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(54) **Powder metal mold**

(57) Described is a process of producing a component from a gamma prime or gamma double prime precipitation-strengthened nickel-base superalloy. The process includes forming a powder of the superalloy and filling a can (10) with the powder wherein the can includes nickel-chromium-molybdenum-niobium alloy. The can (10) is evacuated and sealed in a controlled environment. The can (10) and the powder are consolidated at a temperature, time, and pressure to produce a consolidation. The consolidated billet is forged at a temperature and strain rate to produce a forging with a uniform fine grain throughout. A further aspect described is a mold including a nickel-chromium-molybdenum-niobium alloy can.

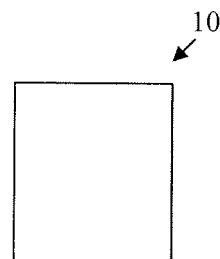


Figure 1

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Description

TECHNICAL FIELD

[0001] This invention relates to powder metal molds and processes for producing forgings using metal powders as the starting material. More particularly, this invention is directed to a mold and process for producing components with improved properties.

BACKGROUND OF THE INVENTION

[0002] A process for manufacturing very large nickel-base alloy rotor forgings, generally in excess of 5000 pounds (about 2300 kg), using powder metallurgy (PM) techniques is discussed in US Pub. 2007/0020135. Powder metal alloys are used to produce nickel-base consolidations 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. A particularly suitable alloy is the commercially available 725 INCONEL® Alloy 725, hereinafter referred to as Alloy 725.

SUMMARY OF THE INVENTION

[0003] An aspect discussed herein is a process of producing a component from a gamma prime or gamma double prime precipitation-strengthened nickel-base superalloy. The process includes forming a powder of the superalloy and filling a can with the powder, wherein the can includes a nickel-chromium-molybdenum-niobium alloy. The can is evacuated and sealed in a controlled environment. The can and the powder are consolidated at a temperature, time, and pressure to produce a consolidation. The billet is forged at a temperature and strain rate to produce a forging.

[0004] A further aspect shown is a mold including a nickel-chromium-molybdenum-niobium alloy can.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] There follows a detailed description of embodiments of the invention by way of example only with reference to the accompanying drawings, in which:

[0006] Figure 1 shows a mold;

[0007] Figure 2 shows a mold after loading with powder metal and HIP processing; and

[0008] Figure 3 shows a mold machined square after loading with powder metal and HIP processing.

DETAILED DESCRIPTION OF THE INVENTION

[0009] Alloy 725 PM billets are created by first filling a welded metal can or mold with powder prior to the hot-isostatic pressing (HIP) process. These cans or molds are typically manufactured from low-cost mild steel or stainless steel. However, cans or molds produced from

low-cost mild steel or stainless steel create an elementally different diffusion layer between the contents of the can and the can itself. The dissimilar steel layer and diffusion layers interfere with ultrasonic testing (UT) of the billet after the HIP process. The diffusion layer should be machined away prior to forming of a part from the billet to maximize the risk of cracking during the billet forging process. Finally, elimination of the diffusion layer would allow for UT inspection without removal of the can.

[0010] An aspect of the disclosure is a can or mold suitable for hot isostatic pressing (HIP). Shown in Fig. 1 is a can 10 suitable for hot isostatic pressing (HIP) of a powder metal. After filling the can 10 with the powder metal and subjecting it to HIP, the can deforms as shown in Fig. 2. The deformed sides of can 10 and the processed metal form a layer 12 that has a composition that is a combination of the powder metal and the material of the can. The next step in the process is to machine the sides of the can 10 so that they are smooth and square for UT inspection. In Fig. 3 a machined can 10 is shown where some of the layer formed from the powder metal and the can is shown in an exaggerated manner by residual layer 13. Once the sides are machined smooth and square, the resulting billet is inspected with ultra sonic testing to detect defects.

[0011] When using a steel can to form a billet of Alloy 725, layer 12 (can plus diffusion layer) shown in Fig. 2 needs to be completely removed, or there is a potential for cracks. If the layer is not fully removed by machining, a residual layer 13 (can and diffusion layer or diffusion) results, as shown in Fig. 3. This boundary layer attenuates the UT signal and counteracts the improved inspection sensitivity brought about by using fine grain Alloy 725 material.

[0012] In one aspect, the can is made from a nickel-chromium-molybdenum-niobium alloy, such as INCONEL® alloy 725. INCONEL® alloy 725 has a composition of, by weight, about 55.0 to about 59.0% nickel, about 19.0 to about 22.5% chromium, about 7.0 to about 9.5% molybdenum, about 2.75 to about 4.00% niobium, about 1.0 to about 1.7% titanium, about 0.35% maximum aluminum, about 0.03 % maximum carbon, about 0.35% maximum manganese, about 0.20% maximum silicon, about 0.015% phosphorous, about 0.010% maximum sulfur, the balance iron and incidental impurities.

[0013] A particularly suitable alloy for illustrating the advantages of this mold or can is a gamma-prime precipitation strengthened nickel-base superalloy based on the commercially available Alloy 725. The superalloy, identified herein as INCONEL® alloy 725, 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.

[0014] Properties of conventionally cast plus wrought Alloy 725 as discussed in U.S. Pat. No. 6,315,846 to Hibner et al. and U.S. Pat. No. 6,531,002 to Henry et al. render the alloy particularly well suited for producing very large forgings from powder metal. These properties include room and elevated temperature tensile strength and ductility.

[0015] While described in reference to the Alloy 725, the teachings herein are applicable to other gamma prime and gamma double prime precipitation-strengthened nickel-based superalloys, such as Alloy 625.

[0016] For the applications of interest to the invention, optimum processability and mechanical properties are achieved by uniform grain sizes of not larger than American Society for Testing and Materials (ASTM) about 8, or preferably about 10. Grain sizes larger than ASTM 8 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, can increase hot working load requirements, and can inhibit the thorough ultrasonic inspection of billets and thick section forgings. Therefore, a preferred aspect 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 8 or finer. Such a process is discussed in US Pub. 2007/0020135.

[0017] The powder is placed in a suitable nickel-chromium-molybdenum-niobium alloy can, whose size will meet the billet size requirement after consolidation. This can is shown in Fig. 1. 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 is accomplished by hot isostatic pressing (HIP). The can be any shape, such as a cylinder or cube but is preferable that the sides are square.

[0018] As shown in Fig. 2, the can is deformed post HIP. The deformed can and processed powder exist as a slightly deformed billet having a layer 12 on the outer edges. The outer edges are machined square as shown in Fig. 3. By eliminating the difference in composition between the can and the powder metal layer that occurs when a can of mild steel or stainless steel is used, less machining is required as removal of the entire layer 12 is not essential. The residual layer 13 (Fig. 3) does not impart any detrimental effects on the resulting billet. In addition, inspection through ultrasonic testing is easier.

[0019] 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 8. 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 and resulting cost savings are enabled by the improved processability of fine-grained billet as well as the enhanced sonic inspectibility thereof.

[0020] The resulting rotor forging preferably undergoes ultrasonic inspecting for potential life-limiting defects. However, since the input billet lacks a diffusion layer, improved inspection is possible as there is less material and time wasted in prepping the billet for UT inspection.

[0021] Inspection 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 industrial gas turbine service. An illustrative example of an appropriate heat treatment process for the Alloy 725 entails a solution heat treatment at a temperature of about 900 °C (about 1650 °F) for approximately four hours, followed by two step aging at a temperature of about 760 °C (about 1400 °F) for approximately eight hours, then cooling at a rate of 56 °C (about 100 °F) per minute to about 620 °C (about 1150 °F) and holding for approximately eight hours, followed by air cooling.

[0022] The terms "first," "second," and the like, herein do not denote any order, quantity, or importance, but rather are used to distinguish one element from another, and the terms "a" and "an" herein do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced item. The modifier "about" used in connection with a quantity is inclusive of the stated value and has the meaning dictated by the context, (e.g., includes the degree of error associated with measurement of the particular quantity). The suffix "(s)" as used herein is intended to include both the singular and the plural of the term that it modifies, thereby including one or more of that term (e.g., the metal(s) includes one or more metals). Ranges disclosed herein are inclusive and independently combinable (e.g., ranges of "up to about 25 w/o, or, more specifically, about 5 w/o to about 20 w/o", are inclusive of the endpoints and all intermediate values of the ranges of "about 5 w/o to about 25 w/o," etc).

[0023] While various embodiments are described herein, it will be appreciated from the specification that various combinations of elements, variations or improve-

ments therein may be made by those skilled in the art, and are within the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

Claims

1. A process of producing a component from a gamma prime or gamma double prime precipitation-strengthened nickel-base superalloy, the process comprising:
 - forming a powder of the superalloy;
 - filling a can (10) with the powder wherein the can comprises nickel-chromium-molybdenum-niobium alloy;
 - 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 billet; and
 - forging the billet at a temperature and strain rate to produce a forging.
2. A process according to claim 1 or 2, wherein the nickel-base 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, a balance of nickel and incidental impurities.
3. A process according to claim 1 or 2, wherein the nickel-chromium-molybdenum-niobium alloy has a composition of, by weight, about 55.0 to about 59.0% nickel, about 19.0 to about 22.5% chromium, about 7.0 to about 9.5% molybdenum, about 2.75 to about 4.00% niobium, about 1.0 to about 1.7% titanium, about 0.35% maximum aluminum, about 0.03 % maximum carbon, about 0.35% maximum manganese, about 0.20% maximum silicon, about 0.015% phosphorous, about 0.010% maximum sulfur, a balance of iron and incidental impurities.
4. A process according to any one of the preceding claims, wherein the billet formed by the consolidation step has a density of at least 99.9 % of theoretical.
5. A process according to any one of the preceding claims, wherein the component is a rotor component of a gas turbine engine.
6. A process according to claim 5, wherein the billet weighs about 1.8 to about 4 times the weight of the component.
7. A process according to any one of the preceding claims, further comprising solution heat treating the forging.
 - solution heat treatment at a temperature of about 900 °C for approximately four hours;
 - aging at a temperature of about 760 °C for approximately eight hours;
 - cooling at a rate of about 56 °C per minute to about 620 °C;
 - holding for approximately eight hours; and
 - air cooling.
8. A process according to claim 7, wherein the solution heat treating comprises:
 - solution heat treatment at a temperature of about 900 °C for approximately four hours;
 - aging at a temperature of about 760 °C for approximately eight hours;
 - cooling at a rate of about 56 °C per minute to about 620 °C;
 - holding for approximately eight hours; and
 - air cooling.
9. A process according to any one of the preceding claims, further comprising machining the forging.
10. A process according to any one of the preceding claims, wherein the billet has a grain size of no larger than about ASTM 8.
11. A process according to any one of the preceding claims, further comprising ultrasonic testing of the forging.
12. A process according to any one of the preceding claims, further comprising ultrasonic testing of the billet.
13. A mold (10) comprising:
 - a nickel-chromium-molybdenum-niobium alloy can.
14. The mold (10) of claim 13, wherein the nickel-chromium-molybdenum-niobium alloy has a composition of, by weight, about 55.0 to about 59.0% nickel, about 19.0 to about 22.5% chromium, about 7.0 to about 9.5% molybdenum, about 2.75 to about 4.00% niobium, about 1.0 to about 1.7% titanium, about 0.35% maximum aluminum, about 0.03 % maximum carbon, about 0.35% maximum manganese, about 0.20% maximum silicon, about 0.015% phosphorous, about 0.010% maximum sulfur, a balance of iron and incidental impurities.
15. The mold (10) of claim 13 or 14 wherein sides of the can are substantially square.

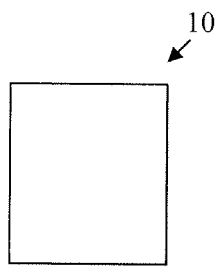


Figure 1

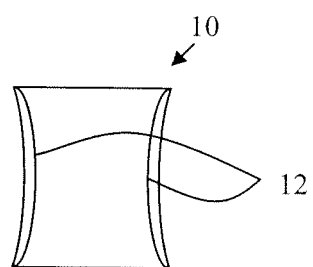


Figure 2

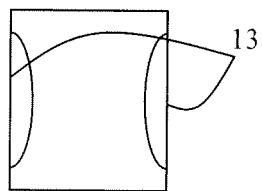


Figure 3

REFERENCES CITED IN THE DESCRIPTION

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