cobalt significantly reduces precipitation kinetics resulting in stability improvements at elevated temperature relative to Alloy 718. Preferably the cobalt plus iron totals about 17-19, preferably 18, weight percent. Previous studies on wrought material indicated reduced aging kinetics in Alloy 718.

[0020] Molybdenum is a strong solid solution hardener in the matrix. If the molybdenum content is greater than the indicated maximum, an embrittling Laves phase may precipitate. If the molybdenum content is less than the indicated minimum, matrix strength properties are insufficient.

[0021] Carbon aids in pinning grain boundaries to avoid excessive coarsening by the formation of carbides with niobium and tantalum at the grain boundaries. If the carbon content is greater than the indicated maximum, low-cycle fatigue performance suffers. If the carbon content is less than the indicated minimum, there is poor creep performance.

[0022] Boron produces borides which aid in achieving ductility at elevated temperatures. If the boron content is greater than the indicated maximum, there may be incipient melting of the borides. If the boron content is less than the indicated minimum, hot ductility is insufficient.

[0023] Under the proper processing conditions, titanium and aluminum combine with nickel primarily to form ordered face centered cubic gamma prime precipitate, denoted generally as $Ni_3(Al,Ti)$. Although the alloy is primarily strengthened by coarse body centered tetragonal gamma double prime precipitate, fine gamma prime phase also precipitates in the matrix to strengthen it.

[0024] Titanium partitions primarily to the gamma prime and gamma double prime precipitates. If the titanium content is greater than the indicated maximum, a needle-like eta phase (Ni_3Ti) may precipitate leading to embrittlement. If the titanium content is less than the indicated minimum, the strengthening gamma prime and gamma double prime precipitates may be less effective and oxidation resistance suffers.

[0025] Aluminum partitions primarily to the gamma prime and gamma double prime phases. If the aluminum content is greater than the indicated maximum, too much gamma prime phase may form, leading to a reduction in malleability and ductility. If the aluminum content is less than the indicated minimum, little or no gamma prime phase precipitates and oxidation resistance is reduced.

[0026] Under the proper processing conditions, niobium combines with nickel, tantalum, aluminum, and titanium to form the body centered tetragonal gamma double prime precipitate. If the niobium content is greater than the indicated maximum, there is unacceptable macrosegregation which adversely affects malleability and mechanical properties. If the niobium content is less than the indicated minimum, the result is insufficient stability at elevated temperature resulting in reduced

strength over time.

[0027] Tantalum is optionally present in an amount of from 0 to about 2 percent. It is desirable that the body centered tetragonal gamma double prime precipitate be more thermodynamically stable in the present alloy at the elevated service temperatures than it is in Alloy 718. Tantalum is a large atom which participates in the formation of the body centered tetragonal gamma double prime phase. Tantalum also diffuses slowly so that the resulting body centered tetragonal gamma double prime phase is more thermodynamically stable when tantalum is present than when it is absent. However, if tantalum is present in an amount of more than about 2 percent, there is macrosegregation similar to that experienced with excessive niobium and there is an excessive increase in elemental costs. Solidification of the present alloy results in tantalum-lean features which can control the material properties. Therefore, a cost-effective variant of the alloy with little or no tantalum content is of interest. The very slow diffusivity of tantalum minimizes the reduction of tantalum segregation even at the higher processing temperatures.

[0028] It is sometimes the case in describing nickel-base alloys that the sum of niobium plus tantalum, $Nb+Ta$, is expressed. There is an implicit suggestion in such an expression that the niobium and tantalum may substitute for each other without significant effect on the final properties of the alloy. That is not the case in the present composition. The niobium and the tantalum must each individually be within the limits discussed herein.

[0029] Figure 2 depicts an approach for preparing and using an article such as the static structure 20. A molten mass of metal having the compositions indicated herein is provided, numeral 30. The molten mass is typically melted by a technique that minimizes inclusions and oxides, preferably vacuum induction melting, although the present approach is not limited to this melting technique.

[0030] The molten mass of metal is thereafter cast into a mold, numeral 32. The preferred casting technique is investment casting, although the present approach is not limited to this technique. As a part of the casting step 32, the casting may be hot isostatically pressed (HIPped) as needed to close porosity. A preferred hot isostatic pressure procedure is to heat the casting to a temperature of 2000-2100°F, preferably about 2050°F, with a pressure of about 15,000 pounds per square inch and a pressing time of about 14 hours.

[0031] The casting is thereafter optionally post-processed as necessary, step 34. Post processing may include weld repair of defects, step 36, heat treatment, step 38, machining, step 40, and other post-processing as may be required. These steps 36, 38, and 40, and the optional hot isostatic pressing, may be performed in any order or with portions of any step intermixed with other post-processing steps.

[0032] The present alloy composition is also readily welded in step 36 or otherwise, in addition to its excellent

castability. The weld repairability of a casting significantly improves the casting yield. Figure 3 depicts an approach for welding the alloy, and Figures 4-5 depict welded structures. A piece 60 of the alloy discussed previously is provided, numeral 50. The piece 60 of the alloy may be an as-cast piece, as illustrated in Figure 4, or otherwise. For example, the piece 60 of the alloy may be that produced at the conclusion of any of the steps 30, 32, 38, or 40 of the method of Figure 2, or it may be produced by any other operable approach. The piece 60 is welded, numeral 52. The welding may be accomplished, numeral 52, by any operable approach, with or without a filler metal. Where used, the filler metal is preferably but not necessarily of the same composition as the piece 60.

[0033] Examples of operable welding approaches are plasma welding and TIG welding. In Figure 4, surface cracks 62 in the single piece 60 of the alloy are welded closed with a filler metal of the same alloy composition as the piece 60, to produce a filled crack 64. This approach is used to repair those surface cracks 62 that are present following casting. In Figure 5 the piece 60 is welded to a second piece 66 at a weld joint 68 of the filler metal. The second piece 66 may be the same composition as the piece 60, or a different composition. After welding, the article is optionally post-processed, numeral 54, such as by heat treating or machining. An example of a heat treatment is to repeat the original solution and age cycles discussed above.

[0034] In the heat treatment 38, the casting is heated to very near the solidus temperature of the alloy, typically about 2000-2100°F, to homogenize the material. The homogenization is followed by a solution heat-treating cycle above the gamma-double prime solvus in the vicinity of the delta solvus, typically at a temperature of about 2000°F, and final aged, typically at a temperature of about 1400°F, to precipitate the gamma double prime phase and a minor amount of the gamma prime phase to achieve the desired mechanical properties.

[0035] The cast article is placed into service, numeral 42. The article produced by the present approach may be used at room and intermediate temperatures, but its greatest benefits are realized when it is used for extended service at higher temperatures than possible with Alloy 718, such as from about 1150°F to about 1300°F.

[0036] An as-cast-and-wrought embodiment of the present invention has been reduced to practice and comparatively evaluated with Alloy 718 and Waspaloy, the closest competitive alloys. As discussed earlier, Alloy 718 has excellent castability and weldability, but insufficient mechanical properties above about 1150°F. Waspaloy has good mechanical properties up to about 1300°F, but is castable and weldable only with difficulty.

[0037] In the reduction to practice and the comparative testing, the present cast-and-wrought alloy, denominated Alloy 991 in the testing, had a nominal composition, in weight percent, of about 17.84 percent chromium, about 9.03 percent cobalt, about 8.93 percent iron,

about 2.97 percent molybdenum, about 5.15 percent niobium, about 0.99 percent tantalum, about 0.99 percent titanium, about 0.48 percent aluminum, about 0.033 percent carbon, about 0.007 percent boron, less than about 0.01 percent zirconium, balance nickel and impurities. The "991" nomenclature is based on the composition of the alloy of about 9 percent cobalt, about 9 percent iron, and about 1 percent tantalum.

[0038] The cast-and-wrought Alloy 718 had a nominal composition, in weight percent, of about 17.86 percent chromium, about 0.01 percent cobalt, about 18.06 percent iron, about 2.99 percent molybdenum, less than about 0.01 percent tungsten, about 0.03 percent copper, about 5.28 percent niobium, less than about 0.01 percent manganese, about 0.02 percent vanadium, less than about 0.01 percent tantalum, about 0.99 percent titanium, about 0.49 percent aluminum, about 0.03 percent carbon, less than about 0.1 percent zirconium, balance nickel and impurities.

[0039] The Waspaloy baseline material had a nominal composition, in weight percent, of about 19.02 percent chromium, about 13.13 percent cobalt, about 0.55 percent iron, about 4.18 percent molybdenum, about 0.01 percent niobium, about 0.02 percent tantalum, less than about 0.01 percent tungsten, less than about 0.01 percent copper, about 0.01 percent manganese, about 0.01 percent vanadium, less than about 0.01 percent silicon, about 2.98 percent titanium, about 1.41 percent aluminum, about 0.03 percent carbon, less than about 0.06 percent zirconium, balance nickel and impurities.

[0040] In casting and weldability trials, the wrought Alloy 991 and the Alloy 718 had excellent castability and weldability, evaluated qualitatively. The Waspaloy baseline alloy was difficult to cast and weld, and showed extensive surface cracking during casting.

[0041] The alloys were tensile tested at 1000°F and 1300°F, and the results are shown in Figure 6. The Alloy 991 achieved the best performance of the three alloys at 1300°F.

[0042] The alloys were tested in creep at 1200°F and 98,000 pounds per square inch load. The accepted measure of performance is the time to creep to 0.2 percent strain, with longer times being better. The Alloy 718 had creep times ranging from 40 to 105 hours. The Alloy 991 had creep times ranging from 155 to more than 210 hours (testing was terminated at 210 hours). The Waspaloy had creep times ranging from 155 to more than 215 hours (testing was terminated at 215 hours). The Alloy 718 is not suitable for service at this temperature, while the Alloy 991 had properties comparable with those of Waspaloy.

[0043] The thermodynamic stability of the alloys at the required service temperatures is an important consideration. To evaluate the thermodynamic stability, specimens were subjected to creep loading at 1200°F for 212 hours at a loading of 98,000 pounds per square inch, and thereafter exposed to a temperature of 1400°F for 100 hours. The specimens were thereafter tensile test-

ed at 1300°F. Comparison specimens were not subjected to the creep testing and exposure at 1400°F, but were tensile tested at 1300°F. In each case, the UTS ratio is the ratio of the ultimate tensile strength of the exposed specimens to the ultimate tensile strength of the unexposed specimens. The YS ratio is the ratio of the 0.2 percent yield strength of the exposed specimens to the 0.2 percent yield strength of the unexposed specimens. A ratio of close to 1 is desirable in each case. For the Alloy 718, the UTS ratio is about 0.8, and the YS ratio is about 0.66. For the Alloy 991, the UTS ratio is about 0.91, and the YS ratio is about 0.87. For the Waspalloy, the UTS ratio is about 1.05, and the YS ratio is about 1.04. Alloy 718 has significant degradation of properties in this test, Alloy 991 has moderate but acceptable degradation of properties, and Waspalloy actually has an improvement in properties.

[0044] The specimens in the stability testing were inspected metallographically, and Figures 7 and 8 show the microstructures of Alloy 718 and Alloy 991 respectively. The Alloy 718 has extensive degradation by precipitation of delta-phase platelets 80, while the Alloy 991 shows some very slight but acceptable precipitation of delta-phase platelets 80.

[0045] It is believed that the unique combination of good castability and weldability and also acceptable mechanical properties in the range of about 1150°F to about 1300°F of the present material is based on its quaternary Ni-Cr-Fe-Co alloying chemistry and the resulting precipitation kinetics. This quaternary alloying chemistry is, in turn, based on the balance of cobalt and iron, and additionally on the presence of the optional small amount of tantalum. As indicated, the high cost of tantalum requires that a tantalum-lean or tantalum-free variant be considered. The mechanical behavior of the casting derives far less benefit by tantalum additions due to dendritic segregation. Even with the benefit of higher thermal exposure during homogenization cycles, the ability to diffuse tantalum to the dendritic core is expected to be marginal.

[0046] This alloy utilizes the gamma double prime phase of the ternary Ni-Fe-Cr system as the basis of its quaternary Ni-Cr-Fe-Co strengthening phase but overages much slower than a Ni-Fe-Cr alloy such as Alloy 718 due in part to the presence of the optimal amount of tantalum, although the impact of lower iron in the presence of cobalt is expected to have the most significant technical impact on metallurgical stability. The Alloy 718 tends to overage rapidly and has poor creep strength at higher temperatures. Ternary Ni-Cr-Co alloys such as Waspalloy are strengthened by the ordered face centered cubic gamma prime phase. This strengthening mechanism imparts improved creep properties with slower overaging at elevated temperatures, but the alloys have limited castability and limited weldability due to strain age cracking caused by rapid re-precipitation of gamma prime during solidification and post-weld heat treatment. The slower aging kinetics of the present

Ni-Cr-Fe-Co alloys results in less brittleness during casting and welding operations than experienced in ternary Ni-Cr-Co alloys, but sufficient strength is achieved for the service temperatures and the strengthening precipitate is relatively stable.

[0047] For completeness, various aspects of the invention are set out in the following numbered clauses:

1. A method of preparing a welded article (60), comprising the steps of:

providing a piece of material having a composition consisting essentially of, in weight percent, from about 16 percent to about 21 percent chromium, from about 6 percent to about 12 percent iron, from about 6 percent to about 12 percent cobalt, from about 2.8 percent to about 3.3 percent molybdenum, from about 5 percent to about 5.4 percent niobium, from 0 to about 2 percent tantalum, from about 0.65 percent to about 1.15 percent titanium, from about 0.2 percent to about 0.8 percent aluminum, from about 0.01 percent to about 0.05 percent carbon, from about 0.005 percent to about 0.01 percent boron, less than about 0.1 percent zirconium, balance nickel and impurities; and welding the piece of material to form the welded article (60).

2. The method of clause 1, including an additional step, after the step of welding, of heating treating the welded article (60).

3. The method of clause 1, wherein the step of providing includes the step of providing the piece of cast material.

4. The method of clause 1, wherein the step of welding includes the step of surface welding the piece of material.

5. The method of clause 1, wherein the step of welding includes the step of joining the piece of material to a second piece of material.

Claims

1. A composition of matter having a composition consisting essentially of, in weight percent, from about 16 percent to about 21 percent chromium, from about 6 percent to about 12 percent iron, from about 6 percent to about 12 percent cobalt, from about 2.8 percent to about 3.3 percent molybdenum, from about 5 percent to about 5.4 percent niobium, from zero to about 2 percent tantalum, from about 0.65 percent to about 1.15 percent titanium, from about 0.2 percent to about 0.8 percent aluminum, from

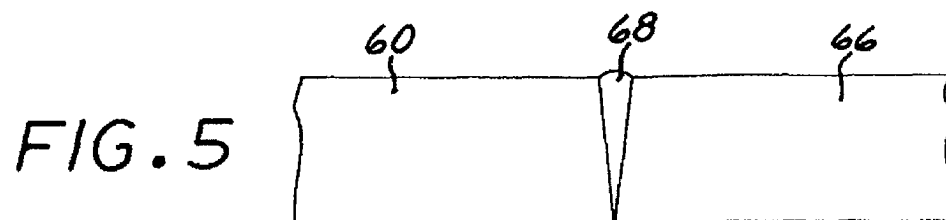
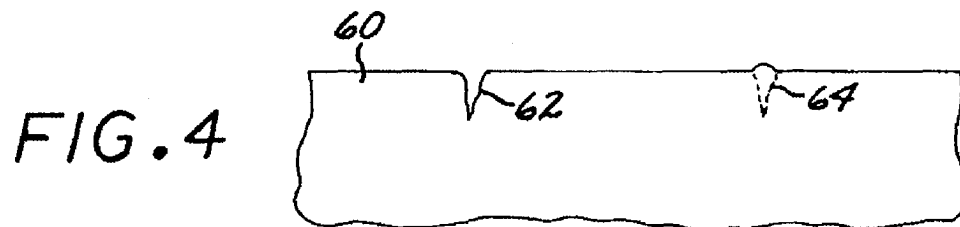
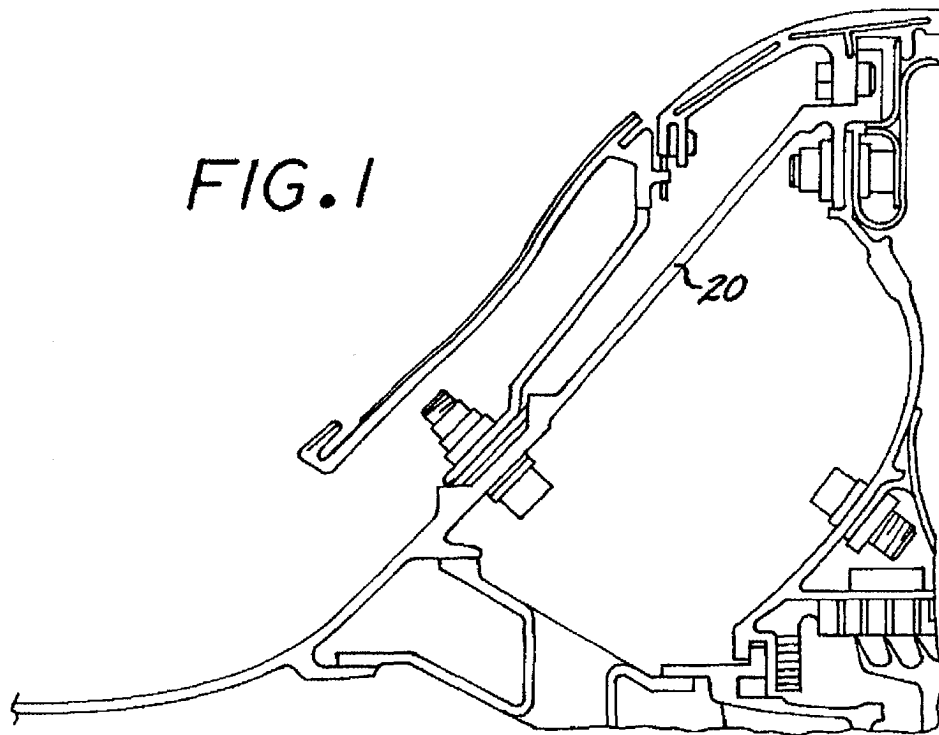
about 0.01 percent to about 0.05 percent carbon, from about 0.005 percent to about 0.01 percent boron, less than about 0.1 percent zirconium, balance nickel and impurities.

2. The composition of matter of claim 1, wherein the tantalum content is less than about 1 percent.
3. The composition of matter of claim 1, wherein the total of iron plus cobalt is from about 17 to about 19 percent.
4. The composition of matter of claim 1, wherein the iron content is from about 8 percent to about 9.5 percent.
5. The composition of matter of claim 1, wherein the chromium content is about 18 percent, the iron content is about 9 percent, the cobalt content is about 9 percent, the molybdenum content is about 3 percent, the niobium content is about 5 percent, the tantalum content is less than about 0.01 percent, the titanium content is about 1 percent, the aluminum content is about 0.5 percent, the carbon content is about 0.03 percent, and the boron content is about 0.007 percent.
6. A method of providing a cast article (20), comprising the steps of:
 - providing a molten mass of metal having a composition consisting essentially of, in weight percent, from about 16 percent to about 21 percent chromium, from about 6 percent to about 12 percent iron, from about 6 percent to about 12 percent cobalt, from about 2.8 percent to about 3.3 percent molybdenum, from about 5 percent to about 5.4 percent niobium, from 0 to about 2 percent tantalum, from about 0.65 percent to about 1.15 percent titanium, from about 0.2 percent to about 0.8 percent aluminum, from about 0.01 percent to about 0.05 percent carbon, from about 0.005 percent to about 0.01 percent boron, less than about 0.1 percent zirconium, balance nickel and impurities; and
 - casting molten mass of metal into a mold to form the cast article (20).
7. The method of claim 6, including an additional step, after the step of casting, of hot isostatic pressing the cast article (20).
8. The method of claim 6, including an additional step, after the step of casting, of heat treating the cast article (20).
9. The method of claim 6, wherein the step of providing the billet includes the step of

providing the billet having an iron content of from about 8 percent to about 9.5 percent.

10. A method of preparing a welded article (60), comprising the steps of:

providing a piece of material having a composition consisting essentially of, in weight percent, from about 16 percent to about 21 percent chromium, from about 6 percent to about 12 percent iron, from about 6 percent to about 12 percent cobalt, from about 2.8 percent to about 3.3 percent molybdenum, from about 5 percent to about 5.4 percent niobium, from 0 to about 2 percent tantalum, from about 0.65 percent to about 1.15 percent titanium, from about 0.2 percent to about 0.8 percent aluminum, from about 0.01 percent to about 0.05 percent carbon, from about 0.005 percent to about 0.01 percent boron, less than about 0.1 percent zirconium, balance nickel and impurities; and welding the piece of material to form the welded article (60).



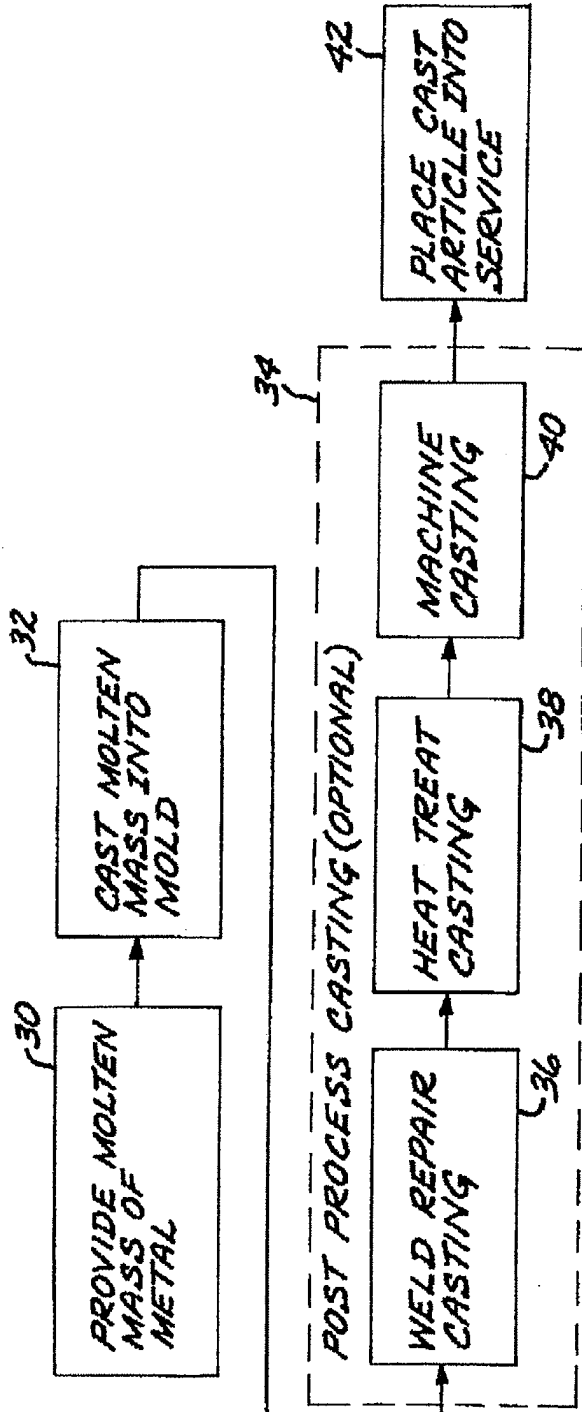


FIG. 2

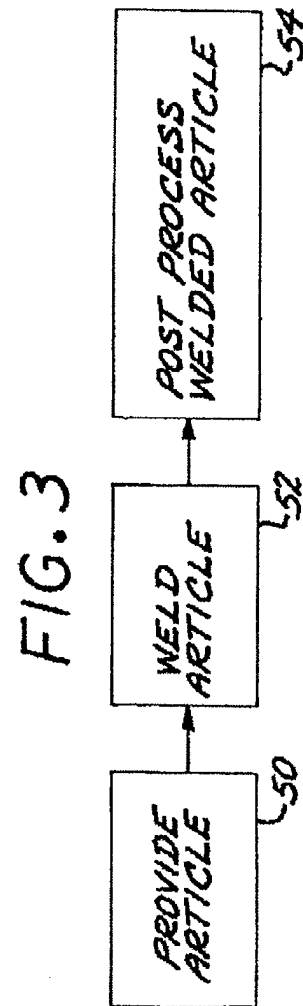


FIG. 3

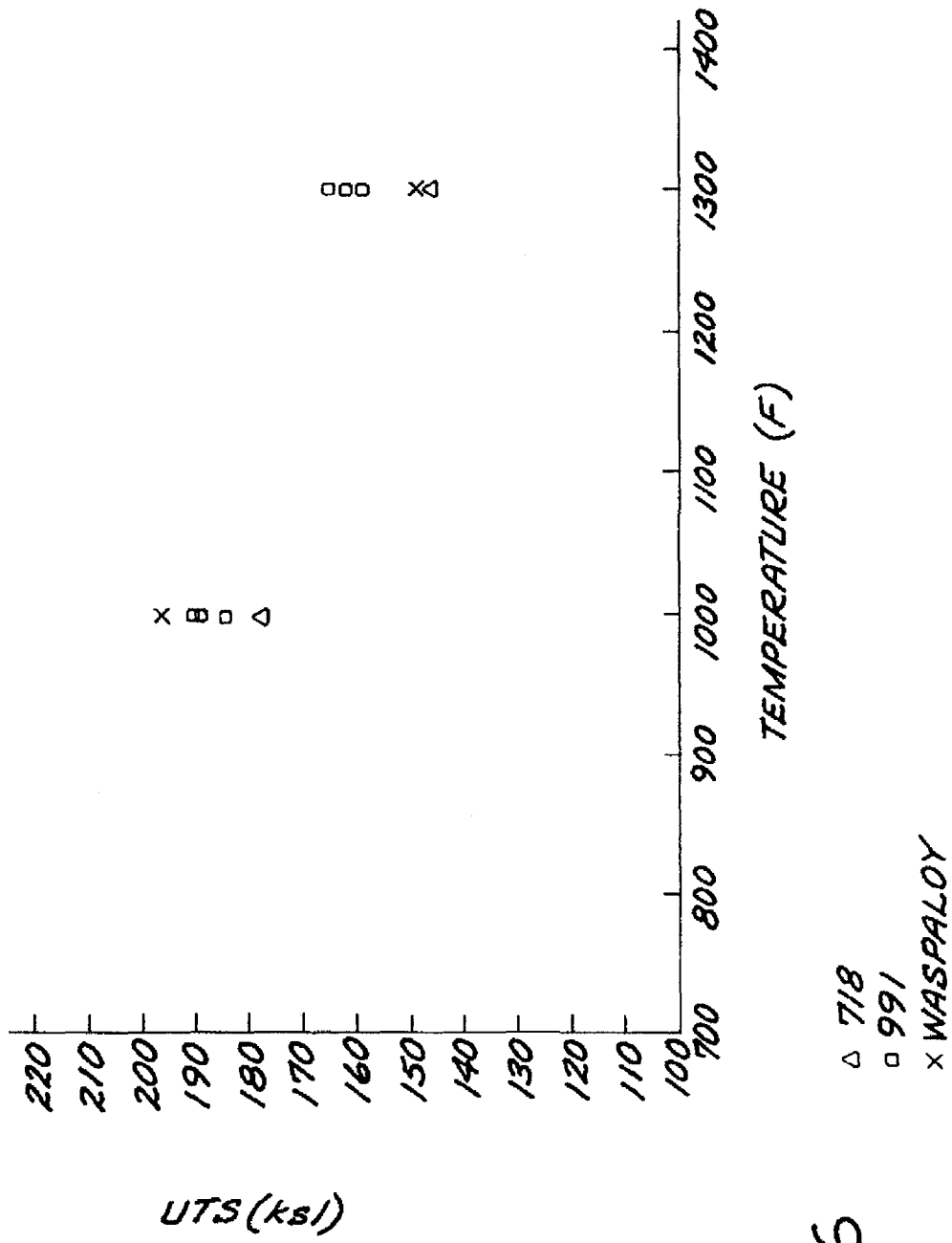


FIG. 6

FIG. 7

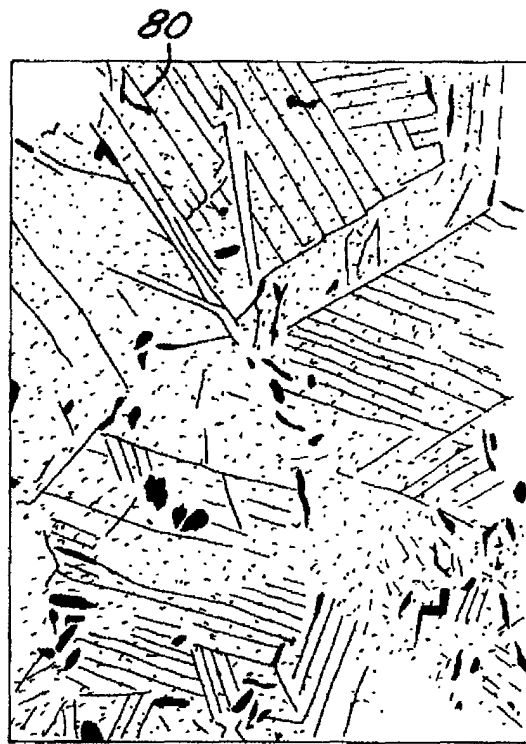


FIG. 8

