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(54) Ni based superalloy and its use as gas turbine disks, shafts and impellers

Ni-basis-Superlegierung und ihre Verwendung als Gasturbinen-Scheiben, -Wellen und -Laufräder

Superalliage à base Ni et son utilisation comme disques, arbres et rotors de turbines à gaz

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Description

[0001] This invention relates to a superalloy having nickel as the major component, and, more particularly, to such a superalloy particularly useful in the production of gas turbine disks, impellers, and shafts by powder metallurgy techniques.

[0002] In a gas turbine (jet) engine, air is drawn into the front end of the engine, compressed by a shaft-mounted compressor disk, and mixed with fuel. The mixture is ignited, producing a hot exhaust gas that is passed through a turbine which provides the power to the compressor, and then exhausted rearwardly to drive the engine and the aircraft, in which it is mounted, forwardly. In the axial flow jet engine, the turbine has a turbine disk which is mounted to a drive shaft, and turbine blades extending from the periphery of the turbine disk. The compressor disk is mounted to its shaft, which is driven by the turbine shaft.

[0003] The turbine disk must carry high multiaxial loads in tension, and must exhibit good creep resistance and dwell fatigue capability as well as good fracture toughness. Turbine disks for use at moderately high temperatures have in the past typically been forged, which tends to produce a degree of anisotropy in the disk. As the operating temperatures have been increased through improvements in alloy compositions, other fabrication techniques have been developed.

[0004] In one currently used approach, the alloy material of construction is provided in the form of fine powders. These powders are compacted together in the form of the turbine disk or shaft, usually by extrusion and isothermal forging, and then heat treated and final machined as necessary. The final article is largely isotropic due to the use of the powders, and has properties determined by the composition of the powder particles and the heat treatment.

[0005] Although operable compositions and techniques are available for producing turbine disks, turbine shafts, compressor impellers, and other articles by this approach, there is always a need for improvements which yield improved properties in the final article. In particular, there is a need for compositions that simultaneously result in reduced dwell fatigue crack growth rates and increased creep times to specified deformations. The present invention fulfills this need, and further provides related advantages.

[0006] US-A-5120373 discloses a process for producing a fine grain forged superalloy article having a high yield strength at intermediate temperatures. A preferred starting composition comprises, by weight, 15% Cr, 13.6%Co, 4.1% Mo, 4.6% Ti, 2.2% Al, 0.01 % C, 0.007%B, 0.07%Zr, balance Ni. This material is forged at a temperature above the gamma prime solvus temperature and a truestrain of at least 0.5. Alternatively the material may be forged below the gamma prime solvus.

[0007] EP-A-0373298 discloses a composition consisting of, in weight percent, 12-18 Co, 7-13 Cr, 2-4 Mo, 0-1.0 W, 2.0-5.0 Al, 5.0-7.0 Ti, 2.0-3.2 Ta, 1.0-1.7 Nb, 0-0.75 Hf, 0-0.1 Zr, 0.0-2.0 V, 0-0.2 C, 0-0.1 B, 0-1.0 Re, 0-0.1 Y, balance Ni.

[0008] EP-A-0849370 discloses a nickel base superalloy article having a machined surface having a composition in weight percent, 1.2-3.5 Al, 3.0-7.0 Ti, 12.0-20 Cr, 2.0-3.9 Mo, 10.0-20.0 Co, 1-4.5 W, 0.005-0.025 C, 0.005-0.05 B, 0.01-0.1 Zr, 0-0.005 Mg, 0-1.0 Ta, 0-1.0 Nb, 0-2.0 Fe, 0-0.3 Hf, 0-0.02 Y, 0-0.1 V, 0-1.0 Re, balance Ni. The article has a plurality of discrete carbides essentially free from molybdenum, for increased fatigues strength.

SUMMARY OF THE INVENTION

[0009] The present invention provides compositions of matter, articles using the compositions of matter, and processing methods for the compositions of matter that achieve improved combinations of properties in conditions experienced in aircraft gas turbine disk and shaft applications. Both dwell fatigue crack growth rate and time to creep specific amounts or elongation are improved as compared with other alloys used for these applications. This combination of improved properties is particularly advantageous for use in aircraft engines which are not operated at the temperatures required for advanced military fighter engines but which spend long periods at moderately elevated temperature in cruise conditions. The selected compositions reflect careful balancing of the amounts of both the major and minor elements.

[0010] A composition of matter consists of, in weight percent, from 16 percent to 20 percent cobalt, from 11 percent to 15 percent chromium, from 2 percent to 4 percent tantalum, from 0.5 to 3 percent tungsten, from 3 to 5 percent molybdenum, from 0.015 to 0.15 percent zirconium, from 1 to 3 percent niobium, from 2.6 to 4.6 percent titanium, from 2.6 to 4.6 percent aluminum, from 0 to 2.5 percent rhenium, from 0 to 2 percent vanadium, from 0 to 2 percent iron, from 0 to 2 percent hafnium, from 0 to 0.1 percent magnesium, from 0.015 to 0.1 percent carbon, from 0.015 percent to 0.045 percent boron, balance nickel and impurities. The ratio (percent zirconium + percent boron)/percent carbon is greater than 1.0.

[0011] The compositions of the invention are prepared in powder form, and processed into articles by combinations of extrusion, hot isostatic pressing, isothermal forging, heat treating, and other operable techniques. The preferred articles made with these compositions are turbine and compressor disks and shafts, and compressor impellers for gas turbine engines. The articles may be heat treated, either by solution treating and ageing or by solution treating followed by a controlled cooling to below the solvus temperature to control residual stresses.

[0012] The articles made according to the invention exhibit a combination of low dwell fatigue crack growth rate and long creep times that are unexpectedly improved over prior materials used for the same applications. Specifically, the articles have properties described by log D $\leq 1.35 \log t - 11.05$, wherein D is the dwell fatigue crack growth rate in inches per second at 704°C (1300°F) of a surface flaw specimen under loading, wherein the ratio R of the minimum load to the maximum load is 0.1 and the maximum stress intensity K_{max} = 30 KSI $(inch)^{1/2}$, and wherein t is the time in hours for a standard tensile specimen to creep 0.2 percent at 649°C (1200°F) and 793 MPa (115 Ksi) in tensile loading.

[0013] The compositions, articles, and methods of the present invention result in improved dwell fatigue crack growth rate and creep properties, while retaining acceptable density and other physical and mechanical properties. This combination of properties is particularly advantageous for use in turbine disk applications in advanced civilian aircraft engines, where the engine has an extended operating cycle at elevated temperature, but where the temperature requirements of the engine are not as great as in military aircraft. 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. The scope of the invention is not, however, limited to this

preferred embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014]

Figure 1A is a perspective view of a turbine disk for a gas turbine, sectioned to show the cross-sectional shape of the turbine disk;

Figure 1B is a perspective view of a gas turbine compressor impeller, with a portion broken away to illustrate the structure;

Figure 2 is a perspective view of a shaft for a gas turbine;

Figure 3 is a block flow diagram of a method of practicing the invention;

Figure 4 is a graph of time to creep for various test alloys;

Figure 5 is a graph of crack growth rate as a function of the ratio of (boron + zirconium)/carbon; and

Figure 6 is a graph of dwell fatigue crack growth rate as a function of time to creep 0.2 percent.

DETAILED DESCRIPTION OF THE INVENTION

[0015] The approach of the present invention may be used to fabricate a wide range of articles. Figure 1A shows a turbine disk 20, Figure 1B shows a compressor impeller 22, and Figure 2 shows a turbine shaft 24 used in a gas turbine engine, each of which may be made by the approach of the invention. A compressor disk has an appearance which is generally similar to that of a turbine disk, and a compressor shaft has an appearance which is generally similar to that of a turbine shaft. Collectively, the turbine disks and compressor disks are termed "gas turbine disks", and the turbine shafts and compressor shafts are termed "gas turbine shafts".

[0016] Figure 3 depicts a method of fabricating articles such as those of Figures 1 and 2. A metallic composition of matter is furnished, numeral 30. The composition of matter of the present invention is, in weight percent, from 16 percent to 20 percent cobalt, from 11 percent to 15 percent chromium, from 2 percent to 4 percent tantalum, from 0.5 to 3 percent tungsten, from 3 to 5 percent molybdenum, from 0.015 to 0.15 percent zirconium, from 1 to 3 percent niobium, from 2.6 to 4.6 percent titanium, from 2.6 to 4.6 percent aluminum, from 0 to 2.5 percent rhenium, from 0 to 2 percent vanadium, from 0 to 2 percent iron, from 0 to 2 percent hafnium, from 0 to 0.1 percent magnesium from 0.015 to 0.1 percent carbon, from 0.015 percent to 0.045 percent boron, balance nickel and impurities.

[0017] This alloy composition produces a gamma/gamma prime microstructure, which may be controlled through heat treatments, with minor amounts of other phases present such as borides and carbides. The gamma prime phase is present in an amount, based on calculation, of from 47 to 55 volume percent of the total volume of the material, in order to produce the desirable properties of the alloy.

[0018] The types and amounts of the elements in the alloy composition are chosen in cooperation with each other to achieve the desired properties, based upon testing and the analysis undertaken by the inventors. Due to the interaction between the elements, the experimental compositions defined the trends for alloying, but only limited ranges of alloy compositions exhibit the final effects of compositional influences, microstructures, and resulting properties. Together the alloying trends and the absolute elemental levels define the preferred ranges of compositions. The effects of individual elements and the results of their amounts in the alloys falling outside the indicated ranges may be summarized as follows.

[0019] The cobalt level is selected to control the gamma prime solvus temperature. Increasing amounts of cobalt lower the gamma prime solvus temperature, which is desirable to achieve a large processing temperature range and reduce the stresses induced by controlled cooling or quenching of the alloy used to define a portion of the gamma prime distribution and the preferred combination of mechanical properties. If the amount of cobalt is substantially less than that indicated, the gamma prime solvus temperature is too high and there is a risk of incipient melting or thermally induced porosity. If the cobalt content is substantially greater than that indicated, the alloy has an undesirably higher elemental cost.

[0020] The presence of chromium is beneficial to oxidation resistance, corrosion resistance, and fatigue crack growth resistance. If the amount of chromium present is substantially less than that indicated, these properties may suffer. If it is substantially more than that indicated, there may be alloy, chemical, or phase instability during extended exposure to elevated temperatures, and creep performance suffers.

[0021] The control of the refractory elements tantalum, tungsten, niobium, and molybdenum is important to achieving the balance required in the alloy and articles of the invention.

[0022] Tantalum, whose presence and percentage content of tantalum is important to achieving the beneficial results obtained for the alloys of the invention, primarily enters the gamma-prime phase and has the effect of improving the stability of the gamma-prime phase and improving the creep resistance and fatigue crack growth resistance of the alloy. If the tantalum content is substantially lower than these amounts, the creep life of the alloy is reduced and the dwell fatigue crack growth resistance is insufficient. Increasing the tantalum substantially above the indicated amounts has the undesirable effect of raising the gamma-prime solvus temperature so as to reduce the processibility of the alloy and increase its density.

[0023] Tungsten and niobium are two relatively dense elements which function together to achieve synergistic positive results with respect to creep capability. Figure 4 shows the time for a standard tensile specimen to creep to 0.2 percent elongation at 649°C (1200°F) and under a load of 793 MPa (115,000 pounds per square inch), With less than 0.5 weight percent tungsten and less than 1 weight percent niobium, or with one or the other of the two elements present but not both, the creep properties are relatively poor. If both tungsten and niobium are present above these indicated minimum limits, the creep properties are markedly better.

[0024] Tungsten enters the matrix as a solid-solution strengthening element, and also aids in forming gamma prime precipitates. If the amount of tungsten is substantially less than that indicated, the creep properties may be insufficient. However, tungsten is relatively dense and also can lead to notch sensitivity and chemical instability. If the amount of tungsten is substantially greater than that indicated, the density of the alloy is too high, and, in addition, notch sensitivity is enhanced and chemical instability is of concern.

[0025] If the amount of niobium is substantially less than that indicated, the creep and tensile properties may be insufficient. However, niobium is relatively dense and also can lead to notch sensitivity, chemical instability, and loss of dwell fatigue crack growth capability. If the amount of niobium is substantially greater than that indicated, the density of the alloy is too high, and, in addition, notch sensitivity is enhanced and chemical instability and reduced dwell fatigue crack growth capability are of concern.

[0026] Molybdenum is another relatively dense refractory element that partitions primarily to the gamma phase and has a beneficial effect on creep capability. If the amount of molybdenum is substantially less than 3 weight percent, the creep capability of the material may be reduced below desirable levels. If the amount of molybdenum is greater than about 5 weight percent, alloy stability is reduced and alloy density is increased above the desired level.

[0027] Titanium is a relatively light element and therefore may be added more freely to the alloy, from a density standpoint, to contribute to gamma prime formation. If titanium is present in an amount substantially less than that indicated, the tensile and dwell fatigue crack growth properties may be insufficient. If titanium is present in an amount substantially greater than that indicated, the heat treat window may be unacceptably reduced because the gamma prime solvus temperature is raised excessively. Substantially greater titanium levels may also stabilize or produce undesirable phases such as eta phase, which ties up the titanium and prevents it from participating in the production of the desired gamma prime microstructure.

[0028] Aluminum is present to contribute to gamma prime phase formation and to promote gamma prime phase stability. Aluminum is the lowest-density gamma prime forming element and offsets the presence of higher-density elements. If aluminum is present in an amount substantially less than or greater than that indicated, then too little or too much of the gamma prime phase is present, and the stability of the alloy is adversely affected.

[0029] Carbon is present to aid in controlling grain size of the alloy. If the carbon content is substantially less than that indicated, the grain size of the alloy tends to grow too large, particularly during supersolvus processing. However, if the carbon content is substantially greater than that indicated, the carbon may have an adverse effect on the fracture properties of the alloy through premature failure. The higher carbon content also adversely affects the dwell fatigue crack growth resistance and creep capability.

[0030] Boron in moderate amounts improves the dwell fatigue crack growth resistance. If the boron is substantially less than that indicated, the alloy has insufficient dwell fatigue crack growth resistance. However, boron in an amount substantially greater than that indicated tends to cause residual porosity or thermally induced porosity and incipient melting during processing, and to reduce creep capability.

[0031] Zirconium is present in an amount of from 0.015 percent to 0.15 percent, more preferably from 0.35 to 0.055 percent, and most preferably from 0.04 to 0.05 percent. The presence of zirconium in controlled small amounts improves the elongation and ductility of the alloy, and also reduces the crack growth rate. Zirconium in amounts substantially in excess of the indicated levels tends to increase the creep rate of the alloy.

[0032] The ratio (percent zirconium + percent boron)/percent carbon is greater than 1.0. As this ratio increases, the dwell fatigue crack growth rate decreases. As shown in Figure 5, for lesser values of this ratio, the dwell fatigue crack growth rate increases to an unacceptably high value of more than about 25.4 nm (10^{-6} inches) per second in testing at 704°C (1300°F) at a maximum stress intensity K_{max}=207 MPa $(2.54\ cm)^{1/2}$ (K_{max} of 30 KSI $(inch)^{1/2}$)

[0033] Several other elements may optionally be added in limited amounts without adversely affecting the properties of the resulting composition. For example, rhenium in an amount up to 2.5 percent by weight, magnesium in an amount up to 0.1 percent by weight, vanadium in an amount up to 2 percent by weight, iron in an amount up to 2 percent by weight, and hafnium in an amount up to 2 percent by weight may be present without adversely affecting the properties. The hafnium may improve the dwell fatigue crack growth rate but with a slight negative effect on low cycle fatigue.

[0034] There are several preferred compositional embodiments of particular interest. A specific most preferred alloy, termed alloy ME1-16, has a composition of, in weight percent, 18.2 percent cobalt, 13.1 percent chromium, 2.7 percent tantalum, 1.9 percent tungsten, 3.8 percent molybdenum, 0.050 percent zirconium, 1.4 percent niobium, 3.5 percent titanium, 3.5 percent aluminum, 0.030 percent carbon, 0.030 percent boron, balance nickel and impurities.

[0035] Another specific most preferred alloy has a composition, in weight percent, of 20 percent cobalt, 13 percent chromium, 2 percent tantalum, 2 percent tungsten, 3.8 percent molybdenum, 0.050 percent zirconium, 1.2 percent niobium, 3.7 percent titanium, 3.7 percent aluminum, 0.05 percent carbon, 0.03 percent boron, balance nickel and impurities.

[0036] The advantageous results attained with the present compositions are a result of the selection of the combination of elements, not any one element in isolation. The more preferred and most preferred compositions yield progressively improved results than the broad composition within the operable range, but it is also possible to attain improved results by combining the narrowed composition ranges of some elements producing improved results with the broader composition ranges of other elements.

[0037] The alloy composition is formed into a powder, numeral 32, by any operable technique. Gas or vacuum atomization is preferred. The powder particles are preferably finer than -60 mesh, and most preferably -140 mesh or -270 mesh.

[0038] The powder is consolidated to a billet or forging preform shape and then subsequently deformed to a final shape, numeral 34. The preferred approach to consolidation is extrusion processing at an extrusion temperature of from 1010°C (1850°F) to 1107°C (2025°F), and a 3:1 to 6:1 extrusion ratio. After consolidation to a billet or forging preform shape, the alloy is deformed to a shaped contour oversize to, but approximating the outline of, the final part. The deformation step is preferably accomplished by isothermal forging in a strain-controlled mode.

[0039] The consolidation, deformation, and a subsequent supersolvus solution heat treatment are preferably selected to yield a grain size of from ASTM 2 to ASTM 8, preferably from ASTM 5 to ASTM 8. For less demanding applications, the consolidation, deformation, and a subsequent subsolvus solution heat treatment are selected to yield a grain size of from ASTM 9 to ASTM 12, preferably from ASTM 10 to ASTM 12.

[0040] The extruded article is heat treated, numeral 36, to produce the desired microstructure. In a preferred heat treating approach, the article is solution heat treated by heating to a supersolvus temperature, such as from 1149°C (2100°F) to 1218°C (2225°F) for a period of time sufficient that the entire article reaches this temperature range. The solution-treated article is quenched (cooled) to room temperature by a fan air cool, optionally followed by an oil quench. The solution-treated-and-quenched article is then aged by reheating to a temperature below the solvus temperature, preferably from 732°C (1350°F) to 816°C (1500°F) for a time of about 8 hours. Optionally, the article may be stress relieved by heating it to a stress-relieving temperature of from 816°C (1500°F) to 982°C (1800°F), most preferably 843°C (1550°F) for 4 hours, either after the quenching step and before the aging step, or after the final age step.

[0041] In an alternative heat treatment, the article is solution treated at a partial subsolvus solution-treating temperature of from 1093°C (2000°F) to 1149°C (2100°F), quenched as described above and aged, or cooled, stress relieved and aged, as described above.

[0042] In yet another approach to the heat treatment, the article is slow cooled from a supersolvus solution temperature at rates of less than 260°C (500°F) per hour to a subsolvus temperature. The article is then quenched as described above and aged, or stress relieved and aged, as described above.

[0043] Specimens within the scope of the invention and comparison specimens were prepared by the preferred approach. These specimens were used to develop the data of Figures 4-6. Figures 4-5 have been discussed previously. Figure 6 illustrates data for dwell fatigue crack growth rates, performed at a temperature of 704°C (1300°F) with a ratio R of minimum to maximum stress during fatigue of 0.1, a maximum stress intensity K_{max} = 207 MPa $(2.54\ cm)^{1/2}$ (K_{max} of 30 KSI $(inch)^{1/2}$), and a dwell period of two hours between loading to maximum load and unloading. Figure 6 also illustrates data for the time for reach 0.2 percent creep when measured at 649°C (1200°F) and a stress of 793 MPa (115,000 pounds per square inch).

[0044] It is important for applications such as disks, shafts, and impellers that good performance be achieved for both the dwell fatigue crack growth and for creep.

Some available alloys achieve one but not the other. The property not achieved then becomes the limiting factor in the design of the article.

[0045] The compositions of the present invention achieve significantly improved dwell fatigue crack growth rates and improved creep times, as compared with conventional alloys. In Figure 6, data is presented for IN100 and Rene 88DT, standard disk and shaft alloys. Alloy ME 1-16 and ME2 are within the scope of the present invention, alloy ME1-12 is outside the scope of the invention. Alloy CH98 is the preferred composition disclosed in US Patent 5,662,749. The alloys of the present invention achieve an improvement of approximately a factor of 50 over IN100 in creep life and approximately a factor of 200 over Rene 88DT in dwell fatigue crack growth rate. The alloys of the present invention have about the same dwell fatigue crack growth performance as alloy CH98, and exhibit substantially improved creep life over alloy CH98.

[0046] Only the present alloys achieve a combined relationship between dwell fatigue crack growth rate and time to creep that satisfies the relationship $\log D \leq 1.35 \log t - 11.05$, wherein D is the dwell fatigue crack growth rate in inches per second at 704°C (1300°F) of a surface flaw specimen under loading wherein the ratio R of the minimum load to the maximum load is 0.1 and maximum stress intensity K_{max} = 207 MPa $(2.54\ \text{cm})^{1/2}$ (K = 30 KSI $(\text{inch})^{1/2}$) and wherein t is the time in hours to creep 0.2 percent of a standard tensile specimen at 649°C (1200°F) and 793 MPa (115 Ksi) loading. Thus, the present alloys provide a level of enhanced performance for both dwell fatigue crack growth rate and time to creep that is desirable for articles such as gas turbine disks and shafts that are subjected to both types of loading during service.

Claims

1. A composition of matter consisting of, in weight percent, from 16 percent to 20 percent cobalt, from 11 percent to 15 percent chromium, from 2 percent to 4 percent tantalum, from 0.5 to 3 percent tungsten, from 3 to 5 percent molybdenum, from 0.015 to 0.15 percent zirconium, from 1 to 3 percent niobium, from 2.6 to 4.6 percent titanium, from 2.6 to 4.6 percent aluminum, from 0 to 2.5 percent rhenium, from 0 to 2 percent vanadium, from 0 to 2 percent iron, from 0 to 2 percent hafnium, from 0 to 0.1 percent magnesium from 0.0 15 to 0.1 percent carbon, from 0.0 15 percent to 0.045 percent boron, balance nickel and impurities; wherein the ratio (percent zirconium + percent boron)/percent carbon is greater than 1.

2. The composition of matter of claim 1, wherein the sum of tungsten plus niobium is from 2.2 percent to 4 percent.

3. The composition of matter of claim 1, wherein the composition consists of, in weight percent, about 18.2 percent cobalt, about 13.1 percent chromium, about 2.7 percent tantalum, about 1.9 percent tungsten, about 3.8 percent molybdenum, about 0.050 percent zirconium, about 1.4 percent niobium, about 3.5 percent titanium, about 3.5 percent aluminum, about 0.030 percent carbon, about 0.030 percent boron, balance nickel and impurities.

4. The composition of matter of claim 1, wherein the composition consists of, in weight percent, about 20 percent cobalt, about 13 percent chromium, about 2 percent tantalum, about 2 percent tungsten, about 3.8 percent molybdenum, about 0.050 percent zirconium, about 1.2 percent niobium, about 3.7 percent titanium, about 3.7 percent aluminum, about 0.05 percent carbon, about 0.03 percent boron, balance nickel and impurities.

5. An article having a composition according to claim 1.

6. The article of claim 5, wherein the article comprises a mass of compacted powders.

7. The article of claim 5, wherein the article has a grain size of from ASTM 2 to ASTM 8.

8. The article of claim 5, wherein the article has a grain size of from ASTM 9 to ASTM 12.

9. The article of claim 5, wherein the article is selected from the group consisting of a turbine disk (20), a turbine shaft (24), a compressor disk (20), a compressor shaft (24), and a compressor impeller (22).

10. A method for preparing an article, comprising the steps of furnishing a mass of compacted powders having a composition consisting of, in weight percent, from 16 percent to 20 percent cobalt, from 11 percent to 15 percent chromium, from 2 percent to 4 percent tantalum, from 0.5 to 3 percent tungsten, from 3 to 5 percent molybdenum, from 0.015 to 0.15 percent zirconium, from 1 to 3 percent niobium, from 2.6 to 4.6 percent titanium, from 2.6 to 4.6 percent aluminum, from 0 to 2.5 percent rhenium, from 0 to 2 percent vanadium, from 0 to 2 percent iron, from 0 to 2 percent hafnium, from 0 to 0.1 percent magnesium from 0.0 15 to 0.1 percent carbon, from 0.0 15 percent to 0.045 percent boron, balance nickel and impurities; wherein the ratio (percent zirconium + percent boron)/percent carbon is greater than 1;
heat treating the mass by the steps of solution treating the mass at a solution-treating temperature above its solvus temperature, and
cooling the solution treated mass to a temperature below its solvus temperature.

11. The method of claim 10, wherein the step of heat treating includes an additional step, after the step of cooling, of aging the solution-treated-and-quenched mass at an aging temperature below its solvus temperature.

12. The method of claim 11, wherein the step of aging includes the step of heating the mass to an aging temperature of from 1350^{0}F (732^{0}C) to 1500^{0}F (816^{0}C).

13. The method of claim 11 including an additional step, after the step of cooling, of stress relieving the article by heating the article to a stress-relieving temperature of from 1500^{0}F (816^{0}C) to 1800^{0}F (982^{0}C).

14. The method of claim 10, wherein the step of solution treating includes the step of heating the mass to a solution-treating temperature of from 2100^{0}F (1149^{0}C) to 2225^{0}F (1218^{0}C).

15. The method of claim 10, wherein the step of solution treating includes the step of heating the mass to a partial subsolvus solution-treating temperature of from 2000^{0}F (1093^{0}C) to about 2100^{0}F (1149^{0}C).

16. The method of claim 15, wherein the step of heat treating includes an additional step, after the step of cooling, of

aging the partial subsolvus solution-treated-and-cooled mass at an aging temperature below its solvus.

17. The method of claim 16, wherein the step of aging includes the step of heating the partial subsolvus solution-treated-and-cooled mass to an aging temperature of from 1350^{0}F (732^{0}C) to 1500^{0}F (816^{0}C).

18. The method of claim 16, including an additional step, after the step of cooling, of stress relieving the article at a stress-relieving temperature of from 1500^{0}F (816^{0}C) to 1800^{0}F (982^{0}C).

19. The composition of matter of claim 1, wherein the tungsten content is from 1.4 to 3 weight percent.

20. The article of claim 6, wherein the tungsten content is from 1.4 to 3 weight percent.

Patentansprüche

1. Materialzusammensetzung bestehend, in Gewichtsprozent, aus 16 Prozent bis 20 Prozent Kobalt, 11 Prozent bis 15 Prozent Chrom, 2 Prozent bis 4 Prozent Tantal, 0,5 bis 3 Prozent Wolfram, 3 bis 5 Prozent Molybdän, 0,015 bis 0,15 Prozent Zirkonium, 1 bis 3 Prozent Niobium, 2,6 bis 4,6 Prozent Titan, 2,6 bis 4,6 Prozent Aluminium, 0 bis 2,5 Prozent Rhenium, 0 bis 2 Prozent Vanadium, 0 bis 2 Prozent Eisen, 0 bis 2 Prozent Hafnium, 0 bis 0,1 Prozent Magnesium, 0,015 bis 0,1 Prozent Kohlenstoff, 0,015 Prozent bis 0,045 Prozent Bor und dem Rest aus Nickel und Verunreinigungen; wobei das Verhältnis (Prozent Zirkonium + Prozent Bor)/Prozent Kohlenstoff größer als 1 ist.

2. Materialzusammensetzung nach Anspruch 1, wobei die Summe von Wolfram plus Niobium 2,2 Prozent bis 4 Prozent beträgt.

3. Materialzusammensetzung nach Anspruch 1, wobei die Zusammensetzung, in Gewichtsprozent, aus etwa 18,2 Prozent Kobalt, etwa 13,1 Prozent Chrom, etwa 2,7 Prozent Tantal, etwa 1,9 Prozent Wolfram, etwa 3,8 Prozent Molybdän, etwa 0,050 Prozent Zirkonium, etwa 1,4 Prozent Niobium, etwa 3,5 Prozent Titan, etwa 3,5 Prozent Aluminium, etwa 0,030 Prozent Kohlenstoff, etwa 0,030 Prozent Bor und dem Rest aus Nickel und Verunreinigungen besteht.

4. Materialzusammensetzung nach Anspruch 1, wobei die Zusammensetzung, in Gewichtsprozent, aus etwa 20 Prozent Kobalt, etwa 13 Prozent Chrom, etwa 2 Prozent Tantal, etwa 2 Prozent Wolfram, etwa 3,8 Prozent Molybdän, etwa 0,050 Prozent Zirkonium, etwa 1,2 Prozent Niobium, etwa 3,7 Prozent Titan, etwa 3,7 Prozent Aluminium, etwa 0,05 Prozent Kohlenstoff, etwa 0,03 Prozent Bor und dem Rest aus Nickel und Verunreinigungen besteht.

5. Artikel mit einer Zusammensetzung gemäß Anspruch 1.

6. Artikel nach Anspruch 5, wobei der Artikel eine Masse aus verdichteten Pulvern aufweist.

7. Artikel nach Anspruch 5, wobei der Artikel eine Korngröße von ASTM 2 bis ASTM 8 aufweist.

8. Artikel nach Anspruch 5, wobei der Artikel eine Korngröße von ASTM 9 bis ASTM 12 aufweist.

9. Artikel nach Anspruch 5, wobei der Artikel aus der aus einer Turbinenscheibe (20), einer Turbinenwelle (24), einer Verdichterscheibe (20), einer Verdichterwelle (24) und einem Verdichterrad (22) bestehenden Gruppe ausgewählt ist.

10. Verfahren zum Herstellen eines Artikels, mit den Schritten:

Zusammenstellen einer Masse aus verdichteten Pulvern mit einer Zusammensetzung bestehend, in Gewichtsprozent, aus 16 Prozent bis 20 Prozent Kobalt, 11 Prozent bis 15 Prozent Chrom, 2 Prozent bis 4 Prozent Tantal, 0,5 bis 3 Prozent Wolfram, 3 bis 5 Prozent Molybdän,

0,015 bis 0,15 Prozent Zirkonium, 1 bis 3 Prozent Niobium, 2,6 bis 4,6 Prozent Titan, 2,6 bis 4,6 Prozent Aluminium, 0 bis 2,5 Prozent Rhenium, 0 bis 2 Prozent Vanadium, 0 bis 2 Prozent Eisen, 0 bis 2 Prozent Hafnium, 0 bis 0,1 Prozent Magnesium, 0,015 bis 0,1 Prozent Kohlenstoff, 0,015 bis 0,045 Prozent Bor und dem Rest aus Nickel und Verunreinigungen; wobei das Verhältnis (Prozent Zirkonium + Prozent Bor)/Prozent Kohlenstoff größer als 1 ist;
Wärmebehandeln der Masse mittels der Schritte von:

Lösungsglühen der Masse bei einer Lösungsglühtemperatur über ihrer Solvus-Temperatur, und
Abkühlen der lösungsgeglühten Masse auf eine Temperatur unter ihrer Solvus-Temperatur.

11. Verfahren nach Anspruch 10, wobei der Schritt der Wärmebehandlung einen zusätzlichen Schritt, nach dem Schritt der Abkühlung, einer Vergütung der lösungsgeglühten und abgeschreckten Masse bei einer Vergütungstemperatur unter ihrer Solvus-Temperatur beinhaltet.

12. Verfahren nach Anspruch 11, wobei der Schritt der Vergütung den Schritt der Erwärmung der Masse auf eine Vergütungstemperatur von 1350 °F (732 °C) bis 1500 °F (816 °C) beinhaltet.

13. Verfahren nach Anspruch 11 mit einem zusätzlichen Schritt, nach dem Schritt der Abkühlung, einer Entspannung des Artikels, indem der Artikel auf eine Entspannungstemperatur von 1500 °F (816 °C) bis 1800 °F (982 °C) erwärmt wird.

14. Verfahren nach Anspruch 10, wobei der Schritt des Lösungsglühens den Schritt der Erwärmung der Masse auf eine Lösungsglühtemperatur von 2100 °F (1149 °C) bis 2225 °F (1218 °C) beinhaltet.

15. Verfahren nach Anspruch 10, wobei der Schritt des Lösungsglühens den Schritt der Erwärmung der Masse auf eine partielle Subsolvus-Lösungsglühtemperatur von 2000 °F (1093 °C) bis etwa 2100 °F (1149 °C) beinhaltet.

16. Verfahren nach Anspruch 15, wobei der Schritt der Wärmebehandlung einen zusätzlichen Schritt, nach dem Schritt der Abkühlung, einer Vergütung der bei partieller Subsolvus-Temperatur lösungsgeglühten-und-abgekühlten Masse bei einer Vergütungstemperatur unter ihrer Solvus-Temperatur beinhaltet.

17. Verfahren nach Anspruch 16, wobei der Schritt der Vergütung den Schritt der Erwärmung der bei partieller Subsolvus-Temperatur lösungsgeglühten-und-abgekühlten Masse auf eine Vergütungstemperatur von 1350 °F (732 °C) bis 1500 °F (816 °C) beinhaltet.

18. Verfahren nach Anspruch 16 mit einem zusätzlichen Schritt, nach dem Schritt der Abkühlung, einer Entspannung des Artikels, indem der Artikel bei einer Entspannungstemperatur von 1500 °F (816 °C) bis 1800 °F (982 °C) entspannt wird.

19. Materialzusammensetzung nach Anspruch 1, wobei der Wolframanteil zwischen 1,4 und 3 Gewichtsprozent beträgt.

20. Artikel nach Anspruch 6, wobei der Wolframanteil zwischen 1,4 und 3 Gewichtsprozent beträgt.

Revendications

1. Composition de matière constituée, en pour-cent en poids, de 16 à 20 pour-cent de cobalt, de 11 à 15 pour-cent de chrome, de 2 à 4 pour-cent de tantale, de 0,5 à 3 pour-cent de tungstène, de 3 à 5 pour-cent de molybdène, de 0,015 à 0,15 pour-cent de zirconium, de 1 à 3 pour-cent de niobium, de 2,6 à 4,6 pour-cent de titane, de 2,6 à 4,6 pour-cent d'aluminium, de 0 à 2,5 pour-cent de rhénium, de 0 à 2 pour-cent de vanadium, de 0 à 2 pour-cent de fer, de 0 à 2 pour-cent d'hafnium, de 0 à 0, 1 pour-cent de magnésium, de 0,015 à 0,1 pour- cent de carbone, de 0,015 à 0,045 pour-cent de bore, le complément étant du nickel et des impuretés ; dans laquelle le rapport (pour-cent de zirconium + pour-cent de bore)/ pour-cent de carbone est supérieur à 1.

2. Composition de matière selon la revendication 1, dans laquelle la somme de tungstène plus niobium est comprise entre 2,2 pour-cent et 4 pour-cent.

3. Composition de matière de la revendication 1, dans laquelle la composition est constituée, en pour-cent en poids, de 18,2 pour-cent environ de cobalt, 13,1 pour-cent environ de chrome, 2,7 pour-cent environ de tantale, 1,9 pour-cent environ de tungstène, 3,8 pour-cent environ de molybdène, 0,050 pour-cent environ de zirconium, 1,4 pour-cent environ de niobium, 3,5 pour-cent environ de titane, 3,5 pour-cent environ d'aluminium, 0,030 pour-cent environ de carbone, 0,030 pour-cent environ de bore, le complément étant du nickel et des impuretés.

4. Composition de matière selon la revendication 1, dans laquelle la composition est constituée, en pour-cent en poids, de 20 pour-cent environ de cobalt, 13 pour-cent environ de chrome, 2 pour-cent environ de tantale, 2 pour-cent environ de tungstène, 3,8 pour-cent environ de molybdène, 0,050 pour- cent environ de zirconium, 1,2 pour-cent environ de niobium, 3,7 pour-cent environ de titane, 3,7 pour-cent environ d'aluminium, 0,05 pour-cent environ de carbone, 0,03 pour-cent environ de bore, le complément étant du nickel et des impuretés.

5. Article présentant une composition selon la revendication 1.

6. Article selon la revendication 5, dans lequel l'article comprend une masse de poudres compactées.

7. Article selon la revendication 6, dans lequel l'article présente une taille de grain de ASTM 2 à ASTM 8.

8. Article selon la revendication 5, dans lequel l'article présente une taille de grain de ASTM 9 à ASTM 12.

9. Article selon la revendication 5, dans lequel l'article est sélectionné à partir du groupe constitué par un disque de turbine (20), un arbre de turbine (24), un disque de compresseur (20), un arbre de compresseur (24), et un rotor de compresseur (22).

10. Procédé de préparation d'un article, comprenant les étapes de Fourniture d'une masse de poudres compactées présentant une composition constituée, en pour-cent en poids, de 16 à 20 pour-cent de cobalt, de 11 à 15 pour-cent de chrome, de 2 à 4 pour-cent de tantale, de 0,5 à 3 pour- cent de tungstène, de 3 à 5 pour-cent de molybdène, de 0,015 à 0,15 pour-cent de zirconium, de 1 à 3 pour-cent de niobium, de 2,6 à 4,6 pour-cent de titane, de 2,6 à 4,6 pour-cent d'aluminium, de 0 à 2,5 pour-cent de rhénium, de 0 à 2 pour-cent de vanadium, de 0 à 2 pour-cent de fer, de 0 à 2 pour-cent de hafnium, de 0 à 0,1 pour-cent de magnésium, de 0,015 à 0,1 pour-cent de carbone, de 0,015 à 0,045 pour-cent de bore, le complément étant du nickel et des impuretés ; dans lequel le rapport (pour-cent de zirconium + pour-cent de bore)/ pour-cent de carbone est supérieur à 1.
traitement thermique de la masse par les étapes de traitement en solution de la masse à une température de traitement supérieure à sa température de limite de solubilité,
et refroidissement de la masse traitée en solution à une température inférieure à sa température de limite de solubilité.

11. Procédé selon la revendication 10, dans lequel l'étape de traitement thermique comprend une étape supplémentaire, après l'étape de refroidissement, de maturation de la masse traitée en solution et recuite à une température de maturation inférieure à sa température de limite de solubilité.

12. Procédé selon la revendication 11, dans lequel l'étape de maturation comporte l'étape de chauffage de la masse à une température de maturation de 732°C (1350°F) à 816°C (1500°F).

13. Procédé selon la revendication 11, comportant une étape supplémentaire, après l'étape de refroidissement, de libération de contraintes de l'article par chauffage de l'article à une température de libération de contraintes de 816°C (1500°F) à 982°C (1800°F).

14. Procédé selon la revendication 10, dans lequel l'étape de traitement en solution comporte l'étape de chauffage de la masse à une température de traitement en solution de 1149°C (2100°F) à 1218°C (2225°F).

15. Procédé selon la revendication 10, dans lequel l'étape de traitement en solution comporte l'étape de chauffage de la masse à une température de traitement en solution inférieure à la limite de solubilité partielle de 1093°C (2000°F) à 1149°C environ (2100°F).

16. Procédé selon la revendication 15, dans lequel l'étape de traitement thermique comporte une étape supplémentaire, après l'étape de refroidissement,
de maturation de la masse traitée en solution et refroidie au-dessous de la limite de solubilité partielle à une température de maturation inférieure à sa limite de solubilité.

17. Procédé selon la revendication 16, dans lequel l'étape de maturation comprend l'étape de
chauffage de la masse traitée en solution et refroidie au-dessous de la limite de solubilité partielle à une température de maturation de 732°C (1350°F) à 816°C (1500°F).

18. Procédé selon la revendication 16, comportant une étape supplémentaire, après l'étape de refroidissement, de libération de contraintes de l'article à une température de libération de contraintes de 816°C (1500°F) à 982°C (1800°F).

19. Composition de matière selon la revendication 1, dans laquelle la teneur en tungstène est de 1,4 à 3 pour-cent en poids.

20. Article selon la revendication 6, dans lequel la teneur en tungstène est de 1,4 à 3 pour-cent en poids.

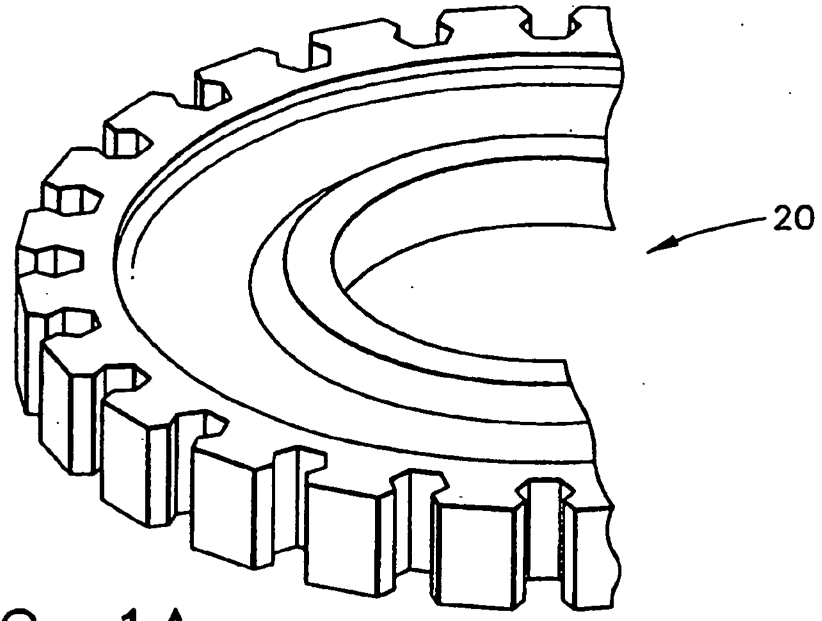


FIG. 1A

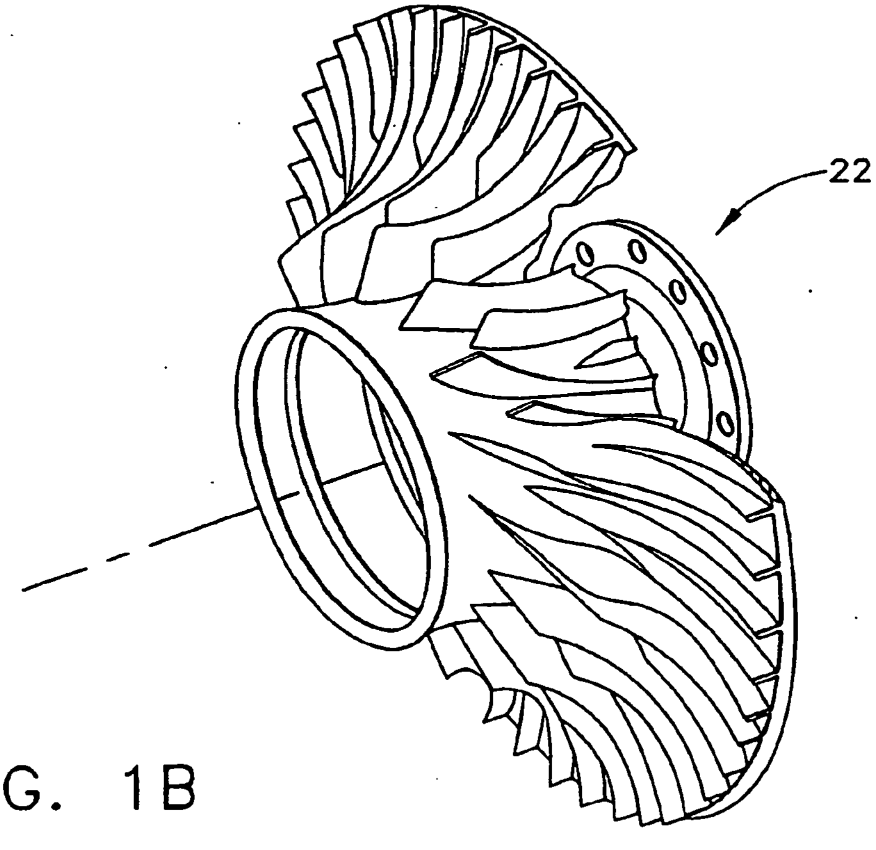


FIG. 1B

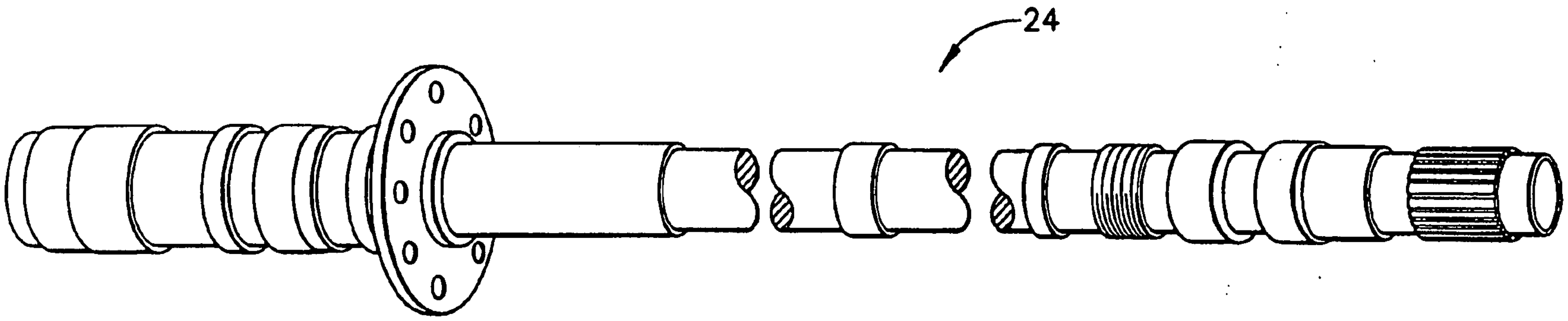

24

FIG. 2

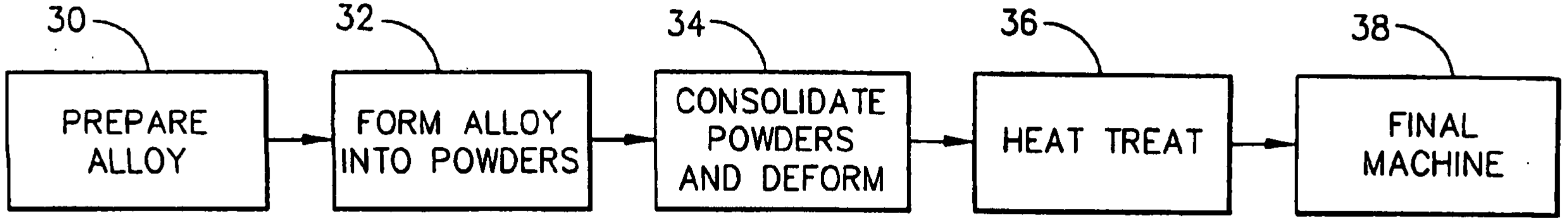

30
PREPARE ALLOY
32
FORM ALLOY INTO POWDERS
34
CONSOLIDATE POWDERS AND DEFORM
36
HEAT TREAT
38
FINAL MACHINE

FIG. 3

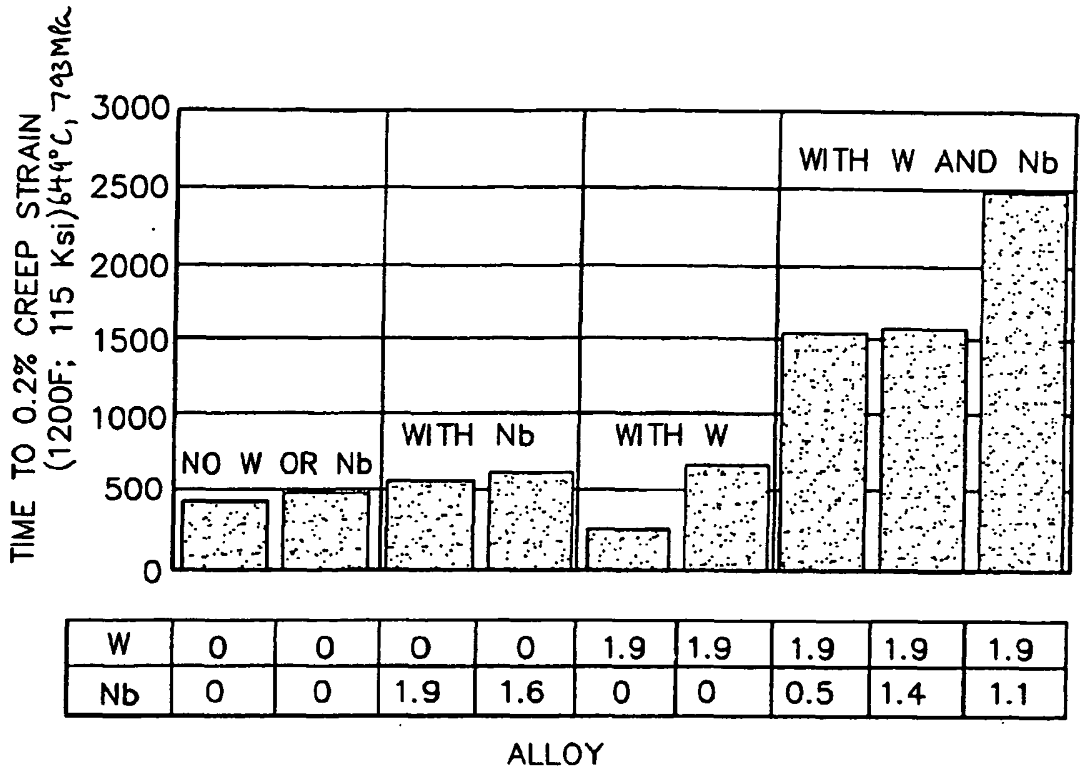

TIME TO 0.2% CREEP STRAIN
(1200F; 115 Ksi)/649°C, 793MPa
3000
2500
2000
1500
1000
500
0
NO W OR Nb
WITH Nb
WITH W
WITH W AND Nb
W
0
0
0
0
1.9
1.9
1.9
1.9
1.9
Nb
0
0
1.9
1.6
0
0
0.5
1.4
1.1
ALLOY

FIG. 4

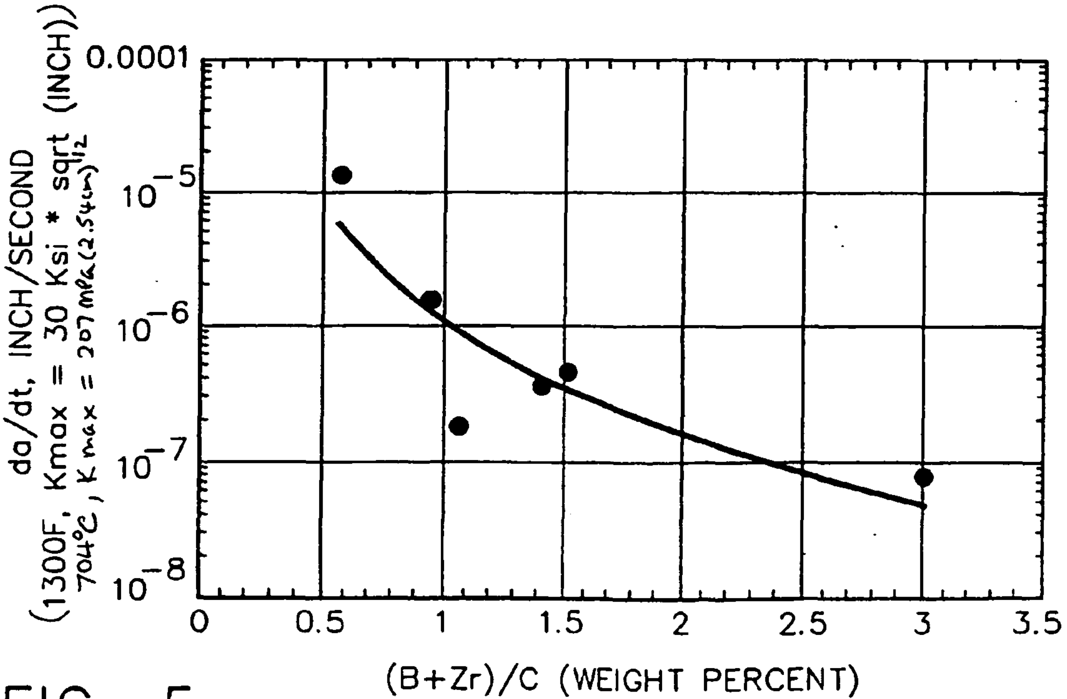
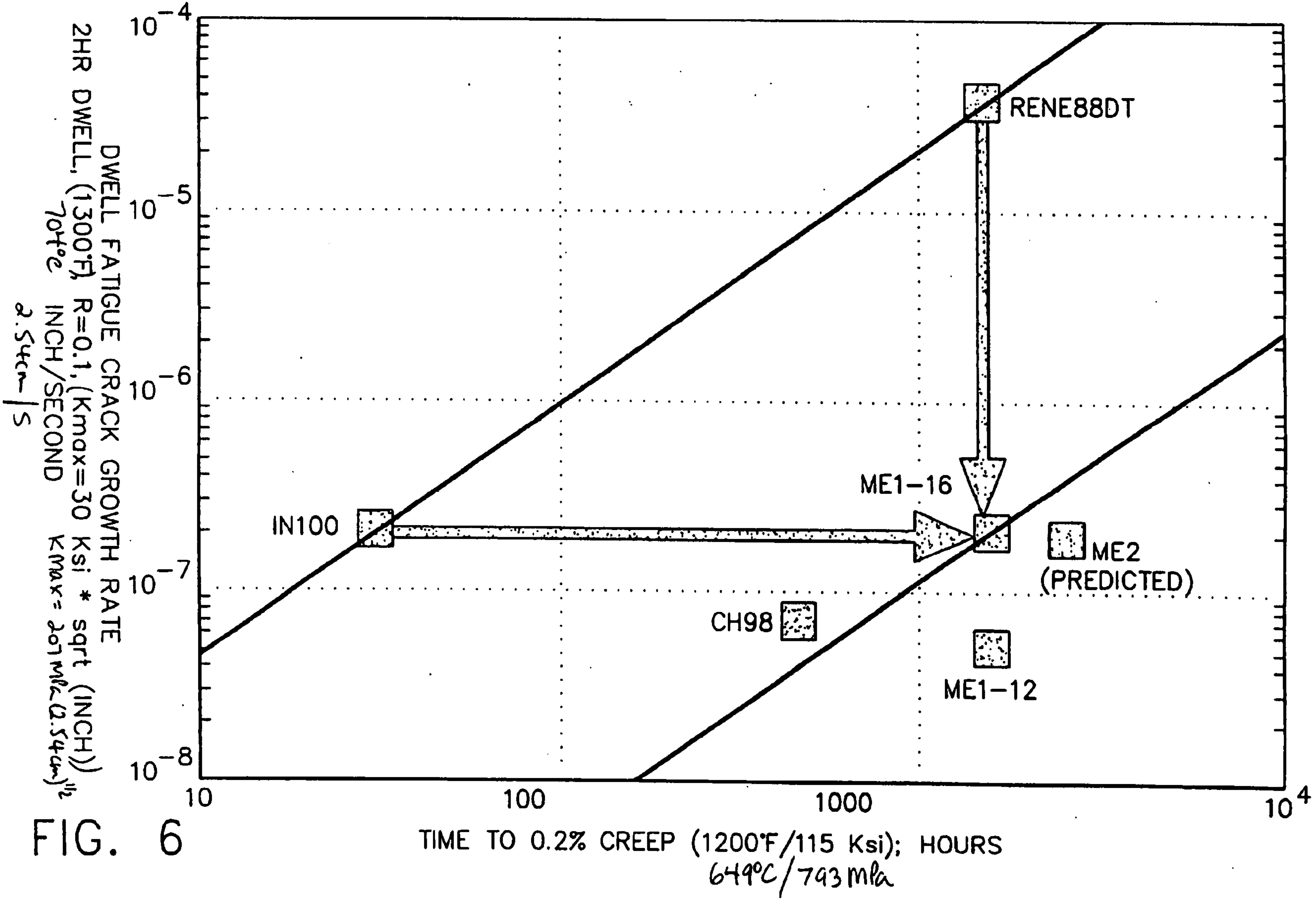

da/dt, INCH/SECOND
(1300F, Kmax = 30 Ksi * sqrt (INCH))
704°C, Kmax = 207 MPa(2.54cm)^1/2
0.0001
10^-5
10^-6
10^-7
10^-8
0
0.5
1
1.5
2
2.5
3
3.5
(B+Zr)/C (WEIGHT PERCENT)

FIG. 5



DWELL FATIGUE CRACK GROWTH RATE
2HR DWELL, (1300°F), R=0.1, (Kmax=30 Ksi * sqrt (INCH))
704°c INCH/SECOND
2.54cm/s
Kmax= 207 MPa (2.54cm)^1/2
10^-4
10^-5
10^-6
10^-7
10^-8
10
100
1000
10^4
TIME TO 0.2% CREEP (1200°F/115 Ksi); HOURS
649°C/793 MPa
RENE88DT
IN100
ME1-16
ME2
(PREDICTED)
CH98
ME1-12

FIG. 6

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- US 5120373 A **[0006]**
- EP 0373298 A **[0007]**
- EP 0849370 A **[0008]**
- US 5662749 A **[0045]**