

July 5, 1960

R. E. LENHART  
METHOD AND APPARATUS FOR MAKING ISOTROPIC  
PROPERTIES BERYLLIUM SHEET

2,943,933

Filed May 21, 1959

2 Sheets-Sheet 1

FIG. 1

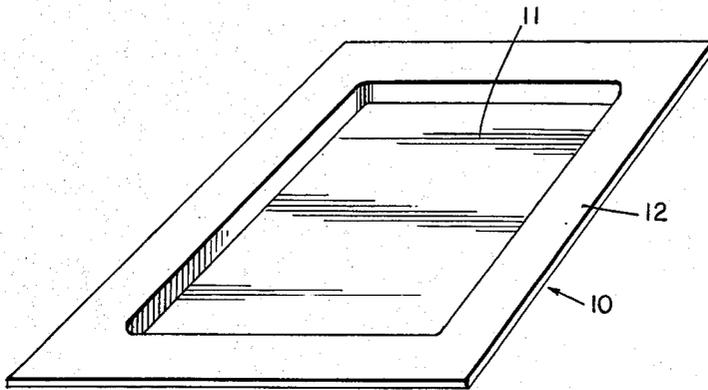


FIG. 2

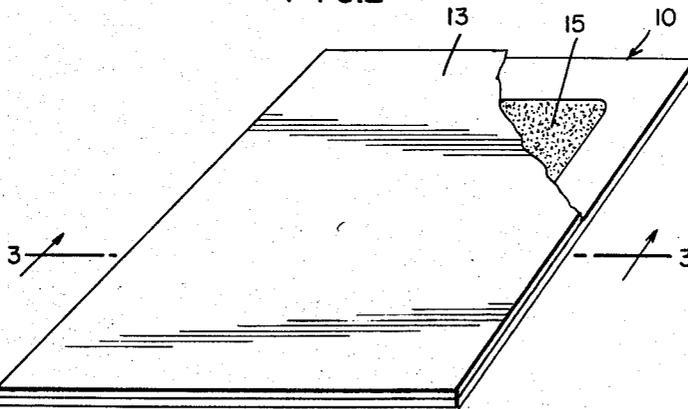
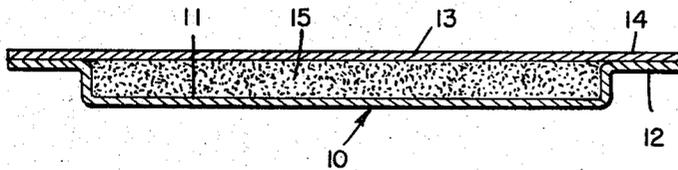


FIG. 3



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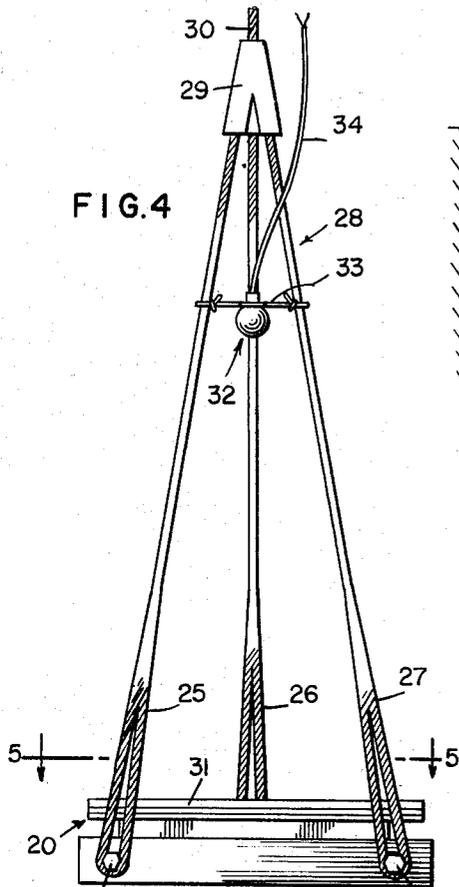


FIG. 4

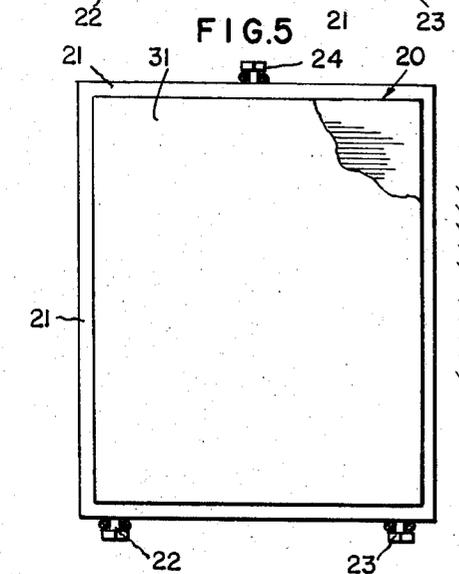


FIG. 5

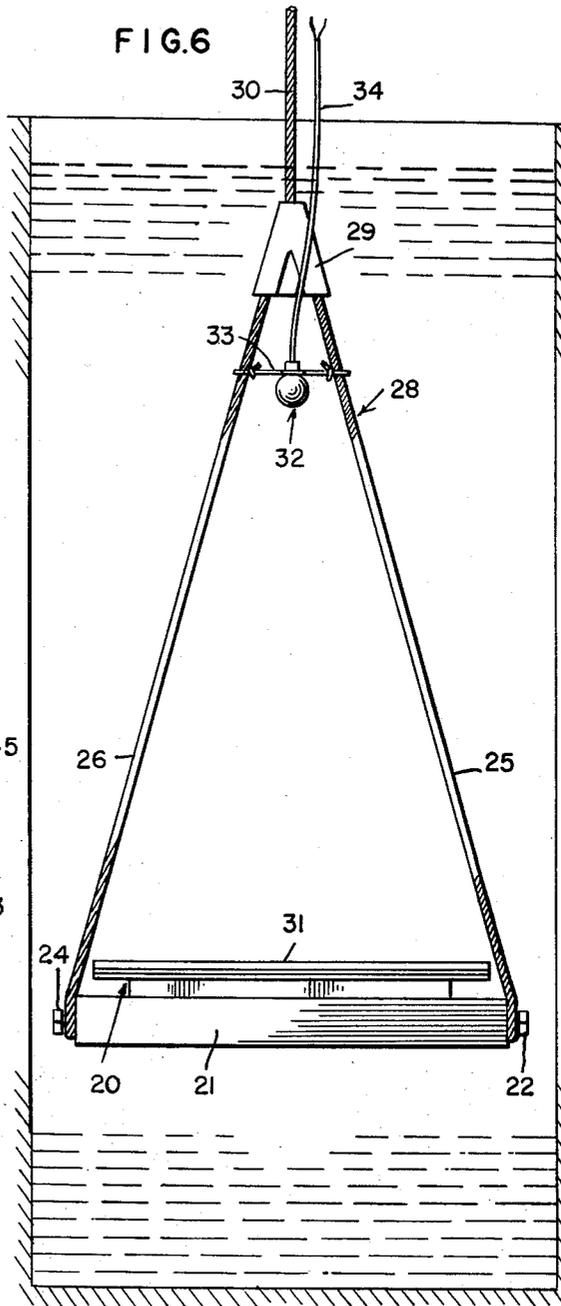


FIG. 6

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1

2,943,933

**METHOD AND APPARATUS FOR MAKING ISOTROPIC PROPERTIES BERYLLIUM SHEET**

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5 Claims. (Cl. 75—214)

This invention relates to the production of beryllium, in particular, into an isotropic form.

More particularly, this invention relates to a method for producing metallic articles from metals which are normally and otherwise anisotropic, in which the articles are characterized by having isotropic properties.

Essentially, the invention is concerned with those metals, such as beryllium, magnesium, zirconium, titanium or zinc, which are characterized by hexagonal crystallographic structure.

The metal beryllium is characterized by its anisotropic characteristics and, although for many applications its anisotropic properties are of no consequence, there are, nevertheless, applications to which beryllium may be put to good use provided it possesses isotropic properties. It is, therefore, of primary concern in connection with this invention to provide a method and apparatus whereby beryllium, in particular, may be fabricated in sheet form where such sheet exhibits isotropic properties.

Since the anisotropic characteristic of beryllium arises from its crystallographic structure, it is conceivable to create a mass exhibiting isotropic properties by means of randomization of the crystallographic mass. Such randomization in rolled, cast or forged beryllium is not contemplated herein. However, the present invention does contemplate the randomization of crystals in the mass, and consequently, the provision of a substantially isotropic property metal by means of compacting an initially finely divided or powdered material into a dense, isotropic property sheet form.

More particularly, the present invention contemplates the randomization and consequent gross removal of anisotropy particularly in beryllium by compacting an initially powdered form of such material primarily by means of the controlled application of an explosive force.

More specifically, it is an object of this invention to compact beryllium powder to sufficient density as to enable it to possess physical properties comparable to rolled sheet, while at the same time possessing these properties isotropically and by producing such compaction by the combination of sintering the powdered material to increase its density and subsequently further increasing its density by means of the controlled application of an explosive force.

Further, this invention contemplates the compaction of beryllium powder both by means of the controlled application of an explosive force and by sintering in which the sintering is carried out at least after the application of the explosive compaction force.

A further object of this invention is to directly convert powdered metal into compacted sheet form by means of the application of an explosive force to the powdered material in which the explosive force, and particularly its controlled application, is effected by placing an explosive charge adjacent to a form or container within which the powdered material is placed and wherein the container and the explosive are submerged in water.

The method in accordance with the present invention,

2

therefore, specifically envisages the fabrication of a normally anisotropic metal in a form which exhibits isotropic properties by means of initially powdering the anisotropic material so as to finely divide the same, confining the thus powdered material in a suitable container, subjecting the thus confined material to at least one pre-sintering step, subjecting the confined and pre-sintered material to a further compaction by means of the controlled application of an explosive force thereto and, lastly, by subjecting the thus compacted material to further sintering. Specifically, the method contemplates the application of the explosive force under a submerged condition, that is, the explosive and the confined material both being submerged in water.

According to the present invention, the apparatus involved has for its primary objective the provision of means to confine an initially finely divided powdered material in predetermined shape and size and to retain the powdered material in such shape during subsequent sintering and compacting operations.

Another object of this invention is to provide an envelope or container for the powdered material which incorporates a dished sheet forming a cavity for the reception of beryllium powder, with there being a lid or cover completely closing such cavity and by means of which the envelope may be evacuated to provide a negative pressure within the envelope or can.

Another object of this invention resides in the provision of a can or envelope for confining powdered beryllium wherein the beryllium may be sintered and subsequently compacted into a given shape and form.

A further object of this invention resides in the provision of apparatus including a die plate adapted to receive an envelope or can within which powdered beryllium is disposed and over which a blanket of resilient material, such as rubber, is disposed, with there being means to lower the entire assemblage below the surface of a well of water and to simultaneously hold an explosive charge in predetermined and fixed distance from the can or envelope placed on the die plate.

With the above and other objects in view, the invention consists in the construction and novel combination and arrangement of parts hereinafter fully described, illustrated in the accompanying drawings and pointed out in the claims hereto appended, it being understood that various changes in the form, proportions, and minor details of construction, within the scope of the claims, may be resorted to without departing from the spirit or sacrificing any of the advantages of the invention.

In the drawings:

Fig. 1 is a perspective view of the lower portion of the envelope or can used for confining the beryllium powder;

Fig. 2 is a perspective view of the envelope or can showing both the upper and lower portions thereof in operative position, and with a portion of the lid or top broken away to show the disposition of the powdered metal within the confines of the can;

Fig. 3 is a transverse section taken through the can substantially along the section line 3—3 in Fig. 2;

Fig. 4 is a side elevational view of the apparatus for effecting the explosive compaction of the powdered metal;

Fig. 5 is a horizontal section taken substantially along the plane of section line 5—5 in Fig. 4; and

Fig. 6 is a sectional view taken through the well showing the apparatus submerged beneath the surface of the water in the well.

Referring now more particularly to Figs. 1-3, the reference numeral 10 indicates, in general, the lower portion of the envelope or can for confining the powdered beryllium metal and which lower section includes a depression or dished central portion 11 leaving the flat

annular flange 12 extending completely therearound. Preferably, the lower section is of generally rectangular form with the depression 11 being generally rectangular also.

As seen most clearly in Figs. 2 and 3, a lid or top 13 is provided for the lower section being preferably of an area coextensive therewith so that the marginal edge portions 14 of the top overlie and rest upon the flange 12 bounding the lower section.

Powdered beryllium metal indicated by the reference character 15 is placed in the depression 11 and the assembly may be subjected to a shaking or settling action to assure the even distribution of the powder throughout the cavity provided by the dished portion 11. The lid or top 13 covers the dished portion and forms a closed cavity therewith, the beryllium powder being introduced in such quantity as to completely fill the cavity and be evenly distributed therewithin. The top is securely joined to the lower section so as to form an air-tight seal and the interior of the cavity is evacuated to remove air therefrom.

After the beryllium powder is confined within the envelope or can, it may be subjected to a presintering operation. In such case, it is preferred that the presintering be carried out at a temperature of 1,000° C. for one hour.

Although it is not intended that this invention be limited to any precise or particular thickness of sheet, it is preferred that the sheet be of approximately  $\frac{1}{16}$  to  $\frac{3}{8}$  inch in thickness. Likewise, it is not intended to limit the size of the sheet to any particular dimension but, as an example, sheets of a size 10 x 12 inches are easily fabricated by the present process, although sheets of much larger dimensions are possible.

After the pre-sintering operation, if such pre-sintering is desired, the can or envelope indicated generally by the reference character 20 in Fig. 4, is placed on a steel or other metal die plate 21 which, in this case, simply consists of a relatively thick metallic plate of generally rectangular form, and preferably slightly larger than the dimensions of the can 20. The die plate may be provided with several outstanding pins thereon, such as those indicated by the reference characters 22, 23 and 24 in Fig. 5, these pins serving as anchoring points for the looped ends 25, 26 and 27 of lengths of cable which form a cradle assembly indicated generally by the reference character 28 for the die plate and the apparatus resting thereon. The upper ends of the lengths of cable forming the cradle 28 are joined by a suitable head member 29 which, in turn, is secured to the lower end 30 of a length of cable issuing from a suitable winch, derrick or the like, by means of which the entire assemblage may be manipulated as desired.

Preferably, although not necessarily, a sheet of flexible material, such as rubber, is placed over the top of the envelope 20 on the die plate 21, such sheet being indicated in Figs. 4-6 by the reference character 31. Although no specific means is shown therefor, this sheet 31 will be provided with some means for securing it in place to prevent its shifting around relative to the can and the die plate. Obviously, since the assemblage is to be immersed in water, some such means is necessary inasmuch as the rubber sheet will usually be lighter than water and will therefore, require some anchoring means.

Secured within the cradle assembly 28 is an explosive charge indicated generally by the reference character 32 and which is anchored in place by means of cord or the like 33 and extending from the explosive charge is a fuse or detonating wire 34 leading to any conventional type of detonator associated with the charge 32.

In use, the assemblage is lowered beneath the surface of water in a well, such as that indicated in Fig. 6, to a predetermined depth with the explosive charge fixed a predetermined height above the can and the charge is then detonated to compact the powdered material within

the can, after which the assembly is removed from the well and the can, with the compacted material therewithin, sintered. Such post-sintering is preferably carried out within the temperature ranges of from between 800° C. to 1000° C. for approximately two hours.

The material is then removed from the jacket and subjected to a further sintering process preferably at a temperature range of from between 1000° C. to 1200° C. for approximately two hours, at which time the sheet is ready for ultimate use.

Sheets produced in such manner exhibit substantially true isotropic properties.

In positioning the explosive relative to the can, of primary consideration is to assure that the shock wave emanating from the explosive charge will strike or impinge upon the surface of the can at all points thereon substantially simultaneously and for this reason, it will be obvious that the relative size of the can and, more specifically, the sheet confined therewithin is of importance with respect to the positioning of the explosive charge. That is to say, the larger the sheet, generally speaking, the further explosive charge will have to be in order to assure that the shock wave strikes all surfaces of the can substantially simultaneously. Conversely, for relatively small objects, an explosive charge may be placed very close to the can. On the other hand, the positioning of the explosive charge also has an effect upon the degree of compaction, entirely independent of the size and power of the charge. That is to say, assuming that the charge is placed at least as far away as is necessary to impinge the shock wave substantially simultaneously over the entire surface, a greater spacing of the explosive charge will vary the compaction effect thereof.

As an explosive is set off under water, several things happen in order:

First, a detonation wave travels through the explosive from the point of initiation to the surface of the charge. Its speed depends upon the reaction velocity of the explosive, which varies among the common compositions from less than 5,000 to more than 20,000 feet per second. Behind the detonation wave, the explosive has turned to super heated gas under very high pressure. Ahead of it, the explosive is intact, and if the charge is symmetrical, homogeneous, and initiated in the exact center, it will turn entirely to gas before it begins to expand.

Second, when the detonation wave reaches the surface of the explosive, it continues outward through the water as a shock wave whose intensity depends on the energy the detonation wave has built up on its way through the explosive. At first, the shock wave travels rapidly, but it decelerates greatly until it becomes an acoustical wave a few feet from the origin, the exact distance again depending on its initial intensity.

Third, the gas bubble begins to expand and force the water ahead of it. Naturally, the deeper it is in the water, the greater the mass it must move, and the greater will be the effect on any workpiece placed near it.

Fourth, the momentum of the water causes the bubble to over expand until it is below normal pressure. It then collapses and again momentum causes over travel and another cycle of expansion. This can continue through several oscillations, depending again on the nature of the charge and the distance from the surface, and during these oscillations, some of the energy pumped into the body of surrounding water will be yielding up to a nearby target.

The shock wave accelerates the workpiece very suddenly. The expansion of the gas bubble imparts to it a strong blow and the oscillation of the bubble imparts a succession of lighter blows and it is these forces which effect the compaction of the material in the can.

Naturally, since the compaction depends upon an actual physical distortion of the material of the can, the can thickness must be selected so as to permit this deformation to take place. Preferably, the thickness of the ma-

5

terial of the can, if constructed of low carbon steel, is from about .020 to .060 inch.

By way of example, the following controlling variables are as listed:

1. Can thickness ----- .020 inch to .060 inch.
2. Explosive pressure ----- 100,000-500,000 p.s.i. (100,000 - 200,000 p.s.i. preferred).
3. Explosive shock wave velocity in the water or fluid --- 200-500 feet per second.
4. Explosive burning or reaction velocity ----- 5,000-20,000 feet per second.
5. Explosive position ----- 1-15 feet (3-6 feet preferred).
6. Thickness of beryllium ----- From  $\frac{1}{16}$  to  $\frac{3}{8}$  inch.
7. Pre-sintering ----- 1000° C. for one hour, if used.
8. Post-sintering:
  - a. Before dejacketing ----- 800-1000° C. for two hours.
  - b. After dejacketing ----- 1000 - 1200° C. for two hours.

The flexible sheet covering the envelope or can may or may not be used. Its purpose when used is to benefit the uniform impingement of the explosive force over the entire surface area of the can.

It is to be understood that the present invention is not to be limited solely to the production of sheet material. For examples, cones, discs, cylinders and the like may as well be fabricated by the instant process, or other shapes which are characterized by capability of production by substantially unidirectional compaction. Moreover, the present invention is not to be construed as limited solely to the use of water as the fluid within which the process is carried out. For example, other fluids, such as air, are feasible as the environmental fluid for the process.

#### I claim:

1. The method of making isotropic propertied beryllium sheets which comprises the steps of confining powdered beryllium metal in an envelope, placing such envelope on a die plate, locating an explosive charge in fixed predetermined distance above said envelope and die plate, lowering the die plate, envelope and explosive charge beneath the surface of a body of water, then detonating the explosive charge to effect compaction of the powdered beryllium metal within the envelope, and sintering said thus compacted powdered beryllium metal while still in said envelope, said sintering carried out at a temperature of from 800 to 1000° C. for approximately two hours, stripping the envelope from the sintered and compacted powdered beryllium and sub-

6

jecting the thus dejacketed sheet to a further sintering at a temperature of from 1000 to 1200° C. for approximately two hours.

2. The method of making isotropic propertied beryllium metal sheets which comprises the steps of confining a quantity of powdered beryllium metal within an envelope, placing such envelope upon a die plate, placing an explosive charge having a shock wave velocity of from between 200 and 500 feet per second at a distance from between 1 to 15 feet above the envelope, lowering the die plate, envelope and explosive charge beneath the surface of a body of water, detonating the explosive charge to produce a pressure compaction of from between 100,000 to 500,000 p.s.i. upon the envelope, removing the envelope from the body of water, and sintering the compacted powdered metal while still in the jacket, said sintering carried out at a temperature of from 800 to 1000° C. for approximately two hours, stripping the envelope from the sintered and compacted powdered beryllium and subjecting the thus dejacketed sheet to a further sintering at a temperature of from 1000 to 1200° C. for approximately two hours.

3. Apparatus for making isotropic propertied beryllium sheets comprising a die plate having a substantially flat upper surface, an air-tight envelope supported on said upper surface of the die plate, means for suspending said die plate with the envelope thereon beneath the surface of a body of liquid, and an explosive charge carried by said means and spaced in vertically spaced relationship above said envelope.

4. Apparatus for making isotropic propertied beryllium sheets comprising a die plate having a substantially flat upper surface, an air-tight envelope supported on said upper surface of the die plate, a flexible elastic mat covering said envelope, means for suspending said die plate with the envelope thereon beneath the surface of a body of liquid, and an explosive charge carried by said means and spaced in vertically spaced relationship above said envelope.

5. The apparatus according to claim 3 wherein said envelope is formed from a pair of superimposed joined metallic sheets, one of which is provided with a depression therein to provide a cavity between the sheets for receiving a quantity of powdered metal.

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