METAL POWDER EXTRUSION PROCESS

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Assistant Examiner—D. C. Reiley, Ill
Attorney, Agent, or Firm—Harness, Dickey & Pierce

ABSTRACT

A ductile extrusion container and a process for consolidating metal powder into a dense mass which incorporates one or a plurality of longitudinally extending core elements of a different material embedded therein. The core elements are subsequently removed, such as by machining or leaching, producing a billet having one or a plurality of elongated apertures at preselected locations therethrough.

4 Claims, 8 Drawing Figures
3,823,463

METAL POWDER EXTRUSION PROCESS

BACKGROUND OF THE INVENTION

Various metals and metallic alloys are of a metallurgical structure in the as-cast condition that renders them exceedingly difficult to shape employing conventional forming operations. Typical of such metallic alloys are the so-called modern “super-alloys” which generally comprise nickel-base alloys that contain relatively large amounts of second-phase gamma-prime and complex carbides in a gamma matrix which are responsible for the excellent high temperature physical properties of such superalloys. These same complex carbides and second-phase gamma-prime constituents, however, make it exceedingly difficult to post-form cast billets of such alloys due to their inherent cast-in segregation which causes failure during such forming operation.

Many of the foregoing problems have been overcome in the fabrication of components from superalloys and other similar expensive and difficult-to-form alloys by resorting to powder metallurgical techniques. In accordance with such practice, the metal alloy is microcast or atomized into a powder of a selected particle size and thereafter is consolidated, while heated to an elevated temperature, into a dense mass approaching 100% theoretical density while in a substantially oxygen-free environment. A protection of the metal powder from oxidation attack during heating prior to compaction is conveniently achieved by placing the powder in a suitable deformable container which has preliminarily been evacuated of air and back-flushed with a suitable inert gas which, after filling with the powder, is re-evacuated and sealed. Such deformable containers are thereafter heated and compacted to effect a densification of the powder into a mass, thereafter the container is removed, such as by machining, from the periphery of the resultant billet. By carefully selecting the shape of the container and the means for effecting a compaction thereof, billets approaching the shape of the final desired part can be produced, minimizing the number and magnitude of forming operations to which the billet must be subjected, as well as substantially reducing the amount of final machining of the component.

A continuing problem associated with the fabrication of components from billets or ingots produced by the foregoing powder metallurgical techniques has been the necessity of removing, by various metal machining operations, a substantial portion of the original metallic mass. In the case of hubs and disks of the type used in aircraft gas turbine engines, for example, a substantial proportion of the central area of the billet is removed in order to accommodate a shaft or other supporting mechanism for the completed component. The poor machinability of materials of this type has reduced design flexibility and has increased the fabrication cost of such components. Additionally, the removal of substantial quantities of metal from the original billet by various machining and metal removal techniques has also detracted from an optimum utilization of the billet and a conservation of the high-cost metal alloy of which it is comprised.

The foregoing problems and disadvantages are overcome in accordance with the practice of the present invention in which billets can be produced comprised of high cost difficult-to-machine and/or work metal alloys, intermetallic compounds and nonmetallic constituents incorporating one or a plurality of core elements therein at preselected locations corresponding to the locations at which a removal of material is to be performed, thereby facilitating such machining operations, as well as optimizing usage of the metal alloy.

SUMMARY OF THE INVENTION

The benefits and advantages of the present invention are achieved in accordance with the apparatus aspects thereof by providing a ductile container defining a chamber within which metallic powders or the like are adapted to be confined in sealed relationship, and wherein the container is adapted to be heated to a controlled elevated temperature and extruded through a die of reduced cross section, effecting a compaction of the metal powder therein into a mass approaching 100 percent theoretical density. The container is further characterized as incorporating a nose section formed with one or a plurality of core elements projecting longitudinally into the chamber and extending for a controlled length thereof. The core elements are concurrently extruded and elongated during the hot extrusion operation and become embedded within the resultant compacted mass or metal powder. The core elements may comprise any material which is deformable and which possesses characteristics enabling a simple and quick removal thereof from the mass, producing a resultant billet having one or a plurality of elongated apertures therethrough disposed at selected locations therealong.

In its method aspects, the present invention encompasses the method of making metal billets employing powder metallurgical techniques and utilizing an extrusion container incorporating one or a plurality of core elements disposed at selected locations within a chamber filled with metal powder, whereby the core elements are concurrently extruded during the hot compaction of the metal powder and subsequently can be removed, providing a billet having one or a plurality of elongated apertures at selected locations therein. The method further contemplates subjecting all or sections of the compacted mass to forming operations prior to the removal of the core elements or residual portions thereof.

Further advantages and benefits of the present invention will become apparent upon a reading of the description of the preferred embodiments, taken in conjunction with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a longitudinal vertical sectional view through an extrusion container incorporating a core element projecting rearwardly from the nose section thereof into a chamber filled with metal powder in accordance with one embodiment of the present invention;

FIG. 2 is a transverse vertical sectional view through the container shown in FIG. 1, as viewed substantially along the line 2--2 thereof;

FIG. 3 is a transverse sectional view similar to FIG. 2 and illustrating the use of four core elements disposed symmetrically about the longitudinal axis of an extrusion container;

FIG. 4 is a transverse vertical sectional view similar to that shown in FIG. 2, and illustrating a container and
core element of an elliptical cross sectional configuration;

FIG. 5 is a longitudinal vertical sectional view of an extrusion container and metal powder after having been subjected to a hot extrusion step;

FIG. 6 is a fragmentary perspective view of a compacted mass of metal powder incorporating a centrally extending circular core element therein;

FIG. 7 is a perspective view of a disk produced from the mass shown in FIG. 6 and with the section of the core element removed therefrom; and

FIG. 8 is a perspective view of a disk fabricated from a compacted mass produced utilizing an extrusion container of the type illustrated in FIG. 3.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is particularly applicable but not necessarily limited to the formation of composite billets composed of so-called nickel-based superalloys and tool steels which are characterized as being extremely difficult to post-form after casting, which are difficult to machine, which are of relatively high cost and which, in some instances, undergo macrosegregation during post-forming operations, preventing the attainment of optimum physical strength properties. Typical nominal compositions of various nickel and iron based alloys which can be advantageously formed employing powder metallurgical techniques in accordance with the practice of the present invention are those listed in Table 1. It will be understood that the specific compositions enumerated in Table 1 are not intended to be limiting of the scope of materials which can be advantageously processed in accordance with the present invention including any one of a variety of metallic powders, as well as powders containing appreciable quantities of intermetallic compounds and nonmetallic compounds.

Metal powders having compositions of the type enumerated in Table 1 can be efficiently produced by a variety of processing techniques, of which the microcasting of a molten mass of the metal alloy by gas atomization constitutes a preferred and convenient method. Apparatus suitable for microcasting the molten alloy into substantially spherical particles is fully described in U.S. Pat. No. 3,253,783, which is assigned to the same assignee as the present invention and the teachings thereof are incorporated herein by reference.

In view of the deleterious effects of oxygen on the physical properties of the final densified billet, it is usually preferred to perform the microcasting of the molten alloy and a solidification and collection of the particles under nonoxidizing conditions, whereby the oxygen content of the resultant powder is less than about 200 ppm, and preferably less than about 100 ppm. This can be conveniently attained by gas atomization of the molten alloy employing an inert gas and collecting the atomized particles in a collection chamber filled with a substantially moisture-free inert gas, of which argon constitutes a preferred substance.

The degree of precaution necessary to maintain the oxygen content of such powders below a preselected level is to a large extent dependent upon the types and quantities of alloying constituents present in the metal alloy. For example, the propensity of aluminum and titanium to react with oxygen necessitates a relatively high degree of precaution when either or both of these alloying constituents are present to prevent a build up of oxygen above about 200 ppm. By exercising reasonable precautions and employing microcasting and collection apparatus which contains an inert atmosphere, it is feasible to produce metal powders of the desired

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<th>C</th>
<th>Cr</th>
<th>Al</th>
<th>Ti</th>
<th>Mo</th>
<th>W</th>
<th>Co</th>
<th>Cb</th>
<th>B</th>
<th>Zr</th>
<th>Fe</th>
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| 18 Ni       |     |    |    | 2.5| 9.8| 10.0| 0.005| 5.0| bal. |
| Maraging Steel |     |    |    |    |    |    |    |    |    |    |    |    | bal. |
| M-2 Tool Steel | 0.85| 4.0|    | 5.0| 6.25| 8.0| 8.5| 8.5| bal.  |
| M-42 Tool Steel | 1.05| 3.5|    | 9.25| 1.3| 7.75| 7.75| 7.75| bal.  |
| WD-65 (PWA 779) | 1.05| 16.75|    | 3.75| 2.0| 5.5| 5.5| 5.5| bal.  |
composition and particle size which usually are of oxygen contents less than about 100 ppm. The use of helium or commercially available argon containing only minimal amounts of conventional impurities has been found particularly satisfactory for providing the substantially dry and inert atmosphere for effecting a gas atomization and collection of substantially oxygen-free metal powders. In accordance with the preferred practice, the interior of the equipment is initially evacuated to remove substantially all of the air therefrom, whereafter it is back-flooded with the inert gas preparatory to the microcasting operation.

Regardless of the particular technique by which the metal powder is produced, it is usually preferred that the individual powder particles are of substantially the same or similar alloy chemistry. The metal powder particles are selected to be of an average size as large as about 250 microns to as small as about one micron. Particularly satisfactory results are obtained when the average size of the powder particles ranges from about 150 microns down to about 10 microns and wherein the particles are randomly distributed over the foregoing range, providing for maximum packing density. Further densification of the free-flowing powder within an extrusion container can be effected by subjecting the container to sonic or supersonic vibrations during the filling operation.

Referring now in detail to the drawing, a device for effecting a hot extrusion compaction of the metal powder comprises an elongated container 10, as best seen in FIGS. 1 and 2, comprised of a nose section 12, a thin-walled body section 14 and an end plate 16, which define in combination an elongated internal chamber 18, which is adapted to be filled with the metal powder 20. The nose section 12 is preferably provided with a forwardly tapered or conical configuration, indicated at 22, to facilitate alignment of the container with an extrusion die (not shown) in response to an advancement of the container toward the left or in the direction of the arrow as indicated in FIG. 1. The nose section 12 is also preferably provided with an annular shoulder 24 on which the body section 14 is disposed in overlying relationship and is tenaciously secured thereto in sealing relationship such as by means of an annular weld 26.

In a similar manner, the end plate 16 is formed with an annular shoulder 28 for slidably receiving the end portion of the body section 14, which is securely fastened thereto in sealed relationship by means of an annular weld 30. The end plate 16 is further provided with a suitable port 32 extending therethrough and disposed in communication with the chamber 18. A deformable tube 34 is affixed, such as by means of welding, to the outer face of the end plate and in alignment with the port 32 through which the metal powder 20 is adapted to be filled during a filling of the container. Upon completion of the filling operation, the deformable tube 34 can be satisfactorily cramped, such as indicated at 36, and further welded, if desired, assuring the formation of a fluid-tight seal.

In accordance with the practice of the present invention, one or a plurality of core elements, such as the core element 38 shown in FIGS. 1 and 2, is affixed to and extends rearwardly of the nose section 12 in substantial alignment with the longitudinal axis, indicated at 40, of the container and chamber therein. The core element 38 extends for a distance through the chamber and terminates at a point spaced from the inner surface of the end plate 16. The point of termination of the core element relative to the end plate is dictated in consideration of such variables as the packing density of the loose metal powder within the chamber; the diameter of the chamber relative to the diameter of the core element; the total volume of the chamber relative to the volume displaced by the core element; and the type of extrusion apparatus and reduction ratio to be used in effecting a hot extrusion and compaction of the filled container. Generally it has been found satisfactory for most processing conditions in which metal powders are packed in the chambers at a density ranging from about 60 percent to about 70 percent of 100 percent theoretical density; wherein the extrusion ratio to which the container is to be subjected is within a range of about 6:1 to about 10:1 and wherein the core element is of a substantially uniform shape and size throughout the length thereof to control the length of the core element such that the volume of the chamber between the end of the core element and the inner face of the end plate comprises between about 30 percent to about 40 percent of the total net volume of the chamber.

In the specific embodiment shown in FIGS. 1 and 2, the container, including the body section 14, as well as the core element 38, is of a substantially circular cross sectional configuration and wherein the periphery of the core element is disposed substantially concentric with respect to the inner surface of the body section. Containers of the foregoing type are particularly satisfactory for hot extrusion through a circular extrusion die. It is also contemplated in accordance with the apparatus and method aspects of the present invention that a plurality of core elements of alternative configuration can also be satisfactorily employed for producing composite billets of any desired configuration and coring arrangement. Typical of such alternative arrangements is that shown in the transverse sectional view comprising FIG. 3, in which a container 42 is illustrated having a body section 44 of a substantially circular cross sectional configuration and wherein four core elements 46 are employed which are arranged symmetrically around the central longitudinally extending axis, indicated at 48, of the container and chamber. As in the case of the container 10 shown in FIGS. 1 and 2, the chamber of the container 42 is filled with the metal powder 20 which completely surrounds the core elements 46.

Still another alternative satisfactory arrangement is a container 50, illustrated in FIG. 4, in which a body section 52 thereof is of an elliptical configuration and wherein a core element 54 is employed having a center coinciding with the longitudinal axis, indicated at 56, of the chamber which is also of an elliptical configuration and in general conformance with the configuration of the body section. The container 50 may conveniently be extruded through an extrusion die of an elliptical configuration to produce a resultant cored billet of the desired size and shape.

Regardless of the particular configuration of the container and the number and shape of the core elements employed, the container and the components thereof may be comprised of any suitable ductile material, of which ductile metals compatible with the metal powder contained therein and which are resistant to the elevated temperatures to which the container is heated during the extrusion compaction operation can be used.
for this purpose. In addition, the metals must be of sufficient strength at elevated temperature to avoid rupture of the side walls during the hot deformation of the container by extrusion, assuring the maintenance of the sealed integrity of the compacted powder particles therein. Among the various ductile metals suitable for this purpose are the various so-called stainless steels, such as AISI Type 304 stainless steel, as well as mild steels, including AISI 1010 steel. Such ductile steels possess the further advantage of being readily fabricated into strong, fluid-tight containers of the various sizes and configurations required or desired.

In the practice of the present invention, a container, such as the container 10 with its filler tube 34 in an open position, is suitably filled with a powder of the prescribed particle size and of the desired alloy chemistry preferably in a dry box under vacuum or inert atmospheric conditions and in the presence of sonic or supersonic vibrations to effect a substantially complete filling of the interior chamber thereof. The container is subsequently evacuated and thereafter the filler tube is crimped, as indicated at 36 in FIG. 1, sealing the contents within the container, which thereafter can be stored for indefinite time periods.

Preparatory to the densification of the metal powder, the container and metal powder therein are heated to an elevated temperature which will vary depending upon the particular composition of the metal powder particles. The specific temperature employed for preheating the metal powder prior to hot extrusion is controlled so as to approach the solids of the particular alloy or a temperature just below the incipient melting point of the powder particles, such as up to about 100°F. below the solids of the metal powder alloy.

After the powder contents of the container have uniformly attained the desired preheat temperature, the container is subjected to hot extrusion by passing the container through a constriction or die effecting a reduction in its cross sectional area of a magnitude ranging from a ratio of initial cross sectional area to final cross sectional area of from about 6:1 up to about 10:1. Such an extrusion is most conveniently effected in a single pass, although multiple passes can be employed, if desired or required, to attain the desired reduction in cross sectional area and final configuration. During the hot extrusion operation, a coalescence and densification of the metal powder particles occurs, whereby a dense alloy mass usually in excess of 99 percent theoretical density, and more usually, substantially 100 percent theoretical density, is obtained. At the same time, a reduction and elongation of the nose section, core elements and end plate of the container occurs.

A typical extruded mass, indicated at 58, is illustrated in FIG. 5, which is conveniently derived from the hot extrusion compaction of the elongated container 10 shown in FIG. 1. As will be noted in FIG. 5, the nose section, indicated at 12', has been reduced in diameter and has become substantially elongated and the core element 38' similarly has been reduced in diameter and has become elongated such that the end thereof extends for substantially the entire length of the compacted powder mass 60 and to a position substantially in contact with the deformed end plate 16'. The thin-walled body section 14' also is of a corresponding reduced diameter and decreased thickness as a result of the extrusion operation.

In the configuration as shown in FIG. 5, the extruded mass 58 is permitted to cool and thereafter the deformed nose section 12' and end plate 16' are removed, such as by cutting along the lines indicated X—X and Y—Y, respectively. The thin-walled extruded body section 14' is thereafter removed from the periphery of the compacted powder mass 60, resulting in a cored billet 62, as such illustrated in FIG. 6. The billet 62 is in the form of an elongated rod having a mild steel or stainless steel core 64 extending longitudinally through the center thereof for substantially the entire length thereof which is surrounded by a dense wrought-like alloy 65 of substantially higher cost and of comparatively poor machinability.

In accordance with one practice of the present invention, the cored billet 62 can be severed into a plurality of billet sections, such as the section 66 shown in FIG. 7, and the residual core section removed therefrom by conventional machining operations, producing a central aperture 68. The billet section 66 may serve as a suitable preformed blank for the fabrication of hubs or rotors for gas turbine engines or the like, requiring only minimal final forming and machining operations.

It is also contemplated in accordance with the process aspects of the present invention that the compacted cored billets derived from the hot extrusion operation can be sectioned as in the case of the billet section 66 shown in FIG. 7, but whereafter they are subjected to further forming operations such as hot forging operations to effect a further deformation thereof prior to removal of the residual core sections therefrom. Typical of a forged billet section is the section 70 shown in FIG. 8 formed with four symmetrically arranged apertures 72 which may conveniently have been derived from the use of the container 42 shown in FIG. 3 after having removed the residual sections of the core elements 46 therefrom.

While it will be apparent that the invention herein disclosed is well calculated to achieve the benefits and advantages hereinafore set forth, it will be appreciated that the invention is susceptible to modification, variation and change without departing from the spirit thereof.

What is claimed is:

1. The process for making consolidated billets from metal powder and the like comprising the steps of confining a metal powder in a ductile extrusion container defining a chamber including at least one core element extending rearwardly from the surface defining the forward end of said chamber for a portion of the length of said chamber and terminating at a point spaced from the surface defining the rearward end of said chamber such that the volume of that part of said chamber disposed rearwardly of the end of said core element comprises between about 30% and about 40 percent of the total volume of said chamber, said core element oriented substantially parallel to the longitudinal axis of said chamber, heating said container and said powder therein to an elevated temperature, passing the heated said container longitudinally through a die of a reduced cross sectional area and extruding and elongating said container and said core and compacting said powder around the elongated said core into an elongated substantially dense coherent mass in which said mass and said core are substantially coextensive, removing said container from the periphery of said mass, and thereof-
9. After removing said core from said mass forming a billet having an elongated aperture therein.

2. The process as defined in claim 1, including the further steps of transversely severing said mass after the removal of said container from the periphery thereof into a plurality of transverse sections, working said sections into disks and thereafter removing the residual portion of said core element from said section.

3. The process as defined in claim 1, wherein said container and said core element are comprised of a ductile steel material and said core element is removed from said mass by machining.

4. The process as defined in claim 1, wherein said container and said core elements are comprised of a ductile steel material and said core element is removed from said mass by leaching.

* * * * *