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DUCTILE POLYCRYSTALLINE BERYLLIUM

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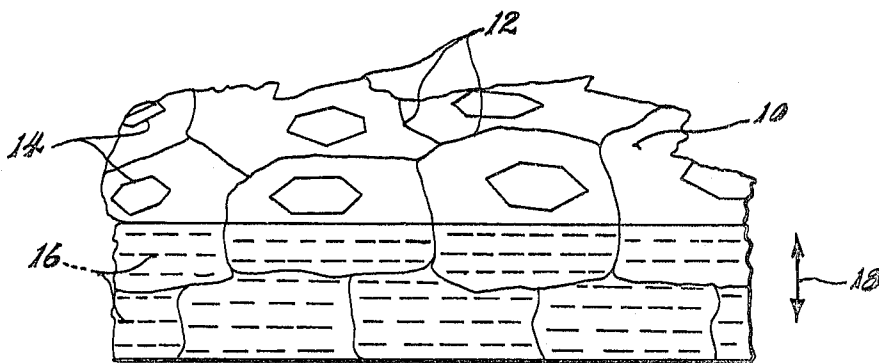


FIG. 1

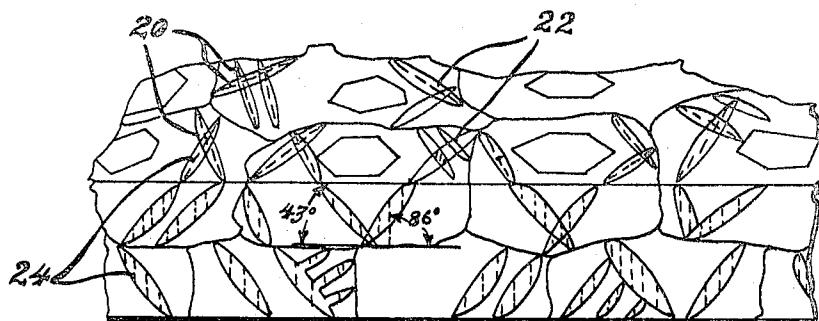


FIG. 2

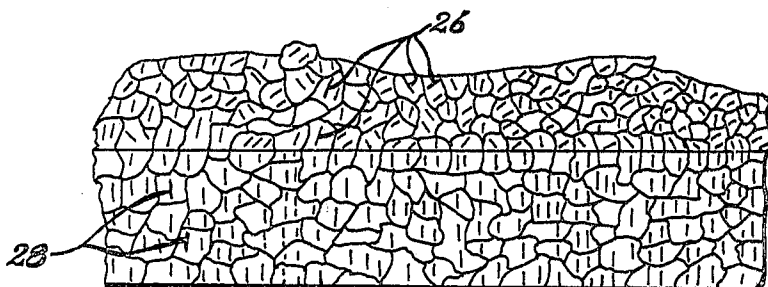


FIG. 3

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DUCTILE POLYCRYSTALLINE BERYLLIUM
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3 Claims

ABSTRACT OF THE DISCLOSURE

A process for producing a ductile polycrystalline beryllium metal product by cryogenically deforming a beryllium plate with a high degree of basal orientation in the plane of the plate, followed by recrystallization of the deformed structure at an elevated temperature of about 2000° F. to effect a two-dimensional, randomly oriented recrystallized structure.

This invention relates to the metal beryllium. More particularly, this invention concerns itself with a process for improving the ductility of certain polycrystalline beryllium shapes and forms.

The element beryllium has proved to be of value as a structural material in the fabrication of precision parts where low mass, high modulus of elasticity, high structural strength and dimensional stability are desired. For example, this metal finds particular application in the manufacture of gimbals and rotors for aircraft and missile gyroscopes.

However, the increased demand for the use of beryllium as a structural component capable of satisfying the rigid operational requirements of modern day aircraft and space rockets has not been satisfied due to the extreme brittleness of the metal. This brittleness is manifested by tensile failure with virtually no plastic deformation occurring prior to failure.

Beryllium is one of four industrial metals with a hexagonal close packed structure having a *c/a* ratio less than the ideal value of 1.633. The other three, zirconium, magnesium and titanium, are not subject to brittleness for two reasons: they possess more modes of deformation than beryllium, and secondly, beryllium crystals cleave along the basal plane at very low stresses while the other three metals do not.

The important deformation modes for the above hexagonal metals are set forth in Table A.

TABLE A

	Primary slip system ¹				Primary twin systems			
Zr.....	{10 $\bar{1}$ 0}	<11 $\bar{2}$ 0>	{10 $\bar{1}$ 2}	<10 $\bar{1}$ 1>	{11 $\bar{2}$ 1}	<11 $\bar{2}$ 6>	{11 $\bar{2}$ 4}	<22 $\bar{4}$ 3>
Mg.....	{0001}	<11 $\bar{2}$ 0>	{10 $\bar{1}$ 2}	<10 $\bar{1}$ 1>	{10 $\bar{1}$ 1}	<10 $\bar{1}$ 2>	{10 $\bar{1}$ 3}	<3032>
Ti.....	{10 $\bar{1}$ 0}	<11 $\bar{2}$ 0>	{10 $\bar{1}$ 2}	<10 $\bar{1}$ 1>	{11 $\bar{2}$ 1}	<11 $\bar{2}$ 6>	{11 $\bar{2}$ 4}	<22 $\bar{4}$ 3>
Be.....	{0001}	<11 $\bar{2}$ 0>	{10 $\bar{1}$ 2}	<10 $\bar{1}$ 1>				

¹ Physical Metallurgy Principles, Reed-Hill, Van Nostrand, 1964.

From an examination of Table A, it can be seen that beryllium has only one mode of elongation along the *c*-axis, twinning on {10 $\bar{1}$ 2}<10 $\bar{1}$ 1> system. This results in less ductility in this direction. In addition to this limitation, beryllium is often unable to twin because cleavage occurs along the basal plane at a stress about one third that necessary to form a {10 $\bar{1}$ 2} twin. It is not understood why beryllium fails in this brittle manner, while zirconium, magnesium, and titanium do not; apparently, the interstitial oxygen atoms in beryllium tend to layer on the basal plane, providing weak atomic bonds in the direction perpendicular to this plane.

There are two ways in which the ductility of polycrystalline beryllium can be improved: (1) by lowering the oxygen content to inhibit or prevent cleavage on the basal plane and (2) by producing a randomly oriented aggregate of crystals so the low ductility along the *c*-axis is "averaged out" in a polycrystalline structure. Beryllium is a reactive metal and it has not been possible to reduce the oxygen content enough to prevent brittle cleavage. It is possible to produce randomly oriented crystal structures in beryllium by casting or sintering, but the crystals are large, so that a crack nucleated by stress in one crystal is easily propagated through the body of the metal under continued stress.

Attempts to reduce the grain size by forming techniques have been successful because hexagonal close packed structures tend to "texture," i.e., with increasing amounts of deformation the basal planes of the grains have an increasing tendency to lie perpendicular to the axis of compression (or parallel to the axis of tension). Generally, the final grain size of a polycrystalline metal aggregate is inversely proportional to the amount of deformation imparted to the metal. Therefore, to produce a small average grain size in a beryllium shape, it has heretofore been necessary to impart a high degree of deformation to the metal. This increases the "texturing" in any given forged shape (other than a sphere), in turn resulting in decreased ductility in the direction parallel to the primary axis of compression (or perpendicular to the axis of tension).

In accordance with this invention, however, it has been discovered that the ductility of polycrystalline beryllium metal can be retained in every direction in a fine-grained aggregate by utilizing the process of this invention. Briefly, the invention comprises the steps of deforming a highly basal-textured beryllium plate through cryogenic deformation followed by recrystallization of the deformed structure to provide a two-dimensional, randomly oriented structure in which the recrystallized basal planes will lie essentially perpendicular to the plane of the plate.

Accordingly, the object of this invention is to provide a process for improving the ductility of polycrystalline beryllium in all directions while maintaining a fine-grain size.

The above and still further objects and advantages of this invention will become apparent upon consideration of the following detailed description thereof taken in conjunction with the accompanying drawings wherein:

FIGURE 1 represents a schematic view of an unde-

formed polycrystalline beryllium material possessing a high degree of basal textures;

FIGURE 2 represents a schematic view of the polycrystalline material of FIGURE 1 following compression at cryogenic temperatures;

FIGURE 3 represents a schematic view of the compressed polycrystalline structure of FIGURE 2 following recrystallization.

The purpose of the cryogenic deformation is to develop {10 $\bar{1}$ 2} twins in the metal. These serve as nuclei during recrystallization. In a given grain, there are six {10 $\bar{1}$ 2}<10 $\bar{1}$ 1> twin systems. According to the inven-

tion, it has been found that maximum randomization of the recrystallized structure is achieved when the grains twin on as many of the six twin planes as possible. This has been accomplished in the following manner: The invention is further illustrated by the example which follows hereinafter. The example illustrates the steps of deforming at cryogenic temperature followed by the step of recrystallization.

Referring to FIGURE 1 in greater detail, there is disclosed a schematic representation of an undeformed beryllium structure having a high degree of basal texture with the plane of the plate designated as 10. The grain boundaries are shown at 12, while the trace of the basal plane on the plane of the plate is shown at 14 with the dotted lines 16 designating the trace of the basal plane on the normal plane. The numeral 18 shows the short transverse direction. FIGURE 2 discloses a schematic illustration of a textured plate following cryogenic compression in accordance with the process of this invention. Compression induces $\{10\bar{1}2\}$ twinning as shown at 20 with the twin intersections 22 indicating potential nucleation sites. The dotted lines 24 show the trace of the basal plane inside the twins. FIGURE 3 represents a schematic illustration of a beryllium material after having been subjected to the compression and recrystallization process steps of this invention showing the basal planes of the recrystallized grains oriented 84° from the original orientation. The new trace of the basal planes 14 and 16 of FIGURE 1 are now shown at 26 and 28, respectively, of FIGURE 3.

EXAMPLE

A beryllium disc, 2.5 inches in diameter and one inch thick, with a high degree of basal texture (as shown in FIGURE 1), was cooled to -321°F. and slipped inside an austenitic stainless steel ring which had been previously heated to about 400°F. The clearance between the cooled beryllium disc and the heated stainless steel ring was kept as small as possible. The entire compact was cooled to -321°F. , and the contraction of the stainless steel ring provided the beryllium disc with a high degree of restraint. The compact was radially press-forged to a peripheral compression of about 10 percent. The restraining stainless steel ring allowed the compression to be distributed essentially uniformly around the periphery of the disc. It was found that cleavage did not occur during forging. The deformed disc was recrystallized by annealing at a temperature of about 2000°F. for one hour.

Deformation in this manner at cryogenic temperatures, is almost entirely by $\{10\bar{1}2\}$ twinning. $\{10\bar{1}0\}\langle 11\bar{2}0\rangle$ slip does not occur because the CRSS for this mode of slip is about three times that for $\{10\bar{1}2\}\langle 10\bar{1}\bar{1}\rangle$ twinning. The resulting structure, shown schematically in FIGURE 2 is an extremely heavily twinned structure with many thin, coherent twins within a given grain.

The purpose of the step of recrystallization, which follows the step of deformation, is to provide a strain-free aggregate of very small grains, in which the basal planes of the new grains lie essentially perpendicular to the plane of the plate. This is possible because it has been found that the recrystallized grains are of the orientation of the $\{10\bar{1}2\}$ twins which were formed during deformation. In this particular process, the basal planes inside the twins formed by the cryogenic deformation will be almost perpendicular (about 86°) to the plane of the plate, as shown in FIGURE 2.

The orientation of the recrystallized structure, is shown in FIGURE 3 in which the basal planes of the recrystallized grains are oriented 84° from original orientation. This structure may also be visualized by considering a number of one inch lengths of hexagonal wooden pencils, all lying on their sides and pointing in different directions. Each segment of pencil represents a separate grain. It is seen that slip can now occur in the short transverse direction, i.e., perpendicular to the plane of the plate, on either

the primary $\langle 0002\rangle\langle 11\bar{2}0\rangle$ or secondary $\{10\bar{1}0\}\langle 11\bar{2}0\rangle$ slip systems. Similarly, a measure of ductility exists in the plane of the plate for two reasons: (1) the basal planes of the recrystallized grains (the flat ends of the pencil segments), are randomly oriented, perpendicular to the plane of the plate, so that a given tensile or compressive stress in the plane of the plate results in cleavage in only a small number of grains, and (2) the very small size of the recrystallized grains, resulting from the low forming temperature and the many nucleation sites for recrystallization at the twinning intersections, prevent the propagation of the cleavage microcracks. Thus, a tensile or compressive stress in the plane of the plate will result in a large amount of slip, a minimum amount of cleavage, and a resultant high ductility in any direction in the plane of the plate.

It has been found that ten percent radial compressing at -321°F. followed by recrystallization at about 2000°F. for one hour provides the optimum conditions for producing the desired twinning and recrystallized structure.

It will be understood that variations and modifications of the time, temperature and deformation relationships referred to may be made without departing from the spirit of the invention, since the particular parameters disclosed are relied upon only for the purpose of producing optimum results. The essential features of this invention reside in the steps of radially compressing a highly basal-textured polycrystalline beryllium plate at cryogenic temperatures followed by annealing at a temperature of about 2000°F. The resultant product possesses the desired degree of ductility needed to improve the overall usefulness of beryllium as a structural material.

What is claimed is:

1. A method for improving the ductility of a fine-grained beryllium metal product comprising the steps of cooling a highly basal-textured beryllium metal workpiece to a cryogenic temperature of about -321°F. , plastically deforming the cooled workpiece about ten percent by radial compression and heating the deformed workpiece to recrystallization temperature of about 2000°F.

2. The product produced by the method of claim 1.

3. A method for improving the ductility of a fine-grained beryllium metal product comprising the steps of cooling a highly basal-textured polycrystalline beryllium metal workpiece to a temperature of -321°F. , encasing the cooled workpiece within a high tensile strength metallic band previously heated to a temperature of 400°F. , cooling the encased workpiece to a temperature of -321°F. to provide the workpiece with a high degree of restraint, radially press forging the cooled encased workpiece to a peripheral compression of about ten percent, and heating the compressed workpiece to an elevated temperature of about 2000°F. to effect a two-dimensional, randomly oriented recrystalline workpiece.

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CHARLES N. LOVELL, Primary Examiner

U.S. Cl. X.R.

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