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(54) **POWDER METAL ROTATING
COMPONENTS FOR TURBINE ENGINES
AND PROCESS THEREFOR**

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(57) **ABSTRACT**

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A process for producing turbine rotors and other large rotating components of power-generating gas turbine engines using powder metallurgy techniques. The process involves forming a powder of a gamma prime or gamma double prime precipitation-strengthened nickel-based superalloy whose particles are about 0.100 mm in diameter or smaller. The powder is placed in a can and consolidated to produce an essentially fully dense consolidation, which is then hot worked to produce a billet of a size sufficient to form a forging of at least 2300 kg. The billet is forged at a temperature and strain rate to produce a forging with a uniform fine grain of ASTM 10 or finer. Thereafter, the forging may undergo a heat treatment to achieve a desired balance of mechanical properties while retaining a uniform grain size of ASTM 10 or finer.

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POWDER METAL ROTATING COMPONENTS FOR TURBINE ENGINES AND PROCESS THEREFOR

BACKGROUND OF THE INVENTION

[0001] This invention relates to processes for producing large forgings using metal powders as the starting material. More particularly, this invention is directed to a process for producing turbine rotors and other large rotating components of turbine engines using powder metallurgy techniques.

[0002] Rotor components for certain advanced land-based gas turbine engines used in the power-generating industry, such as the H and FB class gas turbines of the assignee of this invention, are currently formed from gamma double-prime (γ'') precipitation-strengthened nickel-based superalloys, such as Alloy 718 and Alloy 706. For example, wheels and spacers have been formed from triple-melted (vacuum induction melting (VIM)/electroslag remelting (ESR)/vacuum arc remelting (VAR)) ingots with diameters of about 27 to 36 inches (about 70 to about 90 cm), which are then billetized and forged. Due to potential chemical or microstructural segregation and anticipated hot working losses going from ingot to final forging, starting ingot weights must be from about 1.5 to 3 times the weight of the finished forging, and about 2.5 to 7 times the weight of the finish-machined part. In addition to these substantial material losses, the best current processing practices typically result in nonuniform and relatively coarse-grained microstructures in the billet (e.g., ASTM 00 or larger) and the finish forgings (e.g., ASTM 8.0 or larger) (reference throughout to ASTM grain sizes is in accordance with the standard scale established by the American Society for Testing and Materials). The billet grain size is too large to permit any adequate ultrasonic inspection to identify potential life limiting defects and is consequently not performed on currently used billet. The finished forgings must therefore be ultrasonically inspected for potential life-limiting defects, and typically necessitate a minimum 0.25 inch (about 6 mm) thick sonic shape inspection envelope that defines the finished forged shape envelope.

[0003] In contrast, rotor components for aircraft gas turbine engines have often been formed by powder metallurgy (PM) processes, which are known to provide a good balance of creep, tensile and fatigue crack growth properties to meet the performance requirements of aircraft gas turbine engines. Typically, a powder metal component is produced by consolidating metal powders in some form, such as extrusion consolidation, then isothermally or hot die forging the consolidated material to the desired outline, and finally heat treating the forging before finish machining to complete the manufacturing process. The processing steps of consolidation and forging are designed to retain a very fine grain size within the material to enable high resolution ultrasonic inspection of billets, minimize die loading, and improve shape definition of the finished forging. Unlike advanced turbine systems for land-based gas turbine engines, PM rotor components for aircraft gas turbine engines have been typically formed from gamma prime (γ') precipitation-strengthened nickel-based superalloys with very high temperature and stress capabilities demanded by those parts. In order to improve the fatigue crack growth resistance and mechanical properties at elevated temperatures, some of these alloys are heat treated above their gamma prime solvus

temperature (generally referred to as supersolvus heat treatment) to cause significant, uniform coarsening of the grains. The nickel-based superalloy rotors used in large electrical power generating turbines currently do not require the higher temperature gamma prime alloys nor this grain coarsening process to meet their mission and component mechanical property requirements, though it is foreseeable that such higher temperature alloys could be required at some future date to increase turbine efficiencies or increase component life.

[0004] While powder metal nickel-based superalloys have been processed for use in aircraft engine turbine rotor forgings, whose forgings are typically less than 2000 pounds (about 900 kg), powder metal techniques have not been used to produce the significantly larger forgings required by gas turbines used in the power-generating industry, which can weigh in excess of 5000 pounds (about 2300 kg). However, the ability to use a powder metallurgy process to produce large nickel-based superalloy forgings suitable for rotor components of power-generating gas turbine engines would provide the capability of producing more near-net-shape forgings, thereby reducing material losses. Until recently, these power generation turbine alloys were iron or nickel-based with low alloy content, i.e., three or four primary elements, which permit their melting and processing with relative ease and minimal chemical or microstructural segregation. Powder metal versions of these alloys would offer no significant benefit, either in ease of processing or property gains, to compensate for the higher base cost of PM compared to the cast ingots which can be readily converted into rotor forgings. However, as more complex alloys such as Alloy 718 and beyond become preferred and the size of forgings continues to increase, the concerns of chemical and microstructure segregation, high material losses associated with converting large grained ingots to finish forgings, and limited industry capacity to process large, high strength forgings make the higher base cost PM alloys potentially more cost effective. Reduced processing losses, expanded industry capacity, improved inspectibility of fine grain PM billets and parts, and the ability to produce more near-net-shape forgings are all contributing factors to achieving lower cost large rotor forgings from PM than from the current cast plus wrought practice.

BRIEF SUMMARY OF THE INVENTION

[0005] The present invention provides a process for producing turbine rotors and other large rotating components of power-generating gas turbine engines using powder metallurgy techniques. The method significantly reduces the ratio of input weight to final forging weight by eliminating yield losses during conversion from large grained ingot to a fine grained forging. The method also virtually eliminates chemical and microstructural segregation, and results in a fine, uniform grain size (ASTM 10 or finer) that advantageously reduces the required sonic shape envelope and therefore further reduces the finish forging weight. Additionally, the use of fine grain PM billet has the capability of reducing the press forces required to produce finish forgings, thereby reducing capital equipment cost and expanding the potential supplier base.

[0006] The process of this invention involves forming a powder of a precipitation-strengthened (gamma prime or gamma double prime) nickel-base superalloy whose par-

ticles are about 0.004 inch (about 0.100 mm) in diameter or smaller. The powder is placed in a can, which is evacuated and sealed in a controlled environment and then consolidated at a temperature, time, and pressure to produce an essentially fully-dense consolidation. The consolidation is then hot worked at a temperature to produce a billet with a uniform grain size of ASTM 10 or finer and of a size sufficient to form a forging of at least 5000 pounds (about 2300 kg). The billet is then forged at a temperature and strain rate selected to produce a forging with a uniform fine grain of ASTM 10 or finer throughout. Thereafter, the forging preferably undergoes a heat treatment designed to achieve a desired balance of mechanical properties while retaining a grain size of ASTM 10 or finer.

[0007] As a result of the above process, very large rotor components that were previously limited to processing by conventional cast and wrought techniques may now be formed by powder metallurgy techniques with reduced material losses, as well as microstructural, compositional, and mechanical property advantages that can be achieved with powder metallurgy processes.

[0008] Other objects and advantages of this invention will be better appreciated from the following detailed description.

DETAILED DESCRIPTION OF THE INVENTION

[0009] The present invention provides a process for manufacturing very large nickel-base alloy rotor forgings, generally in excess of 5000 pounds (about 2300 kg), using powder metallurgy techniques. Powder metal alloys are used to produce nickel-base consolidations, which are then hot worked into billets and subsequently forged into large turbine wheels, spacers, or other rotating components of a size suitable for large gas turbine engines used in the power generating industry.

[0010] A particularly suitable alloy for illustrating the advantages of this invention is a gamma-prime precipitation-strengthened nickel-base superalloy based on the commercially-available Alloy 725. The superalloy, identified herein as ARA725, has a composition of, by weight, about 19 to about 23% chromium, about 7 to about 8% molybdenum, about 3 to about 4% niobium, about 4 to about 6% iron, about 0.3 to about 0.6% aluminum, about 1 to about 1.8% titanium, about 0.002 to about 0.004% boron, about 0.35% maximum manganese, about 0.2% maximum silicon, about 0.03% maximum carbon, the balance nickel and incidental impurities. Properties of conventionally cast plus wrought ARA725 cited in U.S. Pat. No. 6,315,846 to Hibner et al. and U.S. Pat. No. 6,531,002 to Henry et al. that are believed to render the alloy particularly well suited for producing very large forgings from powder metal include room and elevated temperature tensile strength and ductility similar to Alloy 718 with significantly improved time dependent crack growth resistance compared to Alloy 718. Though no mechanical property data is yet available for a powder metallurgy version of ARA725, it is anticipated that a properly processed powder metal forging will have similar or possibly better properties than the cast plus wrought forgings. While the invention will be described in reference to the ARA725 alloy, the teachings of this invention are applicable to other gamma prime and gamma double prime

precipitation-strengthened nickel-based superalloys, such as Alloy 625, LC Astroloy (U700), Udimet 720, ARA054, ARA017, and any other nickel-based superalloy with tensile properties equal to or better than Alloy 718 combined with superior time dependent crack growth resistance compared to Alloy 718.

[0011] For the applications of interest to the invention, optimum processability and mechanical properties are achieved by uniform grain sizes of not larger than ASTM 10. Grain sizes larger than ASTM 10 are undesirable in that the presence of such grains can significantly reduce the low cycle fatigue resistance of the component, can have a negative impact on other mechanical properties of the component such as tensile and high cycle fatigue (HCF) strength, increase hot working load requirements, and inhibit the thorough ultrasonic inspection of billets and thick section forgings. Therefore, a preferred aspect of this invention is to achieve a uniform grain size within a nickel-base superalloy, in which random grain growth is prevented so as to yield a maximum grain size of ASTM 10 or finer.

[0012] The process of this invention involves forming a melt whose chemistry is that of the desired alloy (e.g., ARA725). This is typically accomplished by VIM processing but could also be performed by adaptation of ESR or VAR processes to provide melt for subsequent atomization or other powder making method. In view of the reactivity of elements (e.g., aluminum and titanium) contained in preferred gamma prime and gamma double prime precipitation-strengthened alloys, the melt is formed under vacuum or in an inert environment (hereinafter, a controlled environment). While in the molten condition and within chemistry specifications, the alloy is converted into powder by atomization or another suitable process to produce generally spherical powder particles. According to a preferred aspect of the invention, the particles are produced by atomization to have diameters of predominantly 0.004 inch (about 0.100 mm) or smaller. The powder is then sieved in a controlled environment to remove essentially all particles larger than 0.004 inch (about 0.100 mm) for the purpose of reducing the potential for defects in the subsequent billet/forgings. Larger powder sizes may be acceptable if defect particles (e.g., ceramics, etc.) larger than 0.004 inch (about 0.100 mm) can be removed other than by a screening process. Because of the large quantity of powder required to produce billets of the size required by this invention, e.g., 5000 to 20,000 pounds (about 2300 to about 10,000 kg), it may be necessary to blend powders produced from multiple atomization steps to accumulate sufficient powder for use in the process of this invention. Any required storage of such powders is preferable in a controlled environment container.

[0013] Once a sufficient amount of powder has been produced, the powder is placed in a suitable can, preferably a mild steel can, whose size will meet the billet size requirement after consolidation. Loading of the can is performed in a controlled environment (inert gas or vacuum), after which the can is evacuated while subjected to moderate heating (e.g., above about 200° F. (about 93° C.)) to drive off moisture and any volatiles, and then sealed. Thereafter, the can and its contents are consolidated at a temperature, time, and pressure sufficient to produce a consolidation having a density of at least about 99.9% of theoretical. Consolidation can be accomplished by hot isostatic pressing (HIP), extrusion, or another suitable consolidation method.

[0014] The powder consolidation is then hot worked by any of several techniques, such as extrusion, upset plus drawing, etc., to produce an appropriate input billet size for forging. Conditions used to produce the input billet should result in uniform ASTM 10 or finer grain size throughout in order to facilitate ultrasonic inspection thereof prior to forging into the final part shape.

[0015] The billet is then forged using known techniques, such as those currently utilized to produce Alloy 706 and Alloy 718 rotor forgings for large industrial turbines but modified to take advantage of fine grain billet techniques. Forging is performed at temperatures and loading conditions that allow complete filling of the finish forging die cavity, avoid fracture, and produce or retain a fine uniform grain size within the material of not larger than ASTM 10. Notably, because chemical and microstructural segregation are virtually eliminated and a very fine grain size can be achieved through use of the powder metal starting material, the ratio of input (billet) weight to final forging weight can be significantly reduced. For example, it is believed the starting billet weight can be as little as about 1.2 to about 1.5 times the weight of the finished forging, and about 1.8 to about 4 times the weight of the finish-machined rotor component. This weight reduction is enabled by the improved processibility of fine grained billet as well as the enhanced sonic inspectibility thereof.

[0016] The resulting rotor forging preferably undergoes ultrasonic inspecting for potential life-limiting defects. However, due to the enhanced ultrasonic inspectibility of the input billet, this step of component processing could potentially be eliminated which would enable more near-net-shaped forgings to be produced and further reduce input weights.

[0017] Inspection (if performed) is followed by finish machining by any suitable known method to produce the finish-machined rotor component. In order to achieve required mechanical properties of the rotor component, prior to machining the forging is solution heat treated and aged at temperatures and times which achieve the preferred balance of properties for long time industrial gas turbine service. An illustrative example of an appropriate heat treatment process for the ARA725 alloy entails a solution heat treatment at a temperature of about 1650° F. (about 900° C.) for approximately four hours, followed by two step aging at a temperature of about 1400° F. (about 760° C.) for approximately eight hours, then cooling at a rate of 100° F. (about 56° C.) per minute to about 1150° F. (about 620° C.) and holding for approximately eight hours, followed by air cooling.

[0018] In addition to the preferred ARA725 alloy, the process described above can be applied to a broad range of metal alloys whose compositions and temperature capabilities meet a variety of specific product needs. For example, alloys containing conventional strengthening and/or grain boundary pinning dispersoids or nano-dispersoids such as inert oxides, nitrides, and/or carbides may be desired to impart long-term stability. Alloys containing higher levels of high temperature strengthening elements such as cobalt, tungsten, molybdenum, tantalum, niobium, etc., may be desired for applications requiring service up to 1800° F. (about 1000° C.) or higher. In addition to direct melting and atomization of specific alloy compositions, mechanically

alloying two or more separately processed powders can also be employed to obtain desired properties for a rotor component.

[0019] While the invention has been described in terms of a preferred embodiment, it is apparent that other forms could be adopted by one skilled in the art. Accordingly, the scope of the invention is to be limited only by the following claims.

What is claimed is:

1. A process of producing a component from a gamma prime or gamma double prime precipitation-strengthened nickel-base superalloy, the process comprising the steps of:

forming a powder of the superalloy;

filling a can with the powder and evacuating and sealing the can in a controlled environment;

consolidating the can and the powder therein at a temperature, time, and pressure to produce a consolidation;

hot working the consolidation to produce a billet of a size sufficient to form a forging of at least 2300 kg; and then

forging the billet at a temperature and strain rate to produce a forging with a uniform fine grain of ASTM 10 or finer throughout.

2. A process according to claim 1, wherein the nickel-based superalloy has a composition of, by weight, about 19 to about 23% chromium, about 7 to about 8% molybdenum, about 3 to about 4% niobium, about 4 to about 6% iron, about 0.3 to about 0.6% aluminum, about 1 to about 1.8% titanium, about 0.002 to about 0.004% boron, about 0.35% maximum manganese, about 0.2% maximum silicon, about 0.03% maximum carbon, the balance nickel and incidental impurities.

3. A process according to claim 1, wherein the forming step comprises producing a melt of the nickel-based superalloy in a controlled environment and then rapidly cooling the melt to produce the powder.

4. A process according to claim 3, wherein the forming step further comprises sieving the powder in a controlled environment to remove all particles larger than 0.100 mm in diameter.

5. A process according to claim 3, wherein the forming step further comprises blending the powder with a second powder of the nickel-based superalloy.

6. A process according to claim 1, wherein the consolidation formed by the consolidation step has a density of at least 99.9% of theoretical.

7. A process according to claim 1, wherein the forging produced by the forging step weighs at least 2300 kg.

8. A process according to claim 1, wherein the billet formed by the hot working step weighs about 1.2 to about 1.5 times the weight of the forging.

9. A process according to claim 1, wherein the billet formed by the hot working step weighs about 1.8 to about 4 times the weight of the rotor component.

10. A process according to claim 1, wherein the component is a rotor component of a gas turbine engine.

11. A process according to claim 1, wherein the rotor component is chosen from the group consisting of turbine wheels and spacers.

12. A process of producing a gas turbine engine rotor component from a gamma prime or gamma double prime precipitation-strengthened nickel-base nickel-based superalloy, the process comprising the steps of:

melting the nickel-based superalloy in a controlled environment to obtain a melt of the nickel-based superalloy;
convert the melt into a powder of generally spherical particles that are predominantly about 0.100 mm in diameter or smaller;
sieving the powder in a controlled environment to remove all particles larger than 0.100 mm in diameter;
filling a mild steel can with the sieved powder and evacuating and sealing the can in a controlled environment;
consolidating the can and the powder therein at a temperature, time, and pressure to produce a consolidation having a density of at least 99.9 percent of theoretical;
hot working the consolidation to produce a billet of a size sufficient to form a forging of at least 2300 kg with a uniform grain size of ASTM 10 or finer throughout the billet;
forging the billet into a forging at a temperature and strain rate to achieve a uniform fine grain of ASTM 10 or finer throughout the forging;
performing a heat treatment on the forging to achieve a desired balance of mechanical properties and maintain a uniform grain size throughout of ASTM 10 or finer; and
machining the forging to produce the gas turbine engine rotor component.

13. A process according to claim 12, wherein the nickel-based superalloy has a composition of, by weight, about 19 to about 23% chromium, about 7 to about 8% molybdenum, about 3 to about 4% niobium, about 4 to about 6% iron, about 0.3 to about 0.6% aluminum, about 1 to about 1.8% titanium, about 0.002 to about 0.004% boron, about 0.35% maximum manganese, about 0.2% maximum silicon, about 0.03% maximum carbon, the balance nickel and incidental impurities.

14. A process according to claim 12, further comprising the step of blending the powder with a second powder of the nickel-based superalloy before the filling step.

15. A process according to claim 12, wherein the forging produced by the forging step weighs at least 2300 kg.

16. A process according to claim 12, wherein the billet formed by the hot working step weighs about 1.2 to about 1.5 times the weight of the forging.

17. A process according to claim 12, wherein the billet formed by the consolidation step weighs about 1.8 to about 4 times the weight of the rotor component.

18. A process according to claim 12, wherein the rotor component is chosen from the group consisting of turbine wheels and spacers.

19. A process according to claim 18, wherein the rotor component is a component of a land-based gas turbine engine.

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