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[54] **APPARATUS FOR SHOCKING MATERIALS**

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[52] **U.S. Cl.** 241/301

[51] **Int. Cl.** B02c 19/18

[58] **Field of Search** 241/31, 301

[56] **References Cited**

UNITED STATES PATENTS

3,352,503	11/1967	Maroudas	241/301
3,367,766	2/1968	Barrington et al.	241/301 X
3,458,139	7/1969	Edebo	241/301 X
3,463,716	8/1969	Levavasseur	241/301 X

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[57] **ABSTRACT**

Apparatus for shocking materials comprising one or two reusable receiving vessels to which are mounted one or more expendable shocking tubes containing the material to be shocked. A shock wave is generated by the axially progressive detonation of an explosive adjacent to the shocking tube or to a driver tube which collapses and impacts the shocking tube. The shocked material is substantially discharged into the receiver and agglomerates are comminuted.

8 Claims, 3 Drawing Figures

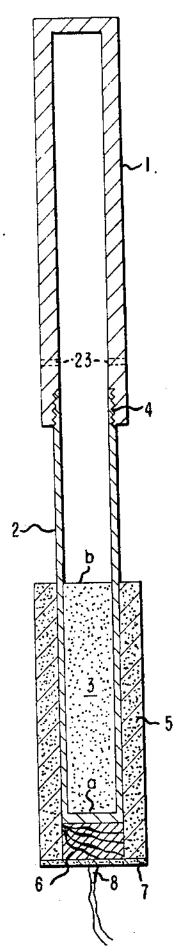

FIG. 1

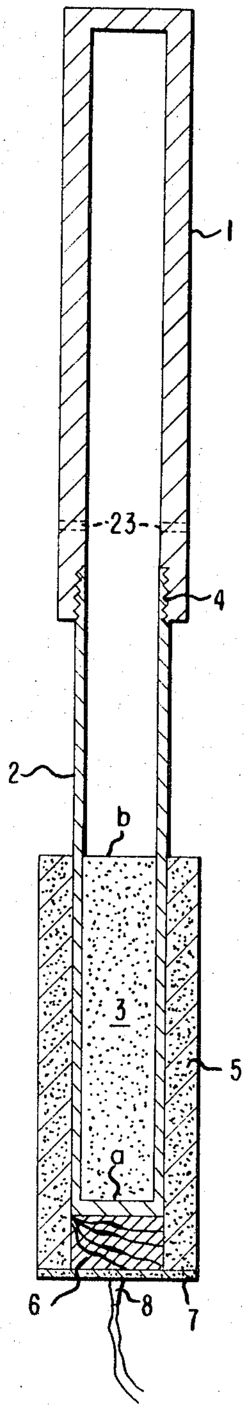

FIG. 2

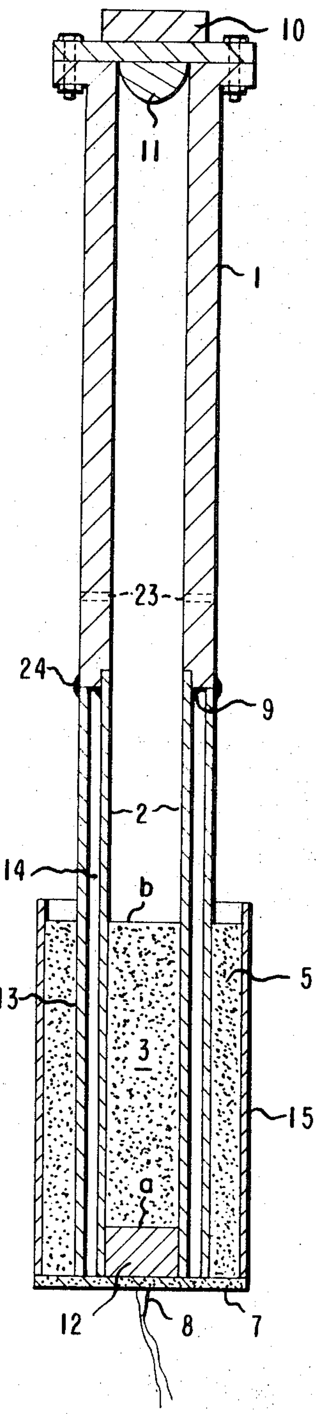

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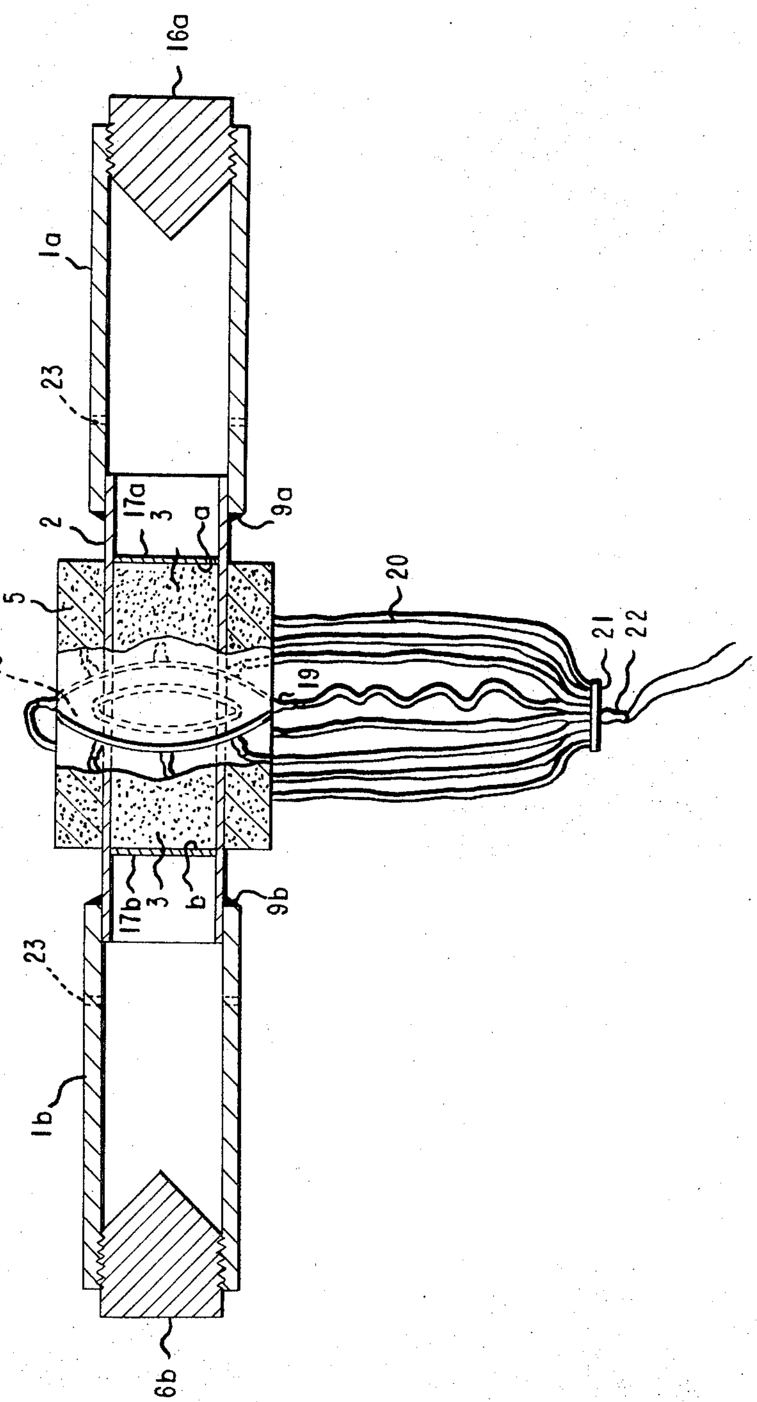
FIG. 3



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APPARATUS FOR SHOCKING MATERIALS

BACKGROUND OF THE INVENTION

This invention relates to an improved apparatus for treating materials with shock waves.

The transient high pressure to which a material is subjected when a shock wave passes through it can be used to perform various kinds of useful work, e.g., to densify a porous material, modify the physical properties or microstructure of a material, or produce a phase change or chemical reaction. The treatment of powders, for example, is often done by amassing the powder within a tubular container, and subjecting the container wall to transient high pressure progressively in an axial direction either by progressive axial detonation of an explosive surrounding the container or by impacting the container wall by the progressive collapse, preferably accelerated explosively, of a concentric tube surrounding the container and initially at a small standoff distance from it. Such a surrounding tube is referred to as a driver tube.

In employing such a technique, for example in the shock comminution process described in U.S. Pat. No. 3,367,766, (Feb. 6, 1968, to Barrington et al.) the common practice has been to fill the container tube with the powder to be treated and seal the powder in the tube at both ends with plugs, the explosive or driver surrounding the container tube at the plug portions as well as the sample portion. The tube and plugs provide tight, effective containment for the powder during the shock process. After such treatment, however, the plugs cannot be removed by simple manual procedures, and the powder, transformed by the shock to a compacted mass, does not pour from the tube. It is necessary to machine through the container so as to permit the container to be peeled or forced off of the compacted powder, a time-consuming procedure which can be costly when required for the processing of many lots or batches of powder on a production scale. In addition, because of the deformation and machining of the container, each time a new mass of powder is to be treated an entirely new assembly must be constructed, a procedure which is expensive not only because of materials costs but also because of the time required to seal off the powder at two ends each time. Thus, the assemblies and methods heretofore employed for shocking powders, while effective for applying the shock wave and containing the powder, have been inefficient for use on a repetitive basis. Also, in many cases, as when the shock-treated powder is to be used as an ingredient for ceramics, it cannot be used in the form of the compacted lumps recovered by machining open the container. The recovered lumps would typically be broken down by ball-milling, a process that causes extra expense and may introduce impurities.

SUMMARY OF THE INVENTION

This invention provides an improved apparatus for shocking materials, especially powders, which facilitates product recovery procedures, permits reuse of part of the apparatus as succeeding lots of material are processed, and also permits production of fine powders from shock-comminutable brittle materials by the shocking step alone, as contrasted to conventional shocking apparatus, wherein the material produced is in the form of aggregates or lumps that need to be de-agglomerated after shocking to produce fine powders. The apparatus of the invention comprises (a) a receiving vessel having at least one primary opening in its wall, at least one such primary opening joined to a shocking tube, any such primary opening not so joined being sealed by a mechanically openable closure member to permit removal of the material after shocking; (b) at least one shocking tube containing the material to be shocked, such that at least a substantial portion of the material will be ejected into the receiving vessel upon shocking, the tube being joined at one end to the receiving vessel in such a manner that the inside of the tube communicates with the inside of the vessel, the other end of the tube being closed; (c) explosive means surrounding the shocking tube for applying axially progressive transient high pressure, i.e., shock, thereto. Alternatively a shocking tube may be attached at each end to a different receiving vessel. In either alternative the apparatus should be provided with means, such as at least one secondary opening, for release of pressure.

The pressure-applying means may comprise an explosive surrounding the shocking tube, or a coaxial tubular metal projectile known as a driver tube surrounding the shocking tube with a standoff distance between facing tube surfaces and an explosive surrounding the projectile, the detonation of the explosive preferably being initiated substantially simultaneously at all points in a transverse plane (i.e., a plane substantially normal to the tube axis), which passes through the boundary of the material to be shocked which is farthest from the receiving vessel or through the approximate center of the material to be shocked in the alternative arrangement, such that a detonation front forms a ring the movement of which defines a cylinder coaxial with the shocking tube.

The present apparatus is employed with particular advantage for the shock comminution of brittle powders to produce fine powders. Using the present apparatus, powders that have been broken down or altered by the incident shock are propelled out of the shocking tube and into the receiving vessel(s), during which process weakly bonded agglomerates of shock-treated powder are broken up. Thus, the present apparatus permits brittle powders to be shock-comminuted and de-agglomerated in a single operation, obviating the need for a de-agglomeration procedure after shocking.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings, which illustrate specific embodiments of the invention,

FIGS. 1, 2 and 3 are longitudinal cross-sectional views of the apparatus of the invention in three different modifications.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The apparatus of this invention includes a shocking portion comprising a tube, which may be expendable, containing the material to be shocked, and a receiving portion, which may be tubular or other shape, and may be reusable. The shocking tube is joined at one end to the receiving vessel in a manner such that their interiors communicate, forming a unified, closed container. As described below, the shocking tube may be closed at the end not connected to the receiver, or may be connected to two receivers, one at each end. The receiving vessel will have at least a single relatively large or "primary" opening in its wall, i.e., the opening at which the vessel is joined to the shocking tube, and it may have additional primary openings, each of which is joined to a mechanically openable closure member, e.g., a threaded plug or bolted cover plate assembly. The apparatus should also have a means of relieving pressure produced in the apparatus by the shock. Such a means may comprise one or more relatively small or "secondary" holes or a mechanical pressure relieving device such as a "pop" valve or rupture disc. Additional shocking tubes can be joined to additional primary openings in the wall of a suitably shaped receiving vessel so that multiple shocking tubes feed into the single receiving vessel.

With reference to FIG. 1, tubular receiving vessel **1** has a single primary opening in its wall, i.e., at one end. At this end the inside wall of tubular vessel **1** is provided with threads which engage matching threads on the outside wall of shocking tube **2**, at the open end thereof, this tube also having one closed end and acting as a mechanically openable closure member for vessel **1**. A cylindrical mass of powder **3** in tube **2** has two transverse boundaries, one, a, adjacent the closed end of tube **2**, and the other, *b*, a free boundary closer to tubular vessel **1**, but short of threaded joint **4** connecting vessel **1** and tube **2**. Powder mass **3** is maintained in position in tube **2** by maintaining tube **2** in a vertical position with its closed end bottommost. The space between free powder boundary *b* and the closed end of tubular vessel **1** is empty, and larger in volume than the volume of powder **3**. A self-supporting tubular layer of detonating explosive 5 is adjacent the outside wall of tube 2, from the plane of boundary *b* to somewhat beyond the closed end of tube 2. In order to achieve pressure uniformity on the wall of tube 2, explosive layer 5 is initiated with practically circular symmetry about its axis. This is accomplished in this instance by extending tubular explosive layer 5 beyond the bottom of tube 2, positioning an inert disc 6, e.g., a wooden dowel, within the tubular extension, positioning a disc of detonating explosive 7 over the outer surfaces of layer 5 and disc 6, and initiating disc 7 at its center by actuating electric blasting cap 8. By this means, tubular explosive layer 5 is initiated at all points in the plane of boundary *a* substantially simultaneously. Vessel 1 is provided with several small (e.g., about 1/32-inch diameter) secondary openings 23 or bleed holes which relieve the pressure generated within the apparatus by the shocking process.

In FIG. 2, tubular receiving vessel 1 has two primary openings, one at each end. Shocking tube 2 acts as a closure member for one end, tube 2 being joined at its open upper end to vessel 1 by means of lap weld 9. The other open end of vessel 1 is closed by means of closure plate 10 which is bolted to a flange portion of vessel 1. A conical member 11 is affixed to the inside surface of closure plate 10, the conical surface acting as a particle deflector to reduce the chances of high-velocity particles entering the bolt connections as a result of the shocking process, and possibly making the removal of the bolts difficult. The closure at the closed bottom end of tube 2 is a metal plug 12, welded in place in tube 2. The pressure-applying means consists of metal tube 13 and surrounding tubular layer of explosive 5. Tube 13, which is known as a driver tube, is positioned coaxially with tube 2 in a manner such as to provide a substantially uniform spacing 14 or standoff distance between facing surfaces of tubes 13 and 2. Tube 13 is joined to vessel 1 by butt weld 24. Explosive 5 is held in position by vessel 15, e.g., a cardboard cylinder, and extends beyond the plane of boundary *a* to provide circularly symmetric initiation in this plane, as disclosed in the above description of FIG. 1. Secondary openings 23 are provided to relieve pressure within the apparatus, as described above.

The pressure application required to generate a shock wave travelling from boundary *a* to a boundary *b* of powder 3 is provided by detonation of explosive layer 5 which detonates progressively in the axial direction in the apparatus shown in FIG. 1, and by axially progressive impact of driver tube 13 with tube 2 as a result of the progressive detonation of explosive layer 5 in the axial direction in the apparatus shown in FIG. 2. Because boundary *b* is free, the high pressure associated with the shock wave causes powder 3 to be propelled from tube 2 into tubular receiving vessel 1. As a result of this process the shocked product is a loose mass of powder which can be recovered readily by pouring after disengagement of the mechanical joint provided. In the case of the assembly shown in FIG. 1, vessel 1 is separated from tube 2 by unscrewing joint 4, and the shocked powder is poured out. Vessel 1 can then be re-used by screwing on a new tube containing powder to be shocked. With the assembly of FIG. 2, closure plate 10 is unbolted from vessel 1, and the shocked powder poured out while vessel 1 and tube 2 still are joined together. Vessel 1 and closure plate 10 can be re-used in a new assembly by rebolting the closure plate to the tube, and joining the open end to a new powder-containing shocking tube and driver tube after cutting the original tubes off. Of course, if desired, the pressure-applying means of FIG. 1 could be substituted for that of FIG. 2.

FIG. 3 depicts an apparatus of the invention wherein two re-usable receiving vessels are employed. Tubular receiving vessels 1*a* and 1*b* each have two primary openings, one at each end, and a number of small, secondary bleed openings 23. Shocking tube 2 also is open at both ends and is connected at its respective ends to vessels 1*a* and 1*b* by means of lap weld 9*a* and lap weld 9*b*, respectively. The other open end of vessel 1*a* is closed by means of threaded plug 16*a*, and that of vessel 1*b* by means of threaded plug 16*b*, plugs 16*a* and 16*b* both having a powder-deflecting conical internal surface. Powder 3 is maintained in position in shocking tube 2 by means of supporting membranes 17*a* and 17*b*, which are thin powder compacts and yield easily under shock pressure. The spaces between membrane 17*a* and plug 16*a*, and between membrane 17*b* and 16*b*, are empty.

A self-supporting tubular layer of detonating explosive 5 is adjacent the outside wall of tube 2 in FIG. 3, extending from the plane of transverse boundary *a* to that of transverse boundary *b* of powder 3. In this case, explosive layer 5 is initiated substantially simultaneously at all points in a transverse plane which passes through approximately the center of powder mass 3. This is accomplished by means of annular initiating disc 18 of detonating explosive and multiple non-electric blasting caps 19 evenly distributed around the periphery of disc 18. Annular disc 18 is embedded in tubular explosive layer 5, coaxial therewith, and in substantially a central plane transverse to the tubular axis, the size of the aperture in disc 18 being such that the inner periphery of disc 18 is out of contact with the outer wall of tube 2. Each blasting cap 19 is actuated by means of low-energy detonating cord 20, each cord being of the same length and all cords detonated simultaneously by disc 21 of detonating explosive initiated at its center by electric blasting cap 22. This causes disc 18 to be detonated substantially simultaneously along its entire outer periphery, and detonation of explosive layer 5 in the two axial directions toward both vessels 1*a* and 1*b*, propelling powder 3 from tube 2 into vessels 1*a* and 1*b*. The loose shocked powder may conveniently be poured out by disengaging plugs 16*a* and 16*b*. After cuts have been made through the assembly to free the end of vessel 1*a* at joint 9*a*, and the end of vessel 1*b* at joint 9*b*, the receiving vessels 1 *a* and 1*b* and plugs 16*a* and 16*b* can be re-used in a new assembly by rescrewing a plug to the end of each vessel, and joining the open end of each vessel to a new powder-containing shocking tube.

It will usually be desirable that the transient high pressure applied to the shocking tube progress along substantially the entire length of the mass of material, e.g., powder, therein, thus neither the material nor the surrounding explosive should extend to the shocking tube-receiver joint. This protects the joint and the receiving vessel from shock-induced distortion which can interfere with the disconnecting of the receiving vessel and/or the re-usability of this vessel. To prevent contamination of the powder, the internal open areas of the apparatus should be free of undesired materials. Essentially non-shatterable solid structures, e.g., ductile metal supports, can be present in this space, however.

When the volume of the receiver is sufficiently large and sufficient pressure is applied to the wall of the shocking tube, substantially all of the powder can be ejected out of the shocking tube and into the receiving vessel, resulting in breakup of weakly bonded powder agglomerates, e.g., agglomerates of fractured particles of brittle powders. Thus, shock comminution and de-agglomeration may be achieved in a single operation. It is believed that such de-agglomeration occurs both by impact of the powder with the walls of the receiver and by rapid decompression and shear as the powder is ejected into the receiver.

When a single shocking tube is used to treat brittle powders such as are defined in U.S. Pat. No. 3,367,766, which are to be recovered in the form of fine powders, the volume of the receiver should be at least equal to, and preferably greater than, the volume of the mass of powder. This space is desirable to permit substantially all of the powder to move out of the shocking tube and undergo de-agglomeration. Generally, an empty space volume which is about 2–4 times the powder volume is effective. Larger spaces are unnecessary but can be employed provided the powder travel distance does not become so great that the desired comminution is interfered with. When two receiving vessels are employed per shocking tube, as in FIG. 3, the volume of each of the two receivers should be at least equal to, and preferably greater than, one-half of the volume of the powder mass. In this instance an empty space volume for each receiver which is about 1–2 times the powder volume would be desirable.

The specific design of the pressure-applying means is not critical to the functioning of the present apparatus. Any means which can provide pressure of the required magnitude and apply the pressure in the specified manner can be employed. Based on convenience and economics, preferred pressure-applying means are (a) a layer of explosive surrounding the shocking tube wall and adapted to detonate progressively in an axial direction, and (b) a coaxial tubular projectile or driver tube surrounding the shocking tube wall with a standoff distance between facing tube surfaces, the projectile being accelerated, preferably explosively by detonation of a surrounding layer of explosive, so as to impact the outer surface of the shocking tube progressively in an axial direction. In most instances the explosive loading (weight of explosive per unit area of tube surface) should be substantially uniform over the entire tube surface. The explosive typically extends for the length of the material to be shocked. The explosive should be initiated with practically circular symmetry about its axis, i.e., substantially simultaneously at all points in a transverse plane of initiation. This plane would approximately coincide with the extremity of the mass of material to be shocked (such as at the closed end of a shocking tube (FIGS. **1** and **2**)), or a plane passing substantially through the center of the mass when both shocking tube ends are open and joined to a receiving vessel (FIG. **3**). Circularly symmetric initiation can be accomplished by embedding a number of blasting caps at evenly spaced points in the desired plane (a) in the explosive layer, (b) in an explosive disc in the explosive layer, or (c) in an explosive cord surrounding the layer, and actuating the caps simultaneously, as by detonating cords of equal lengths, as shown in FIG. **3**. Circularly symmetric initiation of the explosive layer in the plane of a transverse powder boundary, as in FIGS. **1** and **2**, can be achieved by means of one or more line wave generators or by central single-point initiation of an explosive disc abutting the edge surface of a tubular initiating layer of explosive which surrounds an inert disc and is in contact with the explosive layer to be initiated.

When a tubular projectile (driver tube) surrounds the shocking tube, the two tubes are substantially coaxial, and their facing surfaces are substantially parallel to each other or at a small angle, e.g., less than about 5°, to each other. The specific standoff distance between facing tube surfaces can vary, but should be sufficiently large to permit the projectile tube to achieve a velocity upon impact with the shocking tube sufficient to produce the required pressure in the material. Although the mass of material to be shocked, and the explosive surrounding the projectile tube, may not extend as far as the shocking tube/receiving vessel joint, the projectile tube may extend beyond the explosive in an axial direction toward the receiving vessel, and may even extend as far as the joint, as shown in FIG. **2**.

The receiving vessel or vessels can have any desired configuration, e.g., tubular, spherical, box-like, etc. However, except in assemblies in which multiple shocking tubes feed into the same receiving vessel on divergent axes, it is unnecessary to employ a receiving vessel having a much greater transverse dimension (i.e., a dimension normal to the shocking tube axis) than the shocking tube, and therefore a tubular receiving vessel having a diameter on the order of that of the shocking tube ordinarily will be employed when a single shocking tube is joined to the receiving vessel. A convenient assembly for use when more than two shocking tubes are joined to a common receiving vessel is one in which a substantially spherical, or otherwise rotund, receiving vessel has shocking tubes joined thereto at openings in its wall on axes which intersect about at the center of the vessel.

Every primary opening in the receiving vessel wall is joined to either a shocking tube or to a mechanical connect-disconnect joint, e.g., one having threaded or bolted parts. In one embodiment, the joint(s) between the receiving vessel and the shocking tube(s) are mechanical joints, as in FIG. **1**. However, since this requires the provision of a special surface configuration at the end of an expendable element (the shocking tube), the mechanical joint therefore being only partially re-usable, it may be preferred to employ a butt or lap-welded joint between the shocking tube and receiving vessel. The joint between a primary opening in the receiving vessel wall and a closure which is not a shocking tube, e.g., a closure plate or plug, can conveniently be a mechanical disconnectable joint. When a shocking tube and receiving tube are joined by a lap-weld, the end of either tube can overlap the end of the other. Mechanical joints can be protected against seizing as a result of powder entry between the joined surfaces by the use of powder-deflecting surface configurations, e.g., a conical configuration, as illustrated in FIGS. **2** and **3**.

The materials of construction and wall thicknesses of the components of the apparatus can be varied widely, depending, for example, on the magnitude of the pressure to which the component is subjected, the shocking tube of course being subjected to higher pressure than the remaining components. As a rule, to assure good powder containment, the shocking tube, and preferably also the receiving vessel and any other closure members present, are made of a metal, e.g., steel. The wall thicknesses of the shocking tube and receiving vessel can be the same or different. For economic reasons, the expendable portion of the apparatus, the shocking tube, may have a thinner wall than the re-usable portion, the receiving vessel.

When the mass of material to be shocked cannot be maintained in its required position in the shocking tube by gravity alone by vertical positioning of the shocking tube as shown in FIGS. **1** and **2**, one or both ends of the material can be retained by a thin membrane-like layer, e.g., **17*a*** and **17*b*** in the apparatus shown in FIG. **3**, capable of supporting the material but also of rupturing readily by shock pressure so that the material is free to move. In this sense, the transverse material boundaries are "free." While a thin sheet of plastic, rubber, or metal can be used for this supporting layer, an especially useful layer is one which is a coherent compact (e.g., a pressed and/or sintered disc) of powder having the same composition as the material being shocked in the apparatus. This has the advantage that no impurities are introduced into the apparatus. If the particle size of the shocked powder derived from the supporting disc(s) is larger than that of the shocked material, the larger particles can subsequently be removed by screening.

The apparatus of this invention can be employed in various processes which utilize the high pressures associated with shock waves to effect changes in materials, e.g., the modification of properties and microstructure, and phase changes and chemical reactions. As mentioned above, the apparatus is used with particular advantage in processes wherein fine brittle powders are made by shock comminution, the present apparatus permitting brittle powders to be shock-comminuted and de-agglomerated in a single operation. The desirable properties and utility of such fine powders, e.g., carbides, nitrides, borides, oxides, and compounds thereof such as titanates and ferrites, are described in the aforementioned U.S. Pat. No. 3,367,766.

While the apparatus of the present invention finds its greatest present utility in the shocking of dry, particulate solids of small particle size, it will be obvious to one reasonably skilled in the art that the apparatus could also be used to apply shocking forces to other materials for which it is desired to have an unrestrained material boundary during shocking.

The following examples serve to illustrate specific embodiments of the powder-shocking apparatus of this invention. The average particle size given in Examples 1 and 2 is the 50% point on a curve made by plotting size versus weight percent undersize.

EXAMPLE 1

The apparatus described is a hybrid comprised primarily of the apparatus of FIG. 2 but having the receiving tube and shocking tube threaded together as in FIG. 1. Referring to the FIGURES, receiving vessel **1** is a tube made of A–212 steel and having an inner diameter of 1.75 inches, a wall thickness of 1.125 inches, and 18-inch length. One end of the tube has a 1½-inch long threaded region to accommodate an A–212 steel closure plug of the configuration shown in FIG. 3 (**16***a* or **16***b*). It is also desirable for the receiving tube to have about six 1/32-inch diameter, pressure-relieving, secondary bleed holes in its wall about 15 inches from the closed end.

Shocking tube **2**, made of 1015 carbon steel, is 20 inches long and has an inner diameter of 1.75 inches and a wall thickness of 0.188 inch. An open end of the shocking tube fits into the open end of the receiving tube with a 2-inch overlap, and the tubes are threaded together at the overlap (see threaded joint **4** in FIG. 1). The other end of the shocking tube is sealed closed by means of a 1½-inch thick A–212 steel plug (**12** in FIG. 2), welded to the tube. Powder **3** is 424 grams of boron carbide having an average particle size of about 85 microns and packed in the shocking tube to form an 8-inch long cylinder (bulk density 55% of the crystalline density of boron carbide).

Referring to FIG. 2, driver tube **13**, made of 1015 steel, is 18 inches long and has an inner diameter of 3.125 inches and a wall thickness of 3/16 inch. The standoff **14** between the driver tube and the shocking tube is one-half inch, and is maintained by means of two 0.5-inch thick wooden spacers, positioned between the tubes, one at each end of the tube assembly. Explosive **5** is a 1.5-inch thick annular layer of grained 80/20 amatol (80% ammonium nitrate/20% trinitrotoluene, by weight), weighing 8.125 pounds and detonating at an average velocity of 3,300 meters per second. The granular explosive is held in a cylindrical cardboard container. A 145-mil thick, 6½-inch diameter disc **7** of sheet explosive comprised of pentaerythritol tetranitrate (PETN) in an organic rubber and a thermoplastic terpene hydrocarbon resin binder (U.S. Pat. No. 2,999,743) and detonating at a velocity of 6,900 meters per second is placed at the end of the tubular assembly in contact with explosive **5** and plug **12**. A No. 6 electric blasting cap is attached to a length of low-energy detonating cord, the other end of which is affixed to the center of disc **7**.

The assembly is maintained in a vertical position, with the closed end of the receiving tube uppermost, by means of a wooden frame assembly comprised of a base and side braces. Actuation of the blasting cap causes the detonating cord and in turn the explosive to detonate and the projectile tube to impact against the shocking tube wall progressively. The joined receiving tube and shocking tube thereafter are recovered intact, and the shocked boron carbide recovered by removing the threaded plug from the receiving tube and pouring out the powder. The boron carbide is recovered as a powder having an average particle size of approximately 32 microns. The receiving tube, the dimensions of which are unchanged by the shocking process, is separated from the shocking tube by unscrewing and can be re-used repeatedly with new shocking tubes.

EXAMPLE 2

The procedure described in Example 1 is repeated except that the pressure-applying means is that shown in FIG. 1, and the dimensions of the apparatus components are as follows:

Tubular explosive layer **5** is a 0.75-inch thick flexible sheet composition consisting of 20 parts of PETN, 70 parts of red lead, 2 parts of polybutene, and 8 parts (all by weight) of a thermoplastic terpene resin, e.g., a mixture of polymers of β-pinene of the formula $(C_{10}H_6)_n$. This explosive detonates at a velocity of about 4,100 meters per second. The length of the tubular explosive layer is 6¾ inches. Powder **3** is silicon carbide having an average particle size of 13.5 microns. The silicon carbide is recovered as a powder having an average particle size of 8 microns.

EXAMPLE 3

The procedure described in Example 1 is repeated except that powder 3 is diamond powder (250 grams). The particle size analysis of the starting powder and shocked powder is as follows:

size range (μ)	starting material (%)	shocked powder (%)
36+	5.4	8.7
22–36	31.6	12.8
12–22	63.0	29.5
8–12	0	15.4
0–8	0	33.6

I claim:

1. An apparatus for shocking materials comprising: at least one shocking tube, containing material to be shocked; hollow, openable receiving means connected to said shocking tube such that the interior of the shocking tube communicates with the interior of the receiving means; and explosive means for applying transient high pressure to the shocking tube and the material therein such that at least a portion of said material is ejected into said receiving means.

2. An apparatus for shocking materials comprising:

a. a receiving vessel having at least one primary opening in its wall, at least one such primary opening being joined to a shocking tube, any such primary opening not so joined being sealed by a mechanically openable closure member;

b. at least one shocking tube containing material to be shocked, said material being ejectable into the receiving vessel, the tube being joined at one end to the receiving vessel in such a manner that the inside of the tube communicates with the inside of the vessel, the other end of the tube being closed;

c. means surrounding the shocking tube for applying axially progressive transient high pressure thereto such that at least a portion of said material is ejected into said receiving vessel;

said apparatus also containing at least one secondary opening for release of pressure.

3. The apparatus of claim **2** wherein said pressure applying means comprises an explosive surrounding the shocking tube and extending approximately from the closed end of the tube axially along the tube and approximately coextensive with the length of the material within the tube to be shocked, said explosive adapted to be initiated approximately at the closed end of the tube such that a detonation front forms a ring the movement of which defines a cylinder coaxial with the shocking tube.

4. The apparatus of claim **2** wherein said pressure applying means comprises an approximately coaxial driver tube around the shocking tube, and an explosive surrounding the driver tube, said explosive adapted to be initiated approximately at the closed end of the shocking tube such that a detonation front forms a ring the movement of which defines a cylinder coaxial with the shocking tube.

5. An apparatus for shocking materials comprising:

a. a reusable receiving vessel having at least one primary opening in its wall, at least one such primary opening being joined to an expendable shocking tube, any such primary opening not so joined being sealed by a mechanically openable closure member;

b. at least one expendable shocking tube containing material to be shocked, said material being ejectable into the receiving vessel, the tube being joined at one end to the receiving vessel in such a manner that at that end the inside of the tube communicates with the inside of the vessel, the other end of the tube being closed;

c. means surrounding the shocking tube for applying axially progressive transient high pressure thereto and substantially coextensive with the length of material within the tube to be shocked, said means comprising either an explosive or a driver tube surrounded by an explosive, said explosive adapted to be initiated approximately at the closed end of the shocking tube;

said apparatus also containing at least one secondary opening for release of pressure.

6. An apparatus for shocking materials comprising:

a. a shocking tube containing material to be shocked and joined at each end to a different receiving vessel in such a manner that at each respective end the inside of the tube communicates with the inside of the adjacent receiving vessel, said material being ejectable into the adjacent receiving vessel;

b. two receiving vessels, each having at least one primary opening in its wall, such primary opening being joined to the shocking tube, any such primary opening not so joined being sealed by a mechanically openable closure member;

c. means surrounding the shocking tube for applying axially progressive transient high pressure thereto such that at least a portion of said material is ejected into each receiving vessel;

said apparatus also containing at least one secondary opening for release of pressure.

7. The apparatus of claim 6 wherein said pressure applying means comprises an explosive surrounding the shocking tube and approximately coextensive with the material contained within the tube, said explosive adapted to be initiated throughout a plane normal to the axis of the shocking tube and approximately at the center of the length of the material to be shocked.

8. The apparatus of claim 6 wherein said pressure applying means comprises a coaxial driver tube around said shocking tube and approximately coextensive with the shocking tube, and an explosive surrounding the driver tube, said explosive adapted to be initiated throughout a plane normal to the axis of the shocking tube and approximately at the center of the length of the material to be shocked.

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