United States Patent

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[31] **31,117/68**

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[54] **METHOD OF EXPLOSIVELY SHOCKING SOLID MATERIALS**
8 Claims, 3 Drawing Figs.

[52] **U.S. Cl.** **264/84**
[51] **Int. Cl.** **B22f 3/08**
[50] **Field of Search** 264/84

[56] **References Cited**

UNITED STATES PATENTS

3,022,544	2/1962	Coursen et al.	264/84
3,137,937	6/1964	Cowan et al.	29/487

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ABSTRACT: An improved method of explosively shocking solid materials, e.g., powders, powder compacts, or nonporous solids, which are in the form of a solid circular cylinder, and preferably contained within a circular metal cylinder, comprising positioning the solid cylinder coaxially within a hollow circular metal cylinder with a spacing between the facing surfaces of the cylinders; explosively propelling the hollow cylinder to cause progressive collision of the two cylinders; and separating the shocked solid, usually fragmentary or particulate, material from the metal cylinder(s) surrounding it after the collision.

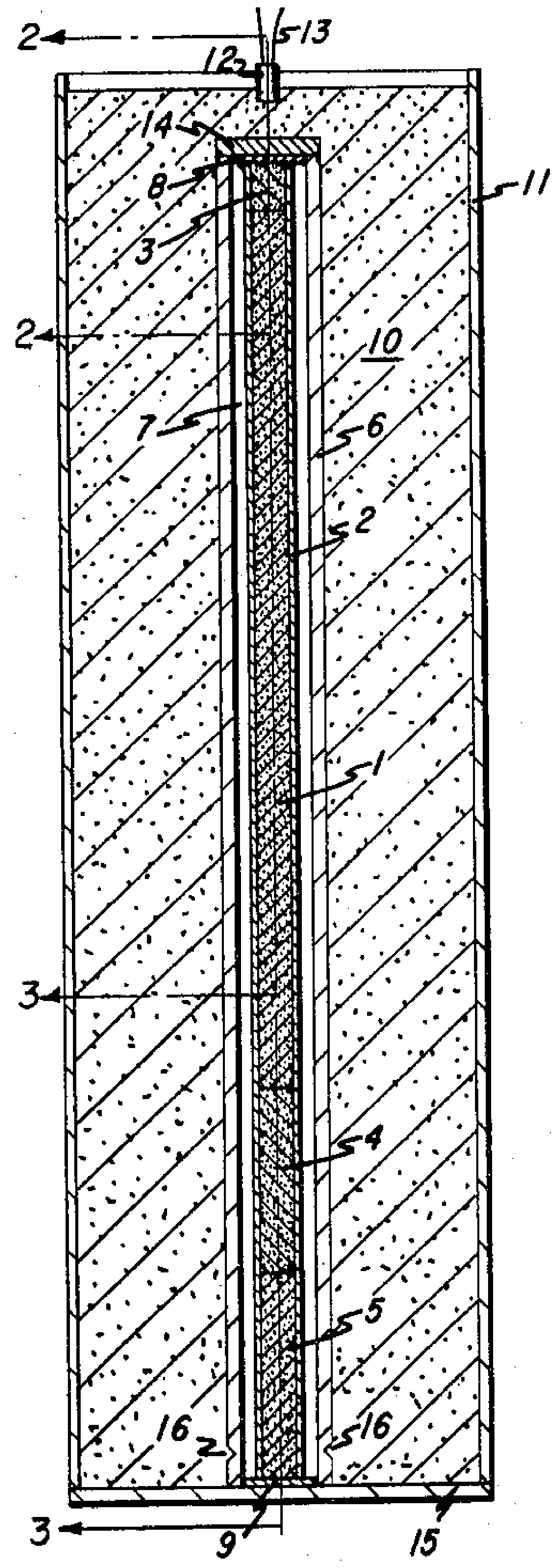


FIG. 1

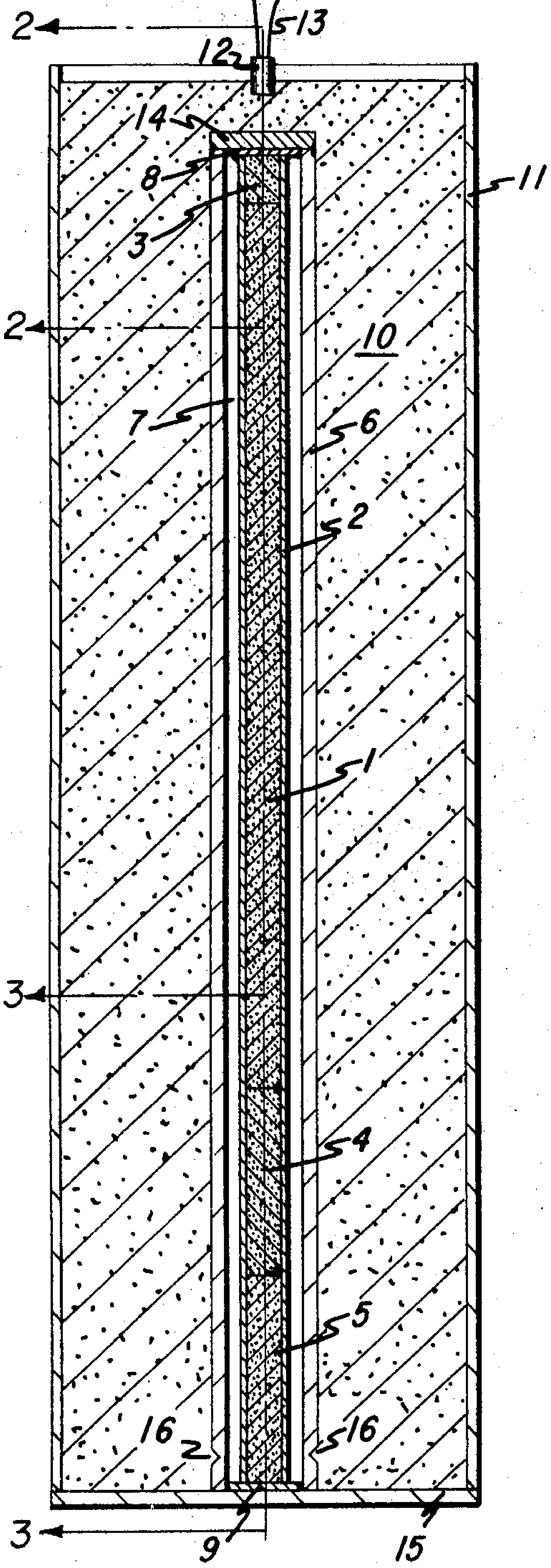


FIG. 2

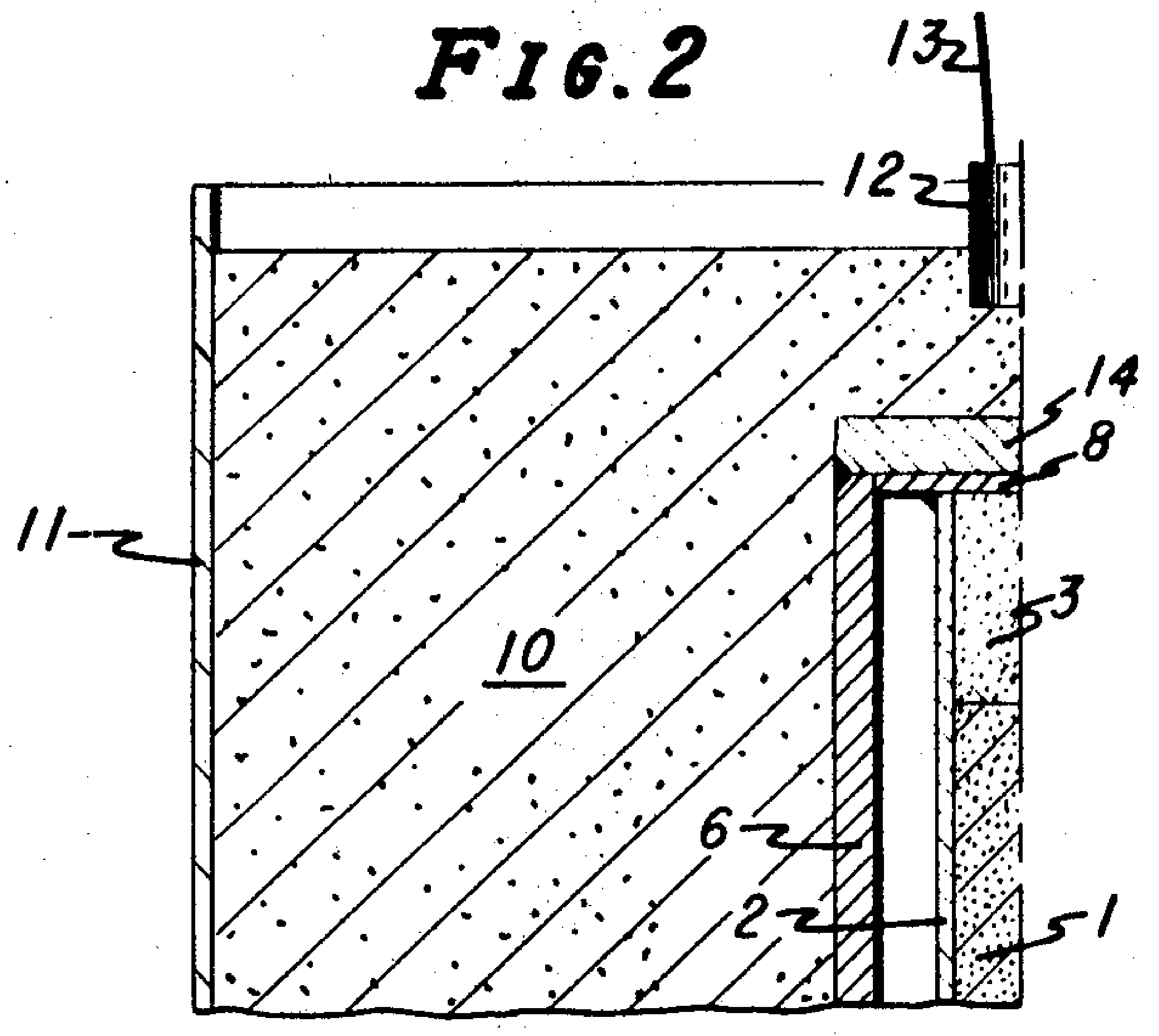
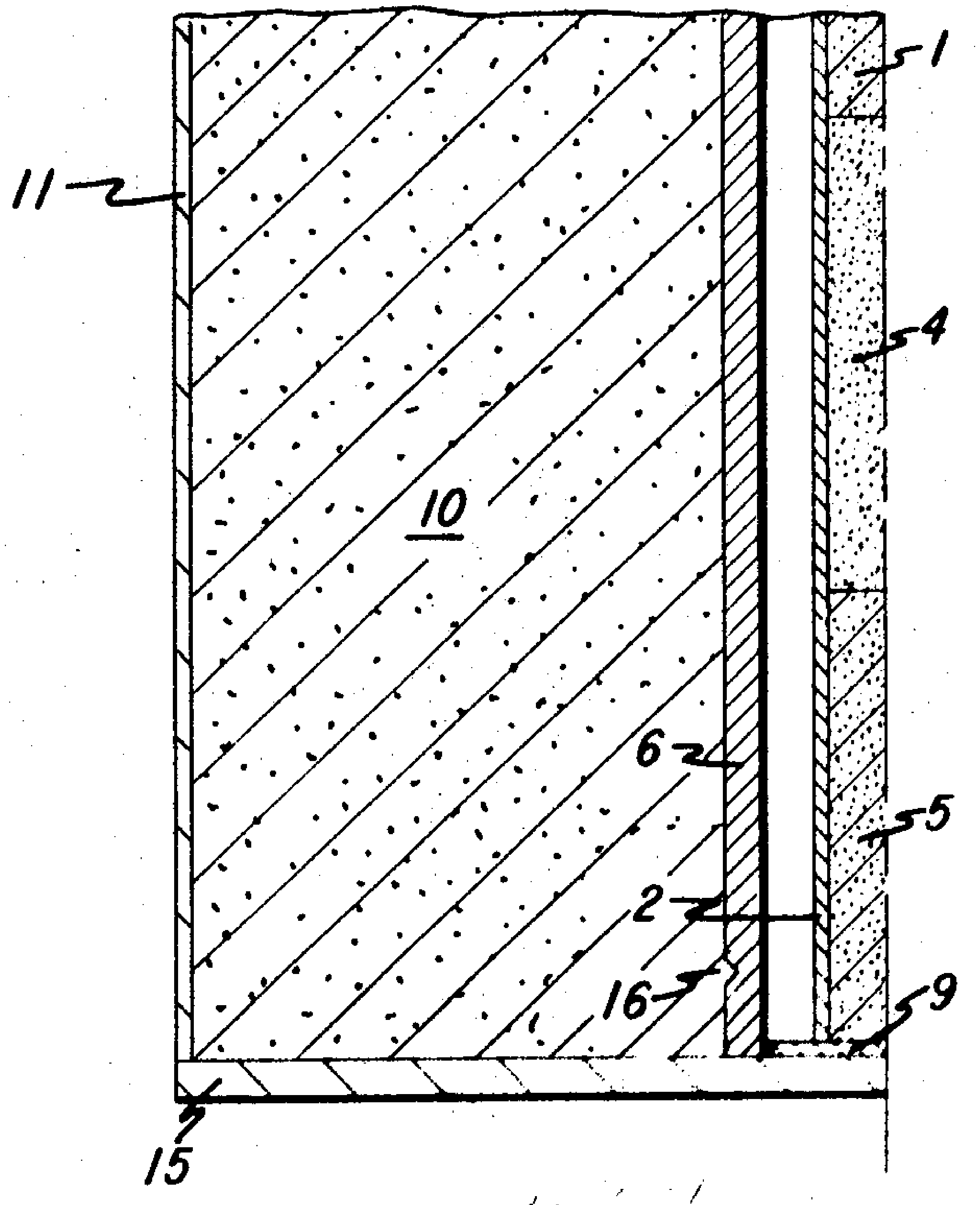


FIG. 3



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METHOD OF EXPLOSIVELY SHOCKING SOLID MATERIALS

BACKGROUND OF THE INVENTION

This invention relates to an improved method of shocking solid materials, e.g., powders, powder compacts, etc.

The introduction of shock waves into solid materials has been employed to effect various kinds of changes therein, e.g., to compact or densify, comminute, modify properties or microstructure, or produce chemical reactions or phase transformations, e.g., the conversion of nondiamond carbon into diamond, or graphitic hexagonal boron nitride into the denser wurtzitic and cubic polymorphs. When, as is often the case, the solid material to be shocked is a particulate mass, e.g., a powder or granular material, or a frangible, self-supporting solid, e.g., a porous and/or brittle body such as a pressed powder (compact), the shocked material may be difficult to recover, particularly as higher shock pressures are employed. Solids of this nature are more easily recovered after shocking if they are contained in a circular metal cylinder, which is less susceptible to rupture than a flat container in which the lateral edges may be difficult to maintain intact. This is one reason why the technique which has been used most often for shocking a particulate or frangible solid involves detonating a layer of explosive adjacent to the outer surface of a metal cylinder containing the solid.

For a given solid material at a given density in a circular metal cylinder, the maximum shock pressure which it is possible to achieve at the boundary between the solid material and the container wall by the detonation of an explosive adjacent to the outer wall of the cylinder is limited by the detonation pressure of the explosive. With the explosives which are commonly available, this pressure is relatively modest, e.g., up to about 150 kilobars for solids of small initial porosity and lower for more porous materials. It is possible to increase this pressure somewhat due to convergence effects by use of a thick-walled cylinder, but the increase is only about proportional to the square root of the ratio of outer to inner diameter. Also, as the wall thickness of cylindrical containers is increased, there is less efficient utilization of explosive energy owing to the greater amount of energy required to plastically deform a thicker wall, as well as to the energy dissipated by a shock wave which may form in the wall.

Summary of the Invention

The present invention provides an improved process for shocking solid materials, e.g., powders, powder compacts, or nonporous solids such as metallic castings, which are in the form of a solid circular cylinder. The method comprises positioning the solid cylinder coaxially within a hollow circular metal cylinder with a spacing between the facing surfaces of the coaxial cylinders, the spacing preferably being at least about equal to the thickness of the hollow cylinder wall; surrounding the convex surface of the hollow metal cylinder with a layer of detonating explosive; initiating the explosive layer with practically circular symmetry, preferably at one end thereof; and separating the shocked solid material, which usually will be a fragmentary or particulate material, from the metal cylinder(s) surrounding it after the collision.

In a preferred embodiment of the process, the solid material is contained in a circular metal cylinder, and both cylinders, i.e., the containing cylinder and the hollow cylinder coaxial therewith, are made of a ductile, high-impedance metal such as steel, since higher pressures are attainable therewith and since both cylinders can then contribute to the containment required to prevent loss of the shocked solid. The term "high-impedance metal" as used herein denotes a metal having a shock impedance of about 3×10^6 dyne-sec/cm^3 or higher at zero pressure. "Shock impedance" is equal to the initial density of a material times the velocity of a shock wave passed through it.

The term "solid circular cylinder" is used herein to describe the shape of the mass of solid material to be shocked. It is meant to include nonself-supporting solids, e.g., powders, contained in a circular cylinder; as well as self-supporting solids, e.g., powder compacts or other frangible solid bodies, in the shape of a circular cylinder, without additional support or supported, e.g., by means of a circular containing cylinder, suspension from an axial metal body, e.g., a rod, etc. The circular cylinder of material to be shocked is termed "solid" to distinguish it from hollow cylinders, which are characterized by an axial passage therethrough. While all materials of the solid cylinder are initially in the solid state, the term "solid is not to be construed as denoting self-supporting or nonparticulate solid bodies.

Initiation with "practically circular symmetry" means that initiation proceeds from a position on the cylinders' common axis or from a set of positions on a circle concentric with, and in a plane normal to such axis, thereby forming a fully developed detonation front having the form of a ring concentric with the cylinder axis.

Brief Description of the Drawing

The process of the invention will be described with reference to the attached drawing, in which:

FIG. 1 is a vertical cross-sectional view of an assembly which can be used to carry out the process of the present invention; and

FIGS. 2 and 3 are enlarged sectional views respectively taken along lines 2—2 and 3—3 of FIG. 1.

Detailed Description of the Invention

In the process of this invention a shock wave is introduced into a solid material (specimen) by the progressive collision of an explosively propelled hollow circular metal cylinder (the outer cylinder) with a solid circular cylinder as defined above (the inner cylinder). When the outer cylinder and a container portion of the inner cylinder (if present) are made of a dense, high-impedance metal, as defined above, the collision can generate considerably higher pressure in the solid material than could the explosive itself were it to detonate along the outside surface of the solid material itself or a containing cylinder. Thus, the present process extends the pressure capability of cylindrical shocking techniques without a sacrifice in the efficiency of the utilization of explosive energy such as is required in the above-described procedure wherein an explosive detonates adjacent to a thick-walled container. With the present process, the total pressure which can be generated with a given explosive composition and mass is higher than with previous cylindrical shocking methods.

In addition, since the propelled cylinder progressively collapses around the specimen as it applies the pressure pulse, the need to initially contain self-supporting solids is eliminated, provided, of course, that the specimen remains solid during shocking. Furthermore, in cases where the specimen is in a cylindrical container, collapse of the propelled cylinder around the container has the effect of producing a double-walled container for the shocked solid as the process proceeds. Thus, the present process can afford the improved product containment, resistance to rapid expansion, and delayed unloading of pressure associated with heavy confinement without, however, requiring an initially thick-walled container, which would lower the efficiency of the process owing to the associated energy losses.

The propelled cylinder is made of metal, the choice of a specific metal being dependent chiefly on the magnitude of the pressure desired and economical factors. Since higher pressures can be attained with a higher-impedance propelled cylinder, metals having a shock impedance of about 3×10^6 dyne-sec/cm^3 or higher at zero pressure are preferred. On this basis and since it is readily available, steel is a preferred outer cylinder metal. A containing cylinder, when used, need not be made of metal since it may only be required for support. However, metal containing cylinders are preferred since they can provide additional containment for the shocked material and higher pressures. Preferably, the container metal will have about the same shock impedance as the outer cylinder as this tends to reduce pressure variations across the material in the container.

The dimensions of the cylinders can vary widely. The propelled cylinder needs to be thick enough that the desired high pressure penetrates to the center of the sample before attenuation, but not so thick that an undesirably high pressure is produced at the center by convergence effects. As a rule, the mass of the propelled cylinder should not be considerably less than the mass of the inner cylinder, e.g., no less than one-fourth the mass of the solid to be shocked plus container, if one is used. In most cases, the wall thickness of the propelled cylinder will be at least about one-eighth inch. A container cylinder need be only sufficiently thick to rigidly support the column of material to be shocked and to provide supplementary strength to that of the outer cylinder, as needed to contain the shocked material and prevent its loss. Container cylinders having a wall thickness of at least about one thirty-second inch usually will be employed.

The cylinders are initially in uniformly spaced-apart, i.e., noncontacting, relationship in order that the propelled cylinder can attain the velocity required to achieve the desired pressure. Preferably, the spacing between the cylinders is at least about equal to the thickness of the propelled cylinder.

The inner cylinder is capped at both ends with blocks of material (preferably steel) that serve as closures for the assembly after the propelled cylinder is collapsed around it. The progressive collision of the outer cylinder with the inner cylinder is effected by the detonation of a layer of explosive along the outer surface of the outer cylinder, the detonation progressing through the explosive in the direction of the longitudinal axes of the cylinders. For this reason, the explosive layer is initiated from a point on the cylinder axis or from a set of positions on a circle concentric with the cylinder axis. Since the material to be shocked (the sample) will be located between the blocks that serve as end closures and since it is desirable that steady-state conditions prevail when the collision reaches the sample region, it is preferred that the explosive be initiated at one end of the cylindrical assembly. To provide pressure uniformity, the explosive in the sample region should be initiated with circular symmetry. This can be effected, for example, by initiating the explosive layer in a circle with a line wave generator bent to initiate on a circle, a number of blasting caps, or one cap connected to a number of points in the explosive layer by detonating cord. The layer also can be initiated at one end by means of a plane wave generator, or the base of a conical explosive layer in which explosive is packed around an inert cone and the conical layer initiated at its apex by a blasting cap. Circular symmetry can also be achieved by center-initiating a circular layer of a cap-sensitive explosive, the circular layer being normal to the axis of the cylindrical assembly and abutting the end of the cylindrical explosive layer, and the initiation point being on the axis of the cylinders.

As a rule, it is desirable that the detonation velocity of the explosive, the explosive loading on the outer cylinder, and the thickness of the cylinder walls be substantially uniform throughout the portion of the cylindrical assembly where collision will occur in planes passing through the material to be shocked. Around the end portions of the assembly, where the planes of collision may pass through the blocks that serve as end closures, the explosive loading, detonation velocity, or wall thicknesses may be varied in the axial direction, e.g., a higher loading or detonation velocity near the initiation end, or decreased loading or velocity, or increased wall thickness at the end opposite the initiation end.

The material to be shocked can be in the form of a particulate mass, e.g., a mass of powder, or a more self-supporting particulate or nonparticulate body, e.g., a powder compact or metallic casting. Solids that are not self-supporting, e.g., powders, are confined in a containing circular cylinder. If the material is self-supporting but segmented, the segments can be fastened, strung, or otherwise attached to an axial cylindrical rod to provide support. If the material is self-supporting, or contains a central supporting rod, a containing cylinder may still be used, but is not required. Even when a containing cylinder is required, a central solid cylindrical rod can be employed if it is desired to shock the material in the form of an annular cylinder. More uniform pressure treatment is easier to obtain if the sample has a diameter which is small compared to its length, or if the end of the specimen where the shock wave initially enters is preceded by a section of solid having about the same shock impedance, and preferably of about the same bulk density as the sample. The purpose is to provide a startup section where the explosive and shock wave can reach steady-state conditions. Preferably, this section will have a length equal to about five times the sample's diameter and will be surrounded by the container (if any), the hollow cylinder and the explosive layer.

The specific combination of explosive conditions selected to be used in the present process, e.g., amount of explosive and its detonation velocity (i.e., velocity of the collison), depend on the pressure it is desired to achieve in a given solid material to be shock treated. Known methods of estimating shock pressures can be used as a guide for any given sample, and optimum conditions for any desired result are easily determined experimentally. For compaction, the explosives and explosive loadings disclosed in U.S. Pat. No. 3,022,544 can be employed, and for comminution the explosives and loadings disclosed in U.S. Pat. No. 3,367,766 are suitable. In both cases, the process of this invention will provide higher shock pressures of longer duration than in the patented contact techniques, while also providing added containment. Also, the present process can be employed to effect phase changes, e.g., the transformation of nondiamond carbon to diamond, under the conditions disclosed in U.S. Pat. No. 3,401,019. In addition, one can use the improved method of shock treating solids, disclosed in our simultaneously filed U.S. application Ser. No. 804,194 filed Mar. 4, 1969 entitled "Method of Treating Solids With High Dynamic Pressures and New Diamond Product," the disclosures of which are incorporated herein by reference.

Irrespective of the purpose for which the process is employed, we have found that pressure oscillations in the wall of the initial container (if any) and in the contracted hollow cylinder will be substantially eliminated, and the chance of disrupting the sample correspondingly reduced, if the hollow cylinder is caused to collide with the specimen or its container under jetting, and preferably jetting and bonding, conditions. Both jetting and bonding conditions are described in U.S. Pat. No 3,137,937.

The collision process collapses the propelled cylinder around the inner cylinder so that the shocked sample is held within a container formed by the propelled cylinder and the capping blocks at the ends of the inner cylinder. If a cylindrical container for the sample is employed, the shocked sample is held within a double-walled container formed by the containing cylinder and the propelled cylinder. The shocked sample is separated from the cylinder(s) surrounding it by an procedure which is suited to the nature of the material. The sample container may be cut open so as to expose the sample section and the contents removed manually where possible. If the sample, or a portion thereof, cannot be removed manually owing to its adherence to the surrounding cylinder wall, separation of the sample may be effected for example, by machining the cylinder off, selectively dissolving the cylinder metal or extruding the sample from the cylinder(s).

The present process can be used to shock a wide variety of solid materials to effect desired changes therein. It can be used to compact powders, for example, especially powders which require higher pressures to compact than have been heretofore available, as well as those in which brittle fracture has been a problem, e.g., refractory metal carbides, silicon carbide, etc. It can be used to particular advantage for effecting phase transformations in solids, e.g., nondiamond carbon to diamond (as in aforementioned U.S. Pat. No. 3,401,019) and low-density hexagonal boron nitride to denser phases. Other changes which can be effected by the use of this process are comminution, modification of properties or microstructure, and chemical reactions.

The process of this invention will now be explained with reference to the accompanying drawing. In the drawing, s solid sample **1** to be shocked is shown packed into circular metal cylinder **2**, the top end of which is closed by plug **3**, e.g., of compacted steel powder, and the bottom end by plug **4** and an optional spall section **5**. Metal cylinder **2** fits coaxially inside circular metal cylinder **6**, with a substantially uniform spacing **7** between the facing surfaces of cylinders **2** and **6**. The coaxial spacing is maintained by metal disks **8** and **9** which abut the inner surface of metal cylinder **6** at the top and bottom ends thereof, respectively. Disk **8** is welded to cylinder **2**, and disk **9** to cylinder **6**. Surrounding outer metal cylinder **6** is a cylindrical layer of granular explosive **10** contained in a cardboard or thin-walled cylindrical container **11**, e.g., a metal cylinder. The explosive extends across the top of the cylindrical assembly, and is initiated axially, e.g., by means of a primer **12**, initiated in turn by detonating cord **13**. Metal disk **14** extends over the top end of the cylindrical assembly and is welded to cylinder **6**. The entire assembly rests on metal plate **15**. A circumferential notch **16** extends around the periphery of cylinder **6** in the region of spall section **5**. This assists in carrying off of the axial momentum in cylinder **6** associated with the collision with cylinder **2**. Spall section **5** and notch **16** do not constitute part of this invention, but generally are employed for large-scale shots where the sample becomes molten at the shock pressures employed. These expedients as well as the requirements on plug **4** when it is used with them are described in the coassigned copending U.S. application Ser. No. 804,199 of George R. Cowan entitled "Plug Closure" and filed on even date herewith, the disclosures of which are incorporated herein by reference.

The following examples serve to illustrate specific embodiments of the process of this invention. However, they will be understood to be illustrative only and not as limiting the invention in any manner.

EXAMPLE 1

Referring to the drawing, cylinder **2** is made of Type 1015 steel, is 53.5 inches long, and has a 1.5-inch outer diameter and a 0.095-inch wall thickness. Cylinder **6** is made of Type 1015 steel, is 54 inches long, and has a 3.5-inch outer diameter and a 0.375-inch wall thickness. Spacing **7** is 0.625 inch.

At one end of cylinder **2** (the top end) is a 3.00-inch-long plug **3** consisting in this case of 6 superimposed 1.31-inch-diameter 0.5-inch-thick pellets of 100-mesh low-carbon steel powder pressed to the following densities, respectively, starting from the outermost pellet: 82, 79.5, 77, 75, 74, and 74 percent (of the theoretical). Abutting this plug is the sample to be shocked **1**. This consists of a mixture of 8 percent by weight of natural graphite having an average particle size of 2.5 microns and 92 percent by weight of copper shot of a size such as to pass a 150-mesh, and be held on a 200-mesh, screen (74–105 microns). The graphite/copper mixture is pressed into pellets from a dried water slurry containing 2 percent guar gum. The density of the graphite in the sample is computed to be 50 percent from a volume obtained by assuming the larger-size copper to be of 100 percent density, and subtracting the calculated volume of the copper from the known volume of the total mixture. The pellets are placed in cylinder **2** so as to form a solid cylinder having a 1.31-inch diameter and 30.5-inch length, and weighing 3,890 grams. After having been loaded into the cylinder, the sample is heated to about 250° C. for several hours. This decomposes the gum.

Abutting the bottom of the sample is a steel member consisting of two sections, **4** and **5**, having a total length of 20 inches. The closure member consists of a number of 0.5-inch-thick superimposed steel powder pellets (same powder as in plug **3**). In section **4**, the plug section, which is 13 inches long, there are six pellets having densities (starting from the sample end) of 74, 74, 75, 76, 77, and 78 percent of the theoretical, respectively, followed by 20 pellets having a density of 79.5 percent of the theoretical. In section **5**, the spall section, which is 7.0 inches long, there are 14 pellets decreasing in density (starting from plug **4**) from 79.5 to 50 percent as follows: 79.5, 77, 74, 71, 68, 65, 62, 59, 56, 53, 50, 50, 50, and 50 percent. In the plug **4**, the density and shock impedance of the steel are matched to the density and shock impedance of the sample adjacent thereto (26 75 percent steel density), thereby preventing reflection of the high-pressure pulse. The plug remains solid during the process and retains the sample. The gradually decreasing density in the spall section **5** carries off the momentum associated with the chock wave without reflecting a tension wave. The momentum is carried off by spalling or separation of material. The decreasing density also causes cylinder **2** to be driven in further as the density decreases, thereby restricting the forward motion of the plug. The circumferential notch **16** is ⅛ inch deep and wide, and is located 1.5 inches from the bottom end of cylinder **6**. This also carries off axial momentum.

Explosive **10** is a 60-inch-high cylinder 16 inches in diameter of a uniform mixture of grained 80/20 amatol (80 percent ammonium nitrate/20 percent trinitrotoluene) and 32 percent sodium chloride (table salt) based on the total weight of the composition (total weight: 509 pounds). The explosive is contained in a cardboard cylinder **11** coaxial with the cylindrical assembly. The explosive is initiated axially at the top end of the assembly, 5 inches above a 2-inch-thick steel cover **14** welded to cylinder **6**, by means of an HDP-1 primer (see Du Pont Blasters' Handbook, 15th Ed., 1966, p. 66). The detonation velocity of the explosive is 4,710 meters per second.

Detonation of the detonating cord **13** initiates the primer and, in turn, the cylindrical explosive layer. After detonation of the explosive, the cylindrical assembly is recovered intact. The bottom portion of the spall section is found to have broken off and the plug to have moved downward about 3 inches. The two cylinders have become bonded to each other, and the bottom 1.5-inch section has sheared off at the notch. Thus, the shocked sample is contained in a double-walled cylinder enclosed at both ends. To recover the shocked sample, the composite cylinder is cut open so as to expose the sample section. Melting of copper is seen to have occurred, and in this zone there is segregation of the carbon from most of the copper as dry powder. The remainder of the sample section is removed from the cylinder by machining down the steel composite cylinder, leaving a thin wall around the sample. Treatment of the segregated powder and the machined sample with nitric acid removes the copper and steel, and the remaining solids (graphite plus diamond) are mixed with lead oxide powder, and the mixture is heated in air for 24 hours at 425° C. to oxidize the graphite. The oxidized mixture is treated with aqua regia to convert the lead oxide to water-soluble salts, and the remaining solids are then treated with an aqueous solution of the tetrasodium salt of the ethylenediaminetetraacetic acid to dissolve the remaining lead salts. The solids are determined to be diamond by X-ray diffraction procedures. The overall yield, in terms of total diamond recovered relative to total carbon recovered, is greater than 30 percent.

EXAMPLE 2

Silicon carbide powder is compacted by the following procedure:

The inner cylinder, which contains the sample to be compacted, is made of Type 304 stainless steel, is 13.6 inches long, and has an outer diameter of one-half inch and a wall thickness of one thirty-second inch. Positioned at the bottom of the cylinder in snug fit is a 2.5-inch-long brass rod attenuator having a conical cavity extending throughout its length, the apex of the cavity being at the flat end of the rod which is at the bottom of the cylinder. The apex angle is 2° 30′. This end of the cylinder is closed by a 2-inch-long, ½-inch-diameter steel plug in the form of a solid cylinder having three crimps evenly spaced lengthwise on its periphery. "FFF" silicon carbide (particle size 10–40 microns) is placed into the attenuator cavity and for a distance of 4.9 inches above the attenuator, to a density of 60 percent. The next 5.7 inches is filled with silicon carbide powder of 1–5 micron average particle size, also packed to 60 percent density. The top of the cylinder is closed by a 2-inch-long, ½-inch-diameter steel plug in the form of a solid cylinder having three crimps evenly spaced lengthwise on its periphery.

The outer cylinder is made of Type 304 stainless steel, is 18 inches long, and has an outer diameter of 1¼ inches and a wall thickness of one-eighth inch. The cylinders are maintained in axial alignment with a one-fourth inch spacing between their facing surfaces by means of a circular cardboard disk fitting inside the outer cylinder near each end, each disk having a central aperture to hold a ⅛-inch-diameter steel rod which connects into the steel plug at each end of the inner cylinder. A steel end plug is epoxied onto the outer cylinder over the cardboard disk.

The explosive is a 0.550-inch-thick, 18-inch-long layer of a sheet explosive of the type described in U.S. Pat. No. 3,093,521 and comprising 20 percent very fine pentaerythritol tetranitrate (PETN), 70 percent red lead, and, as a binder, 10 percent of a 50/50 mixture of butyl rubber and a thermoplastic terpene resin [mixture of polymers of β-pinene of the formula $(C_{10}H_6)_n$], commercially available as "Piccolyte" S-10 (manufactured by the Pennsylvania Industrial Chemical Corp.). The sheet explosive has a density of 3.2 grams per cubic centimeter and detonates at a velocity of 4,500 meters per second. A disk of a PETN sheet explosive of the type described in U.S. Pat. No. 2,999,743 and detonating at a velocity of 7,200 meters per second (loading: 4 grams per square inch) is affixed to the edge of the cylindrical explosive layer, and an electric blasting cap is embedded in the disk at its center.

The cylindrical assembly is encased in an 18-inch-long steel cylinder having an outer diameter of 5½ inches and a ¼-inch-thick steel base plate is affixed to the bottom of the assembly. The sample-containing cylinder and the space between the two cylinders is evacuated to about 50 microns pressure by means of a vacuum connection through the encasing cylinder and propelled cylinder walls, small holes having been provided in the sample-containing cylinder for this purpose. The annulus between the explosive layer and the encasing cylinder is filled with water.

Actuation of the blasting cap initiates the explosive disk, which in turn initiates the cylindrical explosive layer simultaneously at the entire periphery adjacent the cylinder to be propelled. After the detonation of the entire 18-inch-long layer of explosive, the cylinder assembly is recovered intact. The ends are cut off, and the cylinders are found to be firmly bonded together in the form of a composite cylinder, which is sectioned. Photomicrographs of the silicon carbide reveal a dense microstructure with evidence of plastic deformation and recrystallization to a fine-grained structure. The silicon carbide pieces obtained are hard, strong, and well-compacted. They easily scratch tungsten carbide.

EXAMPLE 3

a. Example 1 is repeated with the following modifications: The inner cylinder is 12 inches long and has an inner diameter of 0.442 inch and an outer diameter of 0.569 inch. Starting at the top end of the cylinder, there are 90 percent dense steel powder pellets for a distance of 3 inches, a 3-inch-long sample section of pressed pellets of a graphite/copper mixture containing 3 percent graphite by weight having a 40 percent graphite density, and a 6-inch-long closure section consisting of a 2.1-inch-long section of 90 percent dense steel powder pellets, followed by a 3.9-inch-long section of steel powder pellets of densities decreasing from 86 percent to 56 percent. A ⅛-inch-diameter axial solid steel mandrel passes through the pellets in the top closure section, the sample section, and for the first 1.5 inches of the 90 percent dense steel pellets.

The outer cylinder is 12 inches long and has a 1.068-inch outer diameter and 3/32-inch wall thickness. Spacing **7** is 0.156 inch.

The explosive is a 0.75-inch-thick extruded seamless tubular layer of a PETN sheet explosive of the type described in U.S. Pat. No. 2,999,743 and detonating at a velocity of 6,900 meters per second.

After detonation, a specimen of the material in the sample section is treated with nitric acid, and the remaining solids are treated with a sulfuric-chromic acid mixture to oxidize the graphite present. Of the solids subjected to oxidation, 35.7 percent is recovered. This material is revealed by X-ray diffraction to be 99.5 percent diamond.

b. The procedure described in Part (*a*) above is repeated with the exception that the outer cylinder is omitted and the explosive layer is positioned adjacent the smaller inner cylinder. The material in the sample section is treated in the same way as that described in Part (*a*). In this case, there is no detectable residue after the oxidation. Thus, the yield of diamond is 0 percent. **20**

We claim:

1. A method of explosively shocking solid material, comprising: positioning a solid circular cylinder of said material coaxially within a hollow circular metal cylinder with a spacing between the facing surfaces of said cylinders;

surrounding the convex surface of the hollow metal cylinder with a layer of detonating explosive;

initiating the explosive layer with substantially circular symmetry about said hollow cylinder whereby the explosively generated pressure causes the hollow cylinder to progressively collide with the solid cylinder along the axial direction of the cylinders and thereby introduce by said colliding a shock wave into said solid material, and thereafter recover the shocked solid material.

2. A process of claim **1** wherein the solid cylinder comprises the solid material being treated confined in a containing circular cylinder.

3. A process of claim **2** wherein the container is metal.

4. A process of claim **3** wherein the hollow cylinder progressively collides with the container under jetting and bonding conditions.

5. A process of claim **3** wherein the hollow cylinder progressively collides with the container under jetting conditions.

6. A process of claim **5** wherein the solid material being treated is a mixture of carbon and a metal.

7. A process of claim **6** wherein the mixture is graphite and copper.

8. A process for the production of diamond from carbon, comprising:

forming a mixture of particulate carbon and metal into a solid circular cylinder;

positioning said cylinder coaxially within a hollow circular metal cylinder with a spacing between the facing surfaces of said cylinders at least as great as the radial thickness of the hollow cylinder;

surrounding the convex surface of said hollow metal cylinder with a substantially uniform layer of explosive;

initiating the explosive with essentially circular symmetry at one end of said hollow cylinder whereby the explosively generated pressure causes the hollow cylinder to progressively collide with the solid cylinder along the axial direction of the cylinders and thereby introduce by said colliding a shock wave into said mixture of sufficient magnitude whereby at least a part of the carbon is transformed to diamond, and

recovering diamond from said shocked mixture.