(19) European Patent Office / Europäisches Patentamt / Office européen des brevets

(11) **EP 1 779 946 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
02.05.2007 Bulletin 2007/18

(51) Int Cl.:
B22F 3/15 *(2006.01)* ***B22F 3/14*** *(2006.01)*
B22F 5/10 *(2006.01)* ***C22C 1/04*** *(2006.01)*

(21) Application number: **06255430.8**

(22) Date of filing: **23.10.2006**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IS IT LI LT LU LV MC NL PL PT RO SE SI SK TR
Designated Extension States:
AL BA HR MK YU

(30) Priority: **26.10.2005 US 258663**

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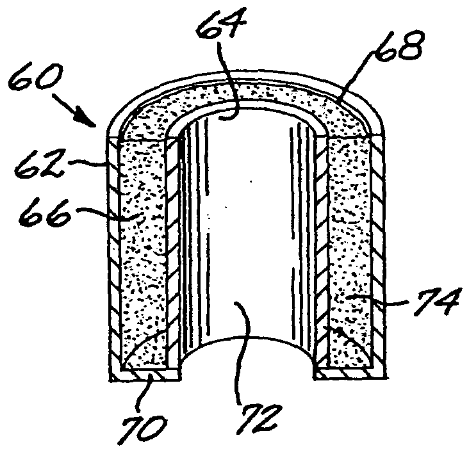
(54) **Supersolvus hot isostatic pressing and ring rolling of hollow powder forms**

(57) An annular metallic article (20) is fabricated by loading a metallic powder (74) into a fill volume (66) of a can (60), compacting the metallic powder (74) by hot isostatic pressing the metallic powder (74) within the can (60) at a temperature above the precipitate solvus temperature and below the solidus temperature of the metallic powder (74) to form a compacted powder mass (76), and ring rolling the compacted powder mass (76) to form the metallic article (20) having the annular circular shape.

FIG. 4



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Description

[0001] This invention relates to the fabrication of annular articles and, more particularly, to the fabrication of such annular articles from metal powders with minimal wasted material.

BACKGROUND OF THE INVENTION

[0002] A number of important commercial articles have the shape of an annulus or annular band. Such articles are typically, but not necessarily, thin-walled cylinders with a large ratio of inner diameter-to-outer diameter (DI/DO) of greater than 0.75 but less than 1.0. For example, in aircraft engines the turbine blade retainers and the turbine cases are thin-walled cylinders having DI/DO of about 0.85 and 0.95, respectively.

[0003] Taking the turbine-blade retainer as an example, this article is often made from a powder-metal, precipitation-strengthened nickel-base superalloy selected for use in severe operating conditions. The nickel-base superalloy composition is melted and atomized to form a powder, and consolidated by a combination of hot isostatic pressing, hot compaction, and extrusion to form re-forge stock. The powder is then worked by isothermal or hot-die forging into the form of a flat or contoured pancake. The center section of the pancake is removed by trepanning, and the outer surface is machined to a generally cylindrical form. This preform is machined to the required ratio of inner diameter-to-outer diameter. The removed center section and chips become revert material sent back to the melting operation.

[0004] While operable and in use today, this approach has several drawbacks. The isothermal upset forge and trepan method is not feasible for components of appreciable axial length (i.e., greater than about 6 inches in length) due to forging and trepan machining equipment limitations. In addition, material flow is normal to the primary in-service stresses, producing unfavorable materials properties. The current process is also uneconomic, because large weights of expensive superalloy material are trepanned and machined away, and are sold as lower-value scrap. Consequently, the "buy-to-fly" cost ratio is high, typically 10:1 1 or more, and the final retainer article is overly expensive to manufacture. The production of other articles such as turbine casings from powder is not feasible due to unacceptable costs and insufficient forge capacity.

[0005] There is a need for an improved approach to the production of annular metallic articles that results in improved properties with reduced cost. The present invention fulfills this need, and further provides related advantages.

SUMMARY OF THE INVENTION

[0006] The present invention provides an approach for fabricating an annular metallic article from a powder starting material. The microstructure of the final article is homogeneous, within the limits of the rolling process. The final article does not have cast-in or working imperfections or cracking associated with production techniques using cast-and-wrought procedures. The present approach is also highly economical in terms of the buy-to-fly cost ratio, because little, if any, material is removed by trepanning or machining of a center section.

[0007] A method for fabricating an annular metallic article comprises the steps of providing a can having an outer wall, an inner wall, and a fill volume between the outer wall and the inner wall, and loading a metallic powder into the fill volume. The metallic powder is of a composition that has a precipitate solvus temperature, and a solidus temperature, which is greater than the precipitate solvus temperature. The method further includes compacting the metallic powder at a temperature between the precipitate solvus temperature and the solidus temperature (i.e., greater than the precipitate solvus temperature and less than the solidus temperature) to form a compacted powder mass, and ring rolling the compacted powder mass to form the annular metallic article. The step of compacting is preferably performed by hot isostatic pressing the can with the metallic powder therein. Preferably, the method includes no press forging; the method includes no extrusion; and the method includes no upset forging. The compacted powder mass may be removed from the can after the step of compacting and before the step of ring rolling, but the ring rolling may instead be performed with the can in place.

[0008] The metallic powder is preferably made of a pre-alloyed nickel-base superalloy having a gamma prime (γ') precipitate solvus temperature and a solidus temperature greater than the precipitate solvus temperature. The step of compacting includes the step of compacting the metallic powder above the gamma prime precipitate solvus temperature and below the solidus temperature to produce a microstructure amenable to deformation by the ring rolling method.

[0009] Ring rolling may be performed in any operable manner, but is preferably performed at a temperature of below the precipitate solvus temperature to control grain size.

[0010] The final article may have an annular circular shape, so that it is cylindrically symmetric with its outer surface and its inner surface both substantially cylindrical. In the preferred case, the annular circular shape has a ratio of an inner diameter to an outer diameter (DI/DO) of greater than 0.75 and less than 1.0. The approach is operable with smaller ratios of DI/DO, but its greatest economic benefits are realized when DI/DO is greater than 0.75 and less than 1.0. The final article need not be cylindrically symmetric, and could have contoured cross-sectional shapes other than cylinders, such as for example, annular truncated cones.

[0011] Thus, in a preferred embodiment a method for fabricating an annular metallic article comprises the steps of providing a can having a cylindrical outer wall, a cylindrical inner wall, and a fill volume between the outer wall and the inner wall, and loading a metallic powder into the fill volume. The metallic powder is a pre-alloyed nickel-base superalloy having a gamma prime precipitate solvus temperature and a nickel-base superalloy solidus temperature above the gamma prime precipitate solvus temperature. The method further includes compacting the metallic powder by hot isostatic pressing within the can at a temperature above the gamma prime precipitate solvus temperature to form a compacted powder mass, and ring rolling the compacted powder mass to form the metallic article having an annular circular shape. No press forging, no extrusion, and no upset forging are employed in the method. Other operable features described herein may be used with this embodiment.

[0012] The present approach fabricates an annular metallic article from powder metal. The material is not cast and wrought, so that there is no cracking, casting segregation, or other imperfection resulting from casting and working operations. The present approach allows the use of some highly alloyed metals that cannot be fabricated into annular articles by the conventional approach, because they are too strong to be fabricated by the conventional approach. The metal powder is initially loaded into the annular fill volume of the can having an inner wall and an outer wall, and then the can with the metal powder is consolidated. The resulting annular powder compact is then ring rolled to the final form. The use of the hollow-can (that is, hollow between its inner wall and its outer wall) approach results in relatively efficient utilization of the powder metal in the final ring-rolled annular article--the "buy-to-fly" ratio is closer to 1.0 than achieved by current methods. This approach greatly reduces or avoids entirely the need to remove and scrap metal from the central portion of a conventional forging as in prior approaches. The result is that the metallurgical and mechanical performances of the final annular article, and its cost, are improved over that achieved by prior approaches.

[0013] The present approach is to be contrasted with conventional ring rolling, in which the ring-rolling stock is prepared by casting and upset forging. The working of the reforge stock to a ring by conventional ring rolling would cause cracking in the nickel-base superalloy, which normally has a high flow stress and limited ductility. Cracking during conventional upset, punch, and ring rolling may be reduced by changing the alloying content of the nickel-base superalloy to increase the ductility and achieve the malleability required for the ring-rolled article, but the result is reduced material performance in service. Textures and other characteristics of the rolled material may be retained into the final article in the conventional ring-rolling approach, resulting in anisotropic properties.

[0014] 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

[0015]

Figure 1 is a perspective view of an annular metallic article;

Figure 2 is a sectional view through the annular metallic article of Figure 1, taken on line 2-2;

Figure 3 is a block diagram of an approach for fabricating the annular metallic article; and

Figure 4 is a schematic perspective view of a can, showing powder filling its interior; and

Figure 5 is a schematic view of a ring-rolling apparatus and operation.

DETAILED DESCRIPTION OF THE INVENTION

[0016] Figures 1 and 2 depict an annular metallic article 20. The annular metallic article 20 has an outer surface 22, an inner surface 24, an interior volume 26 within the inner surface 24, an axis 28 extending through the interior volume 26, and solid metal in an annular volume 30 between the outer surface 22 and the inner surface 24. The annular metallic article 20 may be cylindrical with the axis 28 as a cylindrical axis so that the annular metallic article 20 is circular in cross section as illustrated in Figure 2, or it may be noncircular in cross section. Where the annular metallic article 20 is cylindrical with a circular cross section as shown in Figure 2, the annular metallic article 20 may be described as having an outer diameter DO of the outer surface 22 and an inner diameter DI of the inner surface 24. It is preferred, but not necessary, that the ratio DI/DO be greater than 0.75 and less than 1.0, which is termed herein a "thin-walled" annular article.

[0017] Figure 3 depicts a method for fabricating the annular metallic article 20. The method includes providing a can

60, step 40. The can is desirably made of a metal such as 300-series stainless steel. The can 60, illustrated in Figure 4, has an outer wall 62, an inner wall 64, an annular fill volume 66 between the outer wall 62 and the inner wall 64, an open top 68 to the fill volume 66, and preferably a solid bottom 70 to the fill volume 66. The annular fill volume 66 of the can 60 is initially empty and hollow, but is subsequently filled with powder, as shown. Desirably, an open central space 72 extends through the volume bounded by the inner wall 64.

[0018] A metallic powder 74 is loaded into the fill volume 66 of the can 60, step 42. In the preferred embodiment, the metallic powder 74 is of a nickel-base superalloy composition that has a gamma prime precipitate solvus temperature and a solidus temperature that is greater than the gamma prime precipitate solvus temperature. That is, there is a gamma prime phase that is present below the precipitate solvus temperature, and that phase dissolves into the metallic matrix when the temperature is raised into the range above the precipitate solvus temperature and below the solidus temperature of the metal powder to improve malleability. The metallic powder 74 may be pre-alloyed or not pre-alloyed, but pre-alloyed is preferred because subsequent processing is typically not at a sufficiently high temperature and for a sufficiently long time to achieve substantially complete homogeneity, if the powder is not furnished in the pre-alloyed form.

[0019] In the applications currently of most interest, the metallic powder 74 is a nickel-base superalloy composition. As used herein, "nickel-base" means that the composition has more nickel than any other element. The nickel-base superalloy is defined as a nickel-base alloy strengthened by the precipitation of gamma prime or a related phase. Some nickel-base superalloys of particular interest include ReneTM 88DT, having a nominal composition, in weight percent, of about 13 percent cobalt, about 16 percent chromium, about 4 percent molybdenum, about 3.7 percent titanium, about 2.1 percent aluminum, about 4 percent tungsten, about 0.75 percent niobium, about 0.015 percent boron, about 0.03 percent zirconium, about 0.05 percent carbon, up to about 0.5 percent iron, balance nickel and minor impurity elements; and ReneTM 95, having a nominal composition, in weight percent, of about 13 percent chromium, about 8 percent cobalt, about 3.5 percent molybdenum, about 3.5 percent tungsten, about 3.5 percent niobium, about 2.5 percent titanium, about 3.5 percent aluminum, about 0.01 percent boron, about 0.05 percent zirconium, about 0.06 percent carbon, balance nickel and incidental impurities. Each of these nickel-base superalloys has a gamma-prime precipitate solvus temperature (less than the solidus temperature), above which the gamma-prime phase dissolves into the gamma matrix, and below which the gamma-prime phase is thermodynamically stable. These alloys are of particular interest in fabricating annular metallic articles 20 such as turbine blade retainers and turbine cases because they offer improved mechanical performance to the articles but are of too high a strength and too low a malleability to be fabricated by the conventional casting and upset forging approach. The present approach allows annular metallic articles 20 of such materials to be fabricated of such materials.

[0020] The metallic powder 74 is compacted at a temperature above the precipitate solvus temperature and below the solidus temperature of the metallic powder 74 to form a compacted powder mass with sufficient malleability to work by methods such as ring rolling, step 44. To perform the compacting, the fill volume 66 having the metal powder therein is sealed (and optionally evacuated), as by welding an annular top plate over the open top 68. The compacting is preferably performed by hot isostatic pressing (HIP) the metallic powder 74 within the can 60, thereby using the can as the containment vessel for the hot isostatic pressing. Other operable compacting techniques such as extrusion or upset forging may be used but are less preferred because they tend to impart a preferred orientation to the compacted powder mass. However, if such a preferred orientation is desired, these other techniques may be used. The compacting step 44 increases the relative density of the mass of metallic powder 74 and also causes the individual particles to bond together and become cohesive. Because of the form of the can 60 and the annular fill volume 66, the compacted powder mass is annular in shape. A central portion of the compacted powder mass is therefore not trepanned or otherwise removed, avoiding the need for this costly processing step found in conventional approaches.

[0021] The compacted powder mass may optionally be removed from the can 60 at this point, step 46. Alternatively, the next step may be performed with the compacted powder mass still within the can 60. If the compacted powder mass is removed from the can 60, the removal is preferably accomplished by machining the can 60 from the exterior of the compacted powder mass.

[0022] The compacted powder mass is ring rolled to form the annular metallic article 20, step 48. Ring rolling is a known rolling technology for other applications, but has not been used in the present manner. Figure 5 schematically depicts the compacted powder mass 76 being processed by a ring-rolling apparatus 78. The ring rolling step 48 starts with the annular compacted powder mass 76 resulting from step 44 (or from step 46, if used), and continuously reduces a thickness T of the annular compacted powder mass 76 as each portion passes between the ring rolls, until the desired thickness is reached. If the annular compacted powder mass 76 is cylindrical, the final annular metallic article 20 is typically cylindrical or nearly cylindrical, and can be straightened to a cylindrical form if desired. The ring rolling is preferably performed at a ring-rolling temperature below the gamma prime precipitate solvus temperature to control grain growth and grain structure of the material during the ring rolling.

[0023] If the optional step 46 was not performed and the compacted powder mass was ring rolled in the can 60 in step 48, the ring-rolled annular metallic article 20 may be removed from the remnants of the can 60, step 50. (That is, either step 46 or step 50 is normally performed, but not both steps.) This removal is preferably accomplished by machining the remnants of the can 60 from the ring-rolled annular metallic article 20. Alternatively, for some applications it may be desired to leave the remnants of the metallic can 60 in place, and neither step 46 nor step 50 is performed. Subsequent optional heat treatment processes, step 52, such as solution heat treating and precipitation ageing may be performed with the can intact or after removal of the can.

[0024] The article may optionally be final processed, step 54, such as by final machining and/or coating. The order of steps 50, 52, and 54, when performed, may be interchanged as necessary or desired.

[0025] Although a particular embodiment of the invention has been described in detail for purposes of illustration, various modifications and enhancements may be made without departing from the spirit and scope of the invention. Accordingly, the invention is not to be limited except as by the appended claims.

PARTS LIST

[0026]

20	Annular article	70	Solid bottom
22	Outer surface	72	Central space
24	Inner surface	74	Metallic powder
26	Interior volume	76	Compacted powder
28	Axis	78	Ring-rolling apparatus
30	Annular volume	80	
32		82	
34		84	
36		86	
38		88	
40		90	
42		92	
44		94	
46		96	
48	Figure 3	98	
50		100	
52		102	
54		104	
56		106	
58		108	
60	Hollow can	110	
62	Outer wall	112	
64	Inner wall	114	
66	Fill volume	116	
68	Open top	118	

Claims

1. A method for fabricating an annular metallic article (20), comprising the steps of providing a can (60) having an outer wall (62), an inner wall (64), and a fill volume (66) between the outer wall (62) and the inner wall (64);

loading a metallic powder (74) into the fill volume (66), wherein the metallic powder (74) is of a composition that has a precipitate solvus temperature and a solidus temperature greater than the precipitate solvus temperature;
compacting the metallic powder (74) at a temperature between the precipitate solvus temperature and the solidus temperature to form a compacted powder mass (76); and
ring rolling the compacted powder mass (76) to form the annular metallic article (20).

2. The method of claim 1, wherein the step of loading includes the step of
providing the metallic powder (74) made of a pre-alloyed nickel-base superalloy having a gamma prime precipitate solvus temperature.

3. The method of claim 1, wherein the step of loading includes the step of
providing the metallic powder (74) made of a pre-alloyed nickel-base superalloy having a gamma prime precipitate solvus temperature, and the step of compacting includes the step of
compacting the metallic powder (74) above the gamma prime precipitate solvus temperature.

4. The method of claim 1, wherein the step of loading includes the step of
providing a metallic-powder composition having too high a strength and too low a malleability to be fabricated into an annular metallic article (20) by casting and upset forging.

5. The method of claim 1, wherein the step of compacting includes the step of
hot isostatic pressing the can (60) with the metallic powder (74) therein.

6. The method of claim 1, wherein the method includes no press forging, no extrusion, and no upset forging.

7. The method of claim 1, wherein the step of ring rolling includes the step of
ring rolling the compacted powder mass (76) at a temperature below the precipitate solvus temperature.

8. The method of claim 1, wherein the step of ring rolling includes the step of
ring rolling the compacted powder mass (76) to an annular circular shape.

9. The method of claim 1, wherein the step of ring rolling includes the step of
ring rolling the compacted powder mass (76) to an annular circular shape having a ratio of an inner diameter to an outer diameter of greater than 0.75 and less than 1.0.

10. The method of claim 1, including an additional step, after the step of ring rolling, of heat treating the annular metallic article (20).

FIG.1

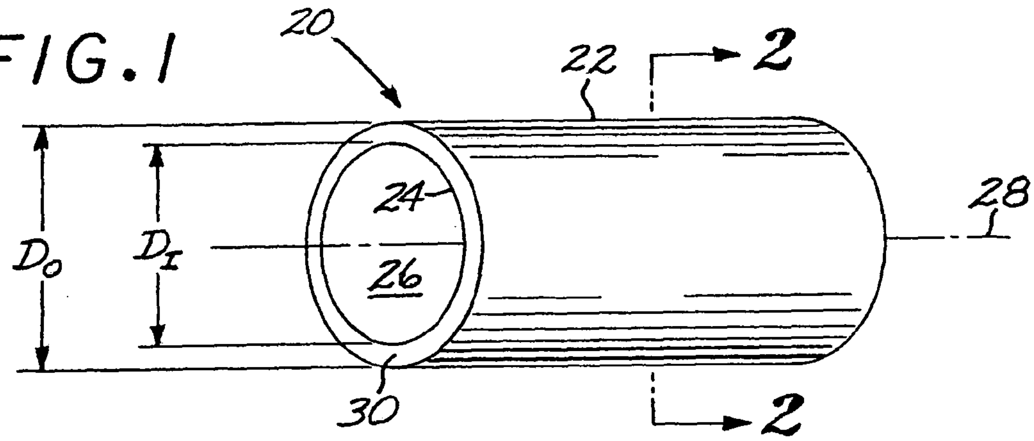


FIG.2

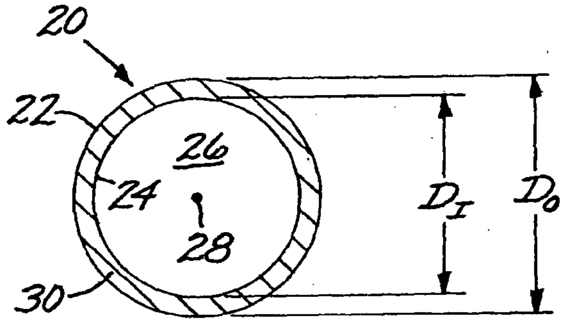


FIG.4

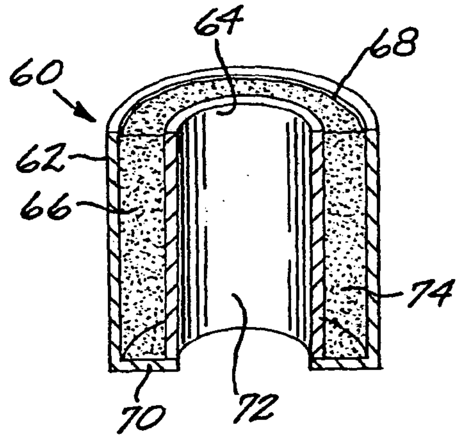
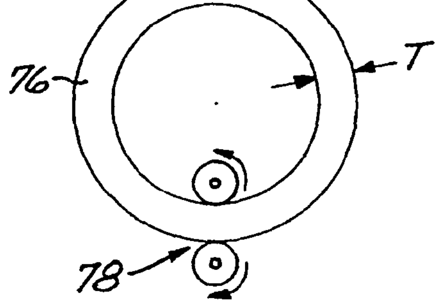


FIG.5



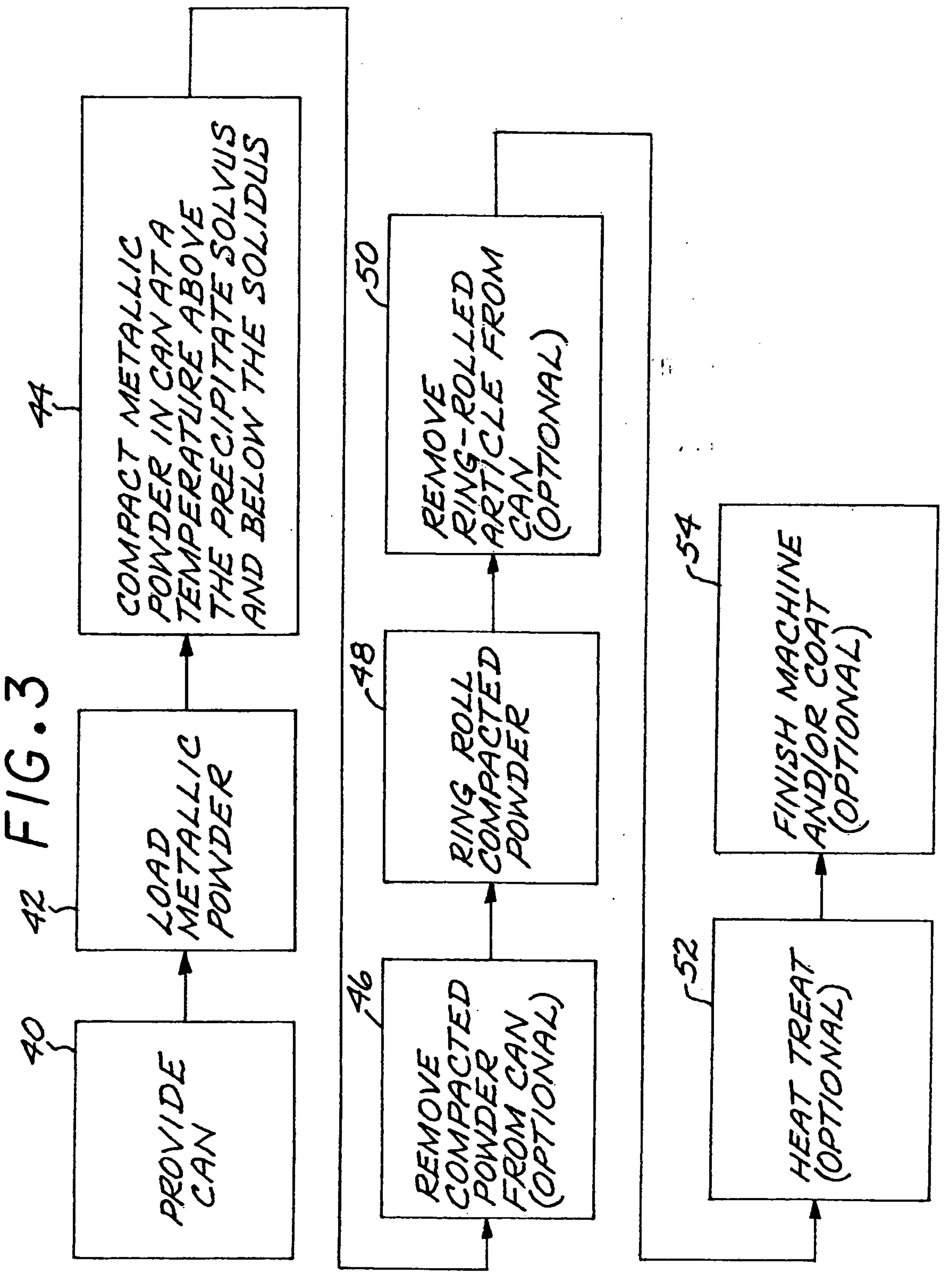

40
PROVIDE CAN
42
LOAD METALLIC POWDER
44
COMPACT METALLIC POWDER IN CAN AT A TEMPERATURE ABOVE THE PRECIPITATE SOLVUS AND BELOW THE SOLIDUS
46
REMOVE COMPACTED POWDER FROM CAN (OPTIONAL)
48
RING ROLL COMPACTED POWDER
50
REMOVE RING-ROLLED ARTICLE FROM CAN (OPTIONAL)
52
HEAT TREAT (OPTIONAL)
54
FINISH MACHINE AND/OR COAT (OPTIONAL)

FIG. 3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 06 25 5430

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	5 February 2007	ALVAZZI DELFRATE, M

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