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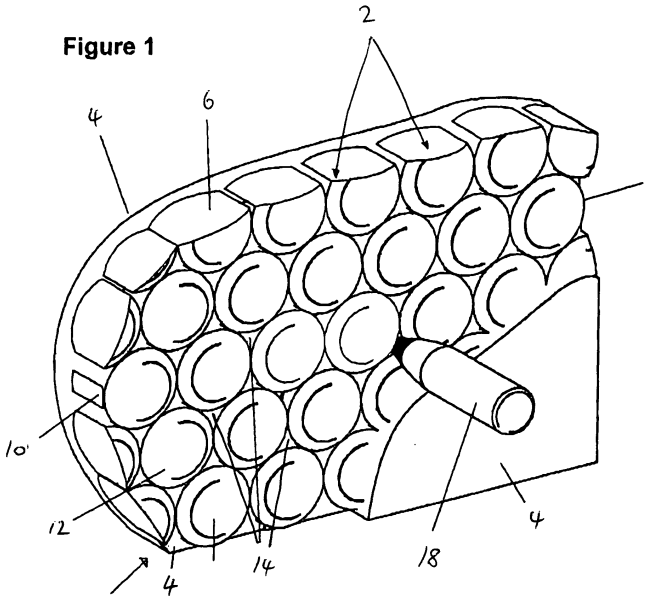
(54) Composite armor plate and method for using the same

(57) The invention provides an armor plate for absorbing and dissipating kinetic energy from armor piercing 7.62mm projectiles, the armor plate comprising a plurality of ceramic pellets and a solidified material, each ceramic pellet having a body portion and a convexly curved end portion, each body portion having two opposite ends, an axis passing through each end and a substantially constant cross-section along the axis, and each convexly curved end portion extending from an end of the corresponding body portion, each body portion having a body portion length along the axis between the two ends, the ceramic pellets being embedded in the solidified material so that the solidified material retains the ceramic pellets in a ceramic pellet layer which is one pellet thick with the convexly curved end portions lying at or adjacent an impact receiving side of the armor plate, wherein the ceramic pellet layer is the only layer of ceramic pellets in the armor plate, wherein the ceramic pellet layer has an edge extending therearound formed by a subset of the ceramic pellets, wherein the ceramic pellets are arranged so that the body portion of substantially each pellet, other than of the pellets of the subset, lies in contact with or closely adjacent to the respective body portions of six neighboring ones of the ceramic pellets.

Figure 1



EP 2 071 272 A2

Description

[0001] The invention relates to an armor plate for absorbing and dissipating kinetic energy from armor piercing 7.62mm projectiles having a projectile length of from 32.8mm to 37mm. The invention also relates to a method of manufacturing an armor plate for absorbing and dissipating kinetic energy from armor piercing 7.62mm projectiles having a predetermined projectile length. The invention further relates to a method of using an armor plate.

[0002] More specifically, the present invention relates to composite ceramic armor and to the tailoring thereof for protecting against 7.62mm caliber armor-piercing projectiles having a predetermined projectile length. Preferably, armor plates tailored to protect against a specific 7.62mm caliber armor-piercing projectile will have multi-hit protection capability for shattering and preventing penetration by a plurality of the 7.62 mm armor piercing projectiles.

[0003] The projectile length is the length of the projectile itself and not the length of the complete bullet including the casing.

[0004] The term "multi-hit" as used herein relates to the property of the plate for shattering three projectiles fired sequentially at a triangular area of said panel, the sides of said triangle being about 6-7 cm each.

[0005] According to a first aspect of the invention, there is provided an armor plate for absorbing and dissipating kinetic energy from armor piercing 7.62mm projectiles having a projectile length of from 32.8mm to 37mm, the armor plate comprising a plurality of ceramic pellets and a solidified material, each ceramic pellet having a body portion and a convexly curved end portion, each body portion having two opposite ends, an axis passing through each end and a substantially constant cross-section along said axis, and each convexly curved end portion extending from an end of the corresponding body portion, each body portion having a body portion length along said axis between the two ends, the ceramic pellets being embedded in the solidified material so that the solidified material retains the ceramic pellets in a ceramic pellet layer which is one pellet thick with said convexly curved end portions lying at or adjacent an impact receiving side of the armor plate, wherein the ceramic pellet layer is the only layer of ceramic pellets in the armor plate, wherein the ceramic pellet layer has an edge extending therearound formed by a subset of said ceramic pellets, wherein said ceramic pellets are arranged so that the body portion of substantially each pellet, other than of the pellets of said subset, lies in contact with or closely adjacent to the respective body portions of six neighboring ones of the ceramic pellets so that there are a plurality of valleys extending through the ceramic pellet layer with each valley being bordered by three adjacent ceramic pellets, wherein substantially each valley has a shape and size such that the diameter of the largest imaginary circle that will fit into said each valley between the neighboring body portions and substantially perpendicularly to the neighboring axes is from 1.96mm to 3.70mm, and in that each body portion length is from 5.57mm to 10.73mm.

[0006] For the first aspect of the invention, the diameter of the largest imaginary circle (as defined above) is preferably chosen to be from 6% to 10% of the length of the projectile against which the armor plate is tailored to protect, while each body portion length is preferably chosen to be from 17% to 29% of the projectile length. Hence, for example, when the projectile length of the projectile to be protected against is from 32.8mm to 34.0mm, the diameter of the largest imaginary circle will preferably be from 1.96mm to 3.40mm and each body portion length will preferably be from 5.57mm to 9.86mm. When the projectile length of the projectile to be protected against is from 34.0mm to 35.0mm, the diameter of the largest imaginary circle will preferably be from 2.04mm to 3.50mm and each body portion length will preferably be from 5.78mm to 10.15mm. When the projectile length of the projectile to be protected against is from 35.0mm to 36.0mm, the diameter of the largest imaginary circle will preferably be from 2.10mm to 3.60mm and each body portion length will preferably be from 5.95mm to 10.44mm. When the projectile length of the projectile to be protected against is from 36.0mm to 37.0mm, the diameter of the largest imaginary circle will preferably be from 2.16mm to 3.70mm and each body portion length will preferably be from 6.12mm to 10.73mm. Values for the largest imaginary circle and for the body portion length can be calculated as a percentage of the projectile length, as discussed above, for any specific projectile length or for any range of projectile lengths. For example, values can be calculated for each projectile length in the range from 32.8mm to 37.0mm.

[0007] According to a second aspect of the invention, there is provided a method of manufacturing an armor plate for absorbing and dissipating kinetic energy from armor piercing 7.62mm projectiles having a predetermined projectile length, comprising:

selecting said projectile length of said armor piercing 7.62mm projectiles for which the kinetic energy is to be absorbed and dissipated by said armor plate;

manufacturing the armor plate wherein the armor plate comprises a plurality of ceramic pellets and a solidified material, each ceramic pellet having a body portion and a convexly curved end portion, each body portion having two opposite ends, an axis passing through each end and a substantially constant cross-section along said axis, and each convexly curved end portion extending from an end of the corresponding body portion, each body portion having a body portion length along said axis between the two ends, the ceramic pellets being embedded in the solidified material so that the solidified material retains the ceramic pellets in a ceramic pellet layer which is one pellet thick with said convexly curved

end portions lying at or adjacent an impact receiving side of the armor plate, wherein the ceramic pellet layer is the only layer of ceramic pellets in the armor plate, wherein said ceramic pellet layer has an edge extending therearound formed by a subset of said ceramic pellets, wherein said ceramic pellets are arranged so that the body portion of substantially each pellet, other than of the pellets of said subset, lies in contact with or closely adjacent to the respective body portions of six neighboring ones of the ceramic pellets so that there are a plurality of valleys extending through the ceramic pellet layer with each valley being bordered by three adjacent ceramic pellets;
wherein said manufacture includes selecting the size and shape of the ceramic pellets according to the predetermined projectile length so that substantially each valley has a shape and size such that the diameter of the largest imaginary circle that will fit into said each valley between the neighboring body portions and substantially perpendicularly to the neighboring axes is from 6% to 10% of the predetermined projectile length, and wherein each body portion length is from 17% to 29% of the predetermined projectile length.

[0008] According to a third aspect of the invention there is provided a method of using an armor plate, said method comprising:

providing an armor plate comprising a plurality of ceramic pellets and a solidified material, each ceramic pellet having a body portion and a convexly curved end portion, each body portion having two opposite ends, an axis passing through each end and a substantially constant cross-section along said axis, and each convexly curved end portion extending from an end of the corresponding body portion, each body portion having a body portion length along said axis between the two ends, the ceramic pellets being embedded in the solidified material so that the solidified material retains the ceramic pellets in a ceramic pellet layer which is one pellet thick with said convexly curved end portions lying at or adjacent an impact receiving side of the armor plate, wherein the ceramic pellet layer is the only layer of ceramic pellets in the armor plate, wherein said ceramic pellet layer has an edge extending therearound formed by a subset of said ceramic pellets, wherein said ceramic pellets are arranged so that the body portion of substantially each pellet, other than of the pellets of said subset, lies in contact with or closely adjacent to the respective body portions of six neighboring ones of the ceramic pellets so that there are a plurality of valleys extending through the ceramic pellet layer with each valley being bordered by three adjacent ceramic pellets;
using said composite armor plate for absorbing and dissipating kinetic energy from armor piercing 7.62mm projectiles having a predetermined projectile length;
and wherein substantially each valley has a shape and size such that the diameter of the largest imaginary circle that will fit into said each valley between the neighboring body portions and substantially perpendicularly to the neighboring axes is from 6% to 10% of the predetermined projectile length, and wherein each body portion length is from 17% to 29% of the predetermined projectile length.

[0009] The projectile will generally be shattered by the armor plate to form projectile fragments.

[0010] Preferably, for any aspect of the invention, the ceramic pellets are directly bound by the solidified material. Hence there is no coating or the like interposed between the ceramic pellets and the solidified material.

[0011] Each body portion preferably has a shape that is symetrical about its axis or symetrical about a plane that is intersected by the axis. One preferred shape for the body portion is a cylinder (that is to say a right circular cylinder). Another preferred shape for the body portion is a prism of generally hexagonal cross-section with rounded edges between each adjacent pair of axially extending faces. A generally hexagonal prism of this type is shown in EP1,521,051.

[0012] Preferably, the shape and arrangement of the body portions is such that each valley is surrounded by convexly curved lateral portions of the adjacent ceramic pellets. In other words, each lateral portion projects into the valley. Hence when the body portion is cylindrical, the valleys will be surrounded by portions of the cylindrical surfaces. When the body portions are hexagonal prisms with rounded edges as discussed above, each valley will be surrounded by three convex rounded edges.

[0013] The convexly curved end face is preferably a segment of a sphere.

[0014] In general, both the solidified material and the armor plate will be slightly flexible. In this case, the terms "elastic" and "flexible" relate to the fact that the plates are bent when a load is applied thereto and more specifically, the plates slightly flex with each projectile impact thereby augmenting the buttressing affect of adjacent pellets to the pellet being impacted or to the valley being entered by the projectile, however upon release of said load, or at the end of the dissipation of the kinetic energy from the impacting high-velocity projectile, the plate tends to return to its original shape, or close to its original shape with the exception of holes which might be formed as a result of the mutual destruction of a projectile and an arresting pellet or pellets.

[0015] When the armor piercing projectile to be protected against has a tungsten carbide core, the diameter of the largest imaginary circle is preferably from 7% to 9% of the predetermined projectile length. Also for projectiles of this type each body portion length is preferably from 22% to 29% of the predetermined projectile length.

[0016] For other projectiles, each body portion length

is preferably from 19% to 24% of the predetermined projectile length.

[0017] Preferably, the ceramic pellets are substantially internal within the solidified material and the outer faces of the armor plate are substantially formed by the solidified material.

[0018] As will be realized, when preparing the composite armor plate of the present invention, said pellets do not necessarily have to be completely covered on both sides by said solidified material, and the term internal is intended to denote that the pellets are either completely or almost completely covered by said solidified material, wherein outer face surfaces of the plate are formed from the solidified material, the plate having an outer impact receiving face, at which face each pellet is either covered by the solidified material, touches said solidified material which forms surfaces of said outer impact receiving face or, not being completely covered by said solidified material which constitutes surfaces of said outer impact receiving face, bulges slightly therefrom.

[0019] Preferably, the body portion of each ceramic pellets has a maximum cross-sectional dimension of greater than 13mm, and more preferably between 14mm and 20mm. The maximum cross-sectional dimension is the longest straight line intersecting the cross-sectional shape. Hence, when the body portion is cylindrical, the maximum cross-sectional dimension is a diameter.

[0020] Preferably, each ceramic pellet has an overall length along its axis of between 11.6mm and 17mm.

[0021] Preferably, the diameter of said largest imaginary circle is no greater than 3mm.

[0022] When the plate is flat, the axes of the ceramic pellets will be generally parallel to one another. However, curved plates can also be formed in which case the axes will be angled relative to one another dependent on the curvature of the plate.

[0023] Preferably the ceramic pellets in an armor plate will have substantially the same shape and size as one another. Even when the ceramic pellets are the same size and shape as one another, the valleys can vary in size due to irregularities in the positions of the pellets in the plate.

[0024] In accordance with a fourth aspect of the invention, a multi-layered armor panel comprises an armor plate according to the first aspect of the invention or made in accordance with the second aspect of the invention, said armor plate forming an outer layer for deforming and shattering into fragments an impacting high-velocity armor piercing projectile, and a second layer positioned inwardly of and adjacent to the armor plate, the second layer comprising a material that is softer than the ceramic pellets and the second layer capturing the fragments and absorbing the remaining kinetic material from the fragments.

[0025] Preferably, the second layer is made of: polyethylene with an ultra high molecular weight; aramid; aluminium; steel; titanium; or reinforced fiberglass. In addition a third layer positioned inwardly (that is to say on the opposite side of the second layer as compared to the armor plate) of the second layer and made of aluminium may be provided.

[0026] The present invention is a modification of the inventions described in US Patents 5,763,813; 5,972,819; 6,289,781; 6,112,635; 6,203,908; and 6,408,734, EP 1,521,051 and in WO-A-9815796 the relevant teachings of which are incorporated herein by reference.

[0027] In US Patent 5,763,813 there is described and claimed a composite armor material for absorbing and dissipating kinetic energy from high velocity, armor-piercing projectiles, comprising a panel consisting essentially of a single internal layer of high density ceramic pellets said pellets having an Al_2O_3 content of at least 93% and a specific gravity of at least 2.5 and retained in panel form by a solidified material which is elastic at a temperature below 250°C ; the majority of said pellets each having a part of a major axis of a length of in the range of about 3-12mm, and being bound by said solidified material in plurality of superposed rows, wherein a majority of each of said pellets is in contact with at least 4 adjacent pellets, the weight of said panel does not exceed 45kg/m^2.

[0028] In US Patent 6,112,635 there is described and claimed a composite armor plate for absorbing and dissipating kinetic energy from high velocity, armor-piercing projectiles, said plate consisting essentially of a single internal layer of high density ceramic pellets which are directly bound and retained in plate form by a solidified material such that the pellets are bound in a plurality of adjacent rows, wherein the pellets have an Al_2O_3 content of at least 93% and a specific gravity of at least 2.5, the majority of the pellets each have at least one axis of at least 12 mm length said one axis of substantially all of said pellets being in substantial parallel orientation with each other and substantially perpendicular to an adjacent surface of said plate and wherein a majority of each of said pellets is in direct contact with 6 adjacent pellets, and said solidified material and said plate are elastic.

[0029] In WO-A-9815796 corresponding to US Patent 5,972,819, there is described and claimed a ceramic body for deployment in a composite armor panel, said body being substantially cylindrical in shape, with at least one convexly curved end face, wherein the ratio D/R between the diameter D of said cylindrical body and the radius R of curvature of said at least one convexly curved end face is at least 0.64:1.

[0030] In US Patent 6,289,781 there is described and claimed a composite armor plate for absorbing and dissipating kinetic energy from high velocity projectiles, said plate comprising a single internal layer of pellets which are directly bound and retained in plate form by a solidified material such that the pellets are bound in a plurality of adjacent rows, characterized in that the pellets have a specific gravity of at least 2 and are made of a material selected from the group consisting of glass, sintered refractory material, ceramic material which does not contain aluminum oxide and ceramic material having an alu-

minum oxide content of not more than 80%, the majority of the pellets each have at least one axis of at least 3 mm length and are bound by said solidified material in said single internal layer of adjacent rows such that each of a majority of said pellets is in direct contact with at least six adjacent pellets in the same layer to provide mutual lateral confinement therebetween, said pellets each have a substantially regular geometric form and said solidified material and said plate are elastic.

[0031] In US Patent 6,408,734 there is described and claimed a composite armor plate for absorbing and dissipating kinetic energy from high velocity, armor-piercing projectiles, as well as from soft-nosed projectiles, said plate comprising a single internal layer of high density ceramic pellets, characterized in that said pellets are arranged in a single layer of adjacent rows and columns, wherein a majority of each of said pellets is in direct contact with at least four adjacent pellets and each of said pellets are substantially cylindrical in shape with at least one convexly-curved end face, further characterized in that spaces formed between said adjacent cylindrical pellets are filled with a material for preventing the flow of soft metal from impacting projectiles through said spaces, said material being in the form of a triangular insert having concave sides complimentary to the convex curvature of the sides of three adjacent cylindrical pellets, or being integrally formed as part of a special interstices-filling pellet, said pellet being in the form of a six sided star with concave sides complimentary to the convex curvature of the sides of six adjacent cylindrical pellets, said pellets and material being bound and retained in plate form by a solidified material, wherein said solidified material and said plate material are elastic.

[0032] The teachings of all of these specifications are incorporated herein by reference.

[0033] As described and explained therein, an incoming projectile may contact the pellet array in the plate in one of three ways:

1. Center contact. The impact allows the full volume of the pellet to participate in stopping the projectile, which cannot penetrate without pulverizing the whole pellet, an energy-intensive task.

2. Flank contact. The impact causes projectile yaw, thus making projectile arrest easier, as a larger frontal area is contacted, and not only the sharp nose of the projectile. The projectile is deflected sideways and needs to form for itself a large aperture to penetrate, thus allowing the armor to absorb the projectile energy.

3. Valley contact. The projectile is jammed, usually between the flanks of three pellets, all of which participate in projectile arrest. The high side forces applied to the pellets are resisted by the pellets adjacent thereto as held by the substrate or plate.

[0034] While the concept of valley contact is described as above in many of the aforementioned patents, it has now been discovered, and not previously described, that there are especially preferred parameters for such valley contact which significantly improve the properties of a composite armor panel comprising an armor plate as defined above, which enhance the ability of said composite armor panel to completely stop a plurality of armor-piercing projectiles from penetrating said composite armor panel.

[0035] In addition, it is to be noted that military authorities constantly change their requirements for performance specifications of armor that is ordered and the prior art does not teach or suggest the necessary or preferred specifications for armor designed to deal with a specific predetermined projectile threat.

[0036] Furthermore, said prior art does not teach or suggest the critical parameters of the through-going valley nor the existence of a critical ratio between the diameter of the largest imaginary circle that fits within said through-going valley as defined above, and the length of a predetermined projectile, or the critical parameters of the ratio of the body portion length of said pellets of the panel to the length of a predetermined projectile threat.

[0037] The term "high velocity projectiles" as used herein relates to projectiles traveling at a speed of at least 700 m/sec.

[0038] In U.S. Patent No: 6,112,635, and in an article by Ko and Song, "Characterization of Multifunctional Composite Armor", pages 947-956 (1996), ceramic spheres are described as being preferred. However it has now been discovered, according to the present invention, that ceramic pellets having the shape defined above, which can be tailored to meet the challenge of a predetermined projectile threat, are superior to spherical pellets and serve to create a through-going valley of a length sufficient to effectively shatter a projectile since the flanks of the three pellets bounding said valley all participate in the shattering of the projectile.

[0039] In especially preferred embodiments of the present invention said ceramic material is selected from the group consisting of aluminum oxide, silicon carbide, silicon nitride and boron carbide.

[0040] Preferably, said pellets have at least one circular cross-section.

[0041] In especially preferred embodiments of the present invention said pellets are of round ended cylindrical shape.

[0042] Another advantage of the plate of the present invention is that in especially preferred embodiments of the present invention, projectile-damaged pellets are removable from the plate and replaceable by intact pellets and matrix material for rapid repair and reuse of the composite armor plate.

[0043] In yet another preferred embodiment of the present invention said predetermined projectile threat is determined to be armor piercing 7.62 mm projectiles, said pellet is of hexagonal cross-section with rounded edges,

as discussed above, and the ratio of body portion length to the length of the predetermined projectile threat is between 0.17 and 0.26.

[0044] There are four main considerations concerning protective armor panels. The first consideration is weight. Protective armor for heavy but mobile military equipment, such as tanks and large ships, is known. Such armor usually comprises a thick layer of alloy steel, which is intended to provide protection against heavy and explosive projectiles. However, reduction of weight of armor, even in heavy equipment, is an advantage since it reduces the strain on all the components of the vehicle. Furthermore, such armor is quite unsuitable for light vehicles such as automobiles, jeeps, light boats, or aircraft, whose performance is compromised by steel panels having a thickness of more than a few millimeters, since each millimeter of steel adds a weight factor of 7.8 kg/m^2.

[0045] Armor for light vehicles is expected to prevent penetration of projectiles, even when impacting at a speed in the range of 700 to 1000 meters per second, or even faster. However, due to weight constraints it is difficult to protect light vehicles from high caliber armor-piercing projectiles, e.g. of 12.7 and 14.5 mm and above, since the weight of standard armor to withstand such projectile is such as to impede the mobility and performance of such vehicles.

[0046] A second consideration is cost. Overly complex armor arrangements, particularly those depending entirely on composite materials, can be responsible for a notable proportion of the total vehicle cost, and can make its manufacture non-profitable.

[0047] A third consideration in armor design is compactness. A thick armor panel, including air spaces between its various layers, increases the target profile of the vehicle. In the case of civilian retrofitted armored automobiles which are outfitted with internal armor, there is simply no room for a thick panel in most of the areas requiring protection.

[0048] A fourth consideration relates to ceramic plates used for personal and light vehicle armor, which plates have been found to be vulnerable to damage from mechanical impacts caused by rocks, falls, etc.

[0049] Fairly recent examples of armor systems are described in U.S. Patent No. 4,836,084, disclosing an armor plate composite including a supporting plate consisting of an open honeycomb structure of aluminum; and U.S. Patent No. 4,868,040, disclosing an antiballistic composite armor including a shock-absorbing layer. Also of interest is U.S. Patent 4,529,640, disclosing spaced armor including a hexagonal honeycomb core member.

[0050] Other armor plate panels are disclosed in British Patents 1,081,464; 1,352,418; 2,272,272, and in U.S. Patent 4,061,815 wherein the use of sintered refractory material, as well as the use of ceramic materials, are described.

[0051] In the majority of the patents by the present inventor, the preferred pellets have a cylindrical body and at least one convexly curved end face and the especially preferred pellet is that described in US Patent 5,972,819 wherein the body is substantially cylindrical in shape with at least one convexly curved end face, and preferably two identical convexly curved end faces, wherein the ratio D/R between the diameter D of said cylindrical body and the radius R of curvature of said convexly curved end faces is at least 0.64:1.

[0052] In EP1521051 there is described and claimed a composite armor plate for absorbing and dissipating kinetic energy from high velocity projectiles, said plate comprising a single internal layer of pellets which are bound and retained in plate form by an elastic material, substantially internally within said elastic material, such that the pellets are bound in a plurality of spaced apart rows and columns, said pellets being made of ceramic material, and said pellets being substantially fully embedded in the elastic material so that the pellets form an internal layer, said pellets being characterized by a substantially regular geometric cross-sectional area, said cross-sectional area being substantially polygonal with rounded corners and wherein a majority of each of said pellets is in direct contact with six adjacent pellets in the same layer to provide mutual lateral confinement therebetween.

[0053] In especially preferred embodiments of the present invention, there is used a plate as defined immediately above, wherein said pellets are of hexagonal cross-section with substantially rounded corners as defined herein.

[0054] Ideally, in the current invention, the body portion of each ceramic pellet (other than the ceramic pellets at the edge of the ceramic pellet layer) contacts the respective body portions of six adjacent pellets. However, in practice direct contact cannot always be achieved. It is known that a ceramic body which has been pressed, by its nature, has an external surface area which is not smooth and has lack of consistency in its diameter along the main axis, and it is because of this that when casting the panel with the solidified material, the casting material (s) (resin, molten aluminium, epoxy, and so on) seeps into spaces between the ceramic bodies, including the very small spaces found between the walls of two or more adjoining cylinders, forming a retaining substance in which the ceramic bodies are confined. Thus, even when the ceramic bodies are closely packed, the casting material will at least partially penetrate between them. This is due to the fact that during the pressing process, the ceramic material is compacted in the die and when the material is released from the die the material has a tendency to try and spring back to a less compact form. This generally occurs in the top part of the material so pressed, which is the first part of the body released from the die. Thus, in this case, there will be a small difference in the diameter of the body along the vertical axis. Secondly, it is well known that during the pressing process there are sometimes differences in densification of the powder in different areas of the ceramic body. When sintering the ceramic body, these small differences will cause the body

to shrink in accordance with the different compressions found in various areas of the body, resulting in another reason for a "small" lack of homogeneity in the diameter along the vertical axis of the body. Thus there is rarely a situation in which one ceramic body is perfectly in direct contact with a second ceramic body in the panel, rather, the casting material will seep between the two bodies, at least partially encasing each of said bodies.

[0055] Furthermore, when the casting material of the plate is a liquefied solid material, if one were to x-ray the panel, one would see that the panel shows a honeycombed shaped casting, which at least partially encloses the ceramic bodies.

[0056] The armor plates described in EP-A-0843149 and European Patent Application 98301769.0 are made using ceramic pellets made substantially entirely of aluminum oxide. In WO-A-9815796. the ceramic bodies are of substantially cylindrical shape having at least one convexly-curved end-face, and are preferably made of aluminum oxide.

[0057] In WO 99/60327 it was described that the improved properties of the plates described in the earlier patent applications of this series is as much a function of the configuration of the pellets, which are of regular geometric form with at least one convexly-curved end face (for example, the pellets may be spherical or ovoidal, or of regular geometric cross-section, such as hexagonal, with at least one convexly-curved end face), said panels and their arrangement as a single internal layer of pellets bound by an elastic solidified material, wherein each of a majority of said pellets is in direct contact with at least four adjacent pellets and said curved end face of each pellet is oriented to substantially face in the direction of an outer impact-receiving major surface of the plate. As a result, said specification teaches that composite armor plates superior to those available in the prior art can be manufactured using pellets made of sintered refractory materials or ceramic materials having a specific gravity below that of aluminum oxide, e.g., boron carbide with a specific gravity of 2.45, silicon carbide with a specific gravity of 3.2 and silicon aluminum oxynitride with a specific gravity of about 3.2.

[0058] In preferred embodiments of the present invention said ceramic material is selected from the group consisting of aluminum oxide, silicon carbide, silicon nitride and boron carbide.

[0059] Thus, it was described in said publication that sintered oxides, nitrides, carbides and borides of magnesium, zirconium, tungsten, molybdenum, titanium, aluminum and silica can be used. Especially preferred for use in said publication and also for use in the ceramic insert bodies of the present invention, is a ceramic material selected from the group consisting of sintered oxide, nitrides, carbides and borides of aluminum, magnesium, zirconium, tungsten, molybdenum, titanium and silica although any suitable or newly discovered ceramic material can be used for forming the inserts and insert pellets of the present invention.

[0060] All of these features are incorporated herein as preferred embodiments of the present invention.

[0061] The solidified material can be any suitable material, such as aluminum, a thermoplastic polymer such as polycarbonate, or a thermoset plastic such as epoxy or polyurethane.

[0062] When aluminum is used as said solidified material an x-ray of the plate shows the formation of a honeycomb structure around the pellets.

[0063] In French Patent 2,711,782, there is described a steel panel reinforced with ceramic materials; however said panel does not have the ability to deflect armor-piercing projectiles unless a thickness of about 8-9 mm of steel is used, which adds undesirable excessive weight to the panel and further backing is also necessary thereby further increasing the weight thereof.

[0064] The composite armor plate according to the present invention can be used in conjunction with and as an addition to the standard steel plates provided on armored vehicles or as add on armor for armored vehicles having aluminum or titanium containing rigid surfaces, as well as in conjunction with the laminated armor described and claimed in US Patent 6,497,966 the teachings of which are incorporated herein by reference.

[0065] According to a further aspect of the invention, there is provided a multi-layered armor panel, comprising an outer, impact-receiving layer formed by a composite armor plate as hereinbefore defined for deforming and shattering an impacting high velocity projectile; and an inner layer adjacent to said outer layer and, comprising a ballistic material for absorbing the remaining kinetic energy from said fragments. Said ballistic material will be chosen according to cost and weight considerations and can be made of any suitable material such as Dyneema, Kevlar, aluminum, steel, titanium, or reinforced fiberglass.

[0066] As described, e.g., in U.S. Patent 5,361,678, composite armor plate comprising a mass of spherical ceramic balls distributed in an aluminum alloy matrix is known in the prior art. However, such prior art composite armor plate suffers from one or more serious disadvantages, making it difficult to manufacture and less than entirely suitable for the purpose of defeating metal projectiles. More particularly, in the armor plate described in said patent, the ceramic balls are coated with a binder material containing ceramic particles, the coating having a thickness of between 0.76 and 1.5 mm and being provided to help protect the ceramic cores from damage due to thermal shock when pouring the molten matrix material during manufacture of the plate. However, the coating serves to separate the harder ceramic cores of the balls from each other, and will act to dampen the moment of energy which is transferred and hence shared between the balls in response to an impact from a bullet or other projectile. Because of this and also because the material of the coating is inherently less hard than that of the ceramic cores, the stopping power of a plate constructed as described in said patent is not as good, weight for

weight, as that of a plate in accordance with the present invention and in which the ceramic pellets are directly in contact with the solidifed material.

[0067] The invention will now be described in connection with certain preferred embodiments with reference to the following illustrative figures so that it may be more fully understood.

[0068] With reference now to the figures in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

[0069] In the drawings:

Figure 1 is a perspective view, partially cut away, of a small section of an armor plate according to the present invention;

Figures 2a, is a side elevation of a ceramic pellet of the type used in the armor plate of Figure 1;

Figure 2b is a side elevation of a predetermined projectile to be protected against by the armor plate of Figure 1;

Figure 2c is a plan view from above of three ceramic pellets of the type shown in Figure 2a and showing a valley between the three pellets; and

Figure 3 is a view of a projectile undergoing shattering and fragmentation as a result of impact with a plate of the present invention.

[0070] Referring to figure 1, an exemplary armor plate consists of a plurality of ceramic pellets 2 which are embedded within a solidified material 4.

[0071] A ceramic pellet 2 of the type used in the armor plate shown in figure 1, is seen in more detail in figure 2a. The ceramic pellet 2 shown in figure 2a has a cylindrical body portion 6 which has two planar opposite ends 8 and a cylindrical surface 10. The body portion 6 has a length which is the distance along the cylindrical axis between the two ends 8, and which is represented in figure 2a by the letter H.

[0072] A respective convexly curved end portion 12 extends from each end 8 of the body portion 6. Each convexly curved end portion 12 has the form of a segment of a sphere and has a base which lies adjacent to the body portion 6 and which has a diameter which is equal to the diameter of the body portion 6.

[0073] Ceramic pellets 2 of the type described above are conveniently formed as a unitary body by pressing and methods for manufacturing such pellets are well known in the art. The ceramic pellet 2 can be made from any suitable ceramic material, and is preferably made from one of the ceramic materials discussed above.

[0074] Looking again at figure 1, it can be seen that the ceramic pellets 2 are arranged in a single layer which is one pellet thick. The ceramic pellets 2 are arranged so that the cylindrical axes of the pellets 2 lie substantially parallel to one another. In this case, each ceramic pellet 2 has a respective convexly curved end portion 12 at each end. Accordingly, convexly curved end portions 12 are found at both sides of the armor plate. However, it will be appreciated that the ceramic pellets 2 need only have a single convexly curved end portion 12. In this case, the ceramic pellets 2 will be arranged so that the convexly curved end portions 12 are located at one side of the armor plate, and this side will be in impact receiving side of the armor plate.

[0075] As seen in figure 1, the ceramic pellets 2 are arranged so that each body portion 6 (other than the body portions 6 of the ceramic pellets 2 which lie at the edge of the armor plate) is either in contact with, or lies closely adjacent to the respective body portions 6 of six adjacent ceramic pellets 2. As discussed above, whereas direct contact between the body portions 6 is preferred, this cannot always be obtained in practice. For those ceramic pellets 2 which lie at the edge of the armor plate, each body portion 6 lies in contact with, or closely adjacent to the body portions of four adjacent ceramic pellets 2.

[0076] As seen in figure 1 and also in figure 2c, a valley 14 is found between each three adjacent ceramic pellets 2. The valleys 14 pass across the layer of ceramic pellets. Referring to figure 2c, each valley 14 has, in cross section, a shape which is generally triangular, with each side of the triangle being concavely curved. This is because, of course, each valley 14 is formed between the cylindrical surfaces 10 of the body portions 6 of the three adjacent ceramic pellets 2. Of course, where the body portions 6 of the ceramic pellets 2 are not cylindrical in shape, then the valleys 14 will have different shapes.

[0077] For the purposes of the current invention, it is important to quantify the size of the valleys 14 - bearing in mind that the shape of the valleys 14 can vary depending upon the shape of the body portions 6 of the ceramic pellets 2. For present purposes, the size of each valley 14 is defined with respect to the largest imaginary circle 16 which can fit within the valley 14, between the neighbouring body portions 6, and lying substantial perpendicularly to the axes of the neighbouring body portions 6. Such an imaginary circle 16, having a diameter d, is shown in the valley 14 in figure 2c.

[0078] As shown in figure 1, the ceramic pellets 2 are embedded in a solidified material 4, which can be any suitable solidified material, and is preferably one of the solidified materials mentioned above. The solidified material 4 passes through the valleys 14 and covers the ceramic pellets 2 on either side of the armor plate. As discussed above, the solidified material is generally slightly elastic so that when the armor plate is impacted by a projectile, the armor plate flexes slightly.

[0079] The armor plate is tailored to be particularly effective against a 7.62 mm calibre projectile 18 having a predetermined projectile length. As seen in figure 2b, the projectile length is the entire length of the projectile 16 (but not including any casing).

[0080] As discussed above, it has been found that when the size and shape of the ceramic pellets 2 are chosen so as to give the body portion length H and the diameter d of the largest imaginary circle 16 specific dimensions relative to the projectile 18, the armor plate is particularly effective at protecting against a projectile 18 of that length. Hence, for any particular projectile length, the size and shape of the ceramic pellets 2 should ideally be chosen so that the body portion length is from 17% to 29% of the projectile length, and the diameter of the largest imaginary circle 16 is from 6% to 10% of the projectile length.

[0081] By way of example, when the projectile length is 35mm, the body portion length may be from 5.95mm to 10.15mm, and the diameter of the largest imaginary circle 16 may be from 2.1mm to 3.5mm. It is also possible to calculate the body portion length and the diameter of the largest imaginary circle 16 based on an anticipated range of projectile length. For example, when the projectile length is anticipated to be from 32.8mm to 37mm, the diameter of the largest imaginary circle 16 will be from 1.96mm to 3.70mm, and the body portion length will be form 5.57mm to 10.73mm.

[0082] The armor plate is used to protect against a projectile of the pre-determined length. The armor plate absorbs and dissipates kinetic energy from the projectile, and the projectile is shattered into fragments. It will be noted that the armor plate does not necessarily prevent penetration of the projectile on its own. The armor plate will generally be used in combination with the second layer, as discussed above. The second layer serves to catch and retain fragments of the projectile and to absorb the remaining kinetic energy of the fragments.

[0083] It will be evident to those skilled in the art that the invention is not limited to the details of the foregoing illustrative embodiments and that the present invention may be embodied in other specific forms. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description.

Claims

1. An armor plate for absorbing and dissipating kinetic energy from armor piercing 7.62mm projectiles having a projectile length of from 32.8mm to 37mm, the armor plate comprising a plurality of ceramic pellets and a solidified material, each ceramic pellet having a body portion and a convexly curved end portion, each body portion having two opposite ends, an axis passing through each end and a substantially constant cross-section along said axis, and each convexly curved end portion extending from an end of the corresponding body portion, each body portion having a body portion length along said axis between the two ends, the ceramic pellets being embedded in the solidified material so that the solidified material retains the ceramic pellets in a ceramic pellet layer which is one pellet thick with said convexly curved end portions lying at or adjacent an impact receiving side of the armor plate, wherein the ceramic pellet layer is the only layer of ceramic pellets in the armor plate, wherein the ceramic pellet layer has an edge extending therearound formed by a subset of said ceramic pellets, wherein said ceramic pellets are arranged so that the body portion of substantially each pellet, other than of the pellets of said subset, lies in contact with or closely adjacent to the respective body portions of six neighboring ones of the ceramic pellets so that there are a plurality of valleys extending through the ceramic pellet layer with each valley being bordered by three adjacent ceramic pellets, wherein substantially each valley has a shape and size such that the diameter of the largest imaginary circle that will fit into said each valley between the neighboring body portions and substantially perpendicularly to the neighboring axes is from 1.96mm to 3.7mm, and wherein each body portion length is from 5.57mm to 10.73mm.

2. An armor plate according to claim 1, wherein the diameter of the largest imaginary circle is from 1.96mm to 3.40mm and each body portion length is from 5.57mm to 9.86mm; or wherein the diameter of the largest imaginary circle is from 2.04 mm to 3.50mm and each body portion length is from 5.78mm to 10.15mm; or wherein the diameter of the largest imaginary circle is from 2.10mm to 3.60mm and each body portion length is from 5.95mm to 10.44mm; or wherein the diameter of the largest imaginary circle is from 2.16mm to 3.70mm and each body portion length is from 6.12mm to 10.73mm.

3. A method of manufacturing an armor plate for absorbing and dissipating kinetic energy from armor piercing 7.62mm projectiles having a predetemined projectile length, comprising:

   selecting said projectile length of said armor piercing 7.62mm projectiles for which the kinetic energy is to be absorbed and dissipated by said armor plate;

   manufacturing the armor plate wherein the armor plate comprises a plurality of ceramic pellets and a solidified material, each ceramic pellet having a body portion and a convexly curved end portion, each body portion having two opposite ends, an axis passing through each end and a substantially constant cross-section along

said axis, and each convexly curved end portion extending from an end of the corresponding body portion, each body portion having a body portion length along said axis between the two ends, the ceramic pellets being embedded in the solidified material so that the solidified material retains the ceramic pellets in a ceramic pellet layer which is one pellet thick with said convexly curved end portions lying at or adjacent an impact receiving side of the armor plate, wherein the ceramic pellet layer is the only layer of ceramic pellets in the armor plate, wherein said ceramic pellet layer has an edge extending therearound formed by a subset of said ceramic pellets, wherein said ceramic pellets are arranged so that the body portion of substantially each pellet, other than of the pellets of said subset, lies in contact with or closely adjacent to the respective body portions of six neighboring ones of the ceramic pellets so that there are a plurality of valleys extending through the ceramic pellet layer with each valley being bordered by three adjacent ceramic pellets;
wherein said manufacture includes selecting the size and shape of the ceramic pellets according to the predetermined projectile length so that substantially each valley has a shape and size such that the diameter of the largest imaginary circle that will fit into said each valley between the neighboring body portions and substantially perpendicularly to the neighboring axes is from 6% to 10% of the predetermined projectile length, and wherein each body portion length is from 17% to 29% of the predetermined projectile length.

4. A method of using an armor plate, said method comprising:

providing an armor plate comprising a plurality of ceramic pellets and a solidified material, each ceramic pellet having a body portion and a convexly curved end portion, each body portion having two opposite ends, an axis passing through each end and a substantially constant cross-section along said axis, and each convexly curved end portion extending from an end of the corresponding body portion, each body portion having a body portion length along said axis between the two ends, the ceramic pellets being embedded in the solidified material so that the solidified material retains the ceramic pellets in a ceramic pellet layer which is one pellet thick with said convexly curved end portions lying at or adjacent an impact receiving side of the armor plate, wherein the ceramic pellet layer is the only layer of ceramic pellets in the armor plate, wherein said ceramic pellet layer has an edge extending therearound formed by a subset of said ceramic pellets, wherein said ceramic pellets are arranged so that the body portion of substantially each pellet, other than of the pellets of said subset, lies in contact with or closely adjacent to the respective body portions of six neighboring ones of the ceramic pellets so that there are a plurality of valleys extending through the ceramic pellet layer with each valley being bordered by three adjacent ceramic pellets;
using said composite armor plate for absorbing and dissipating kinetic energy from armor piercing 7.62mm projectiles having a predetermined projectile length;
and wherein substantially each valley has a shape and size such that the diameter of the largest imaginary circle that will fit into said each valley between the neighboring body portions and substantially perpendicularly to the neighboring axes is from 6% to 10% of the predetermined projectile length, and wherein each body portion length is from 17% to 29% of the predetermined projectile length.

5. A method according to claim 3 or claim 4, wherein the armor piercing projectile has a tungsten carbide core and the diameter of the largest imaginary circle is from 7% to 9% of the predetermined projectile length.

6. A method according to any one of claims 3 to 5, wherein the armor piercing projectile has a tungsten carbide core and each body portion length is from 22% to 29% of the predetermined projectile length.

7. A method according to claim 3 or claim 4, wherein each body portion length is from 19% to 24% of the predetermined projectile length.

8. An armor plate or method according to any preceding claim, wherein the ceramic pellets are substantially internal within the solidified material and the outer faces of the armor plate are substantially formed by the solidified material.

9. An armor plate or method according to any preceding claim, wherein the body portion of each ceramic pellets has a maximum cross-sectional dimension of greater than 13mm, and preferably between 14mm and 20mm.

10. An armor plate or method according to any preceding claim, wherein each ceramic pellet has an overall length along said axis of between 11.6mm and 17mm.

11. An armor plate or method according to any preceding claim, wherein the diameter of said largest imaginary

circle is no greater than 3mm.

12. An armor plate or method according to any preceding claim, wherein the shape of the body portion of each ceramic pellet is either circular cylindrical, or generally hexagonal with rounded edges between each pair of adjacent axially extending faces.

13. A multi-layered armor panel comprising an armor plate according to claim 1 or any claim dependent thereon, or made in accordance with claim 3 or any claim dependent thereon, said armor plate forming an outer layer for deforming and shattering into fragments an impacting high-velocity armor piercing projectile, and a second layer positioned inwardly of and adjacent to the armor plate, the second layer comprising a material that is softer than the ceramic pellets and the second layer capturing the fragments and absorbing the remaining kinetic material from the fragments.

14. A multi-layered armor panel according to claim 13, wherein the second layer is made of: polyethylene with an ultra high molecular weight; aramid; aluminium; steel; titanium; or reinforced fiberglass.

15. A multi-layered armor panel according to claim 13 or claim 14, further comprising a third layer positioned inwardly of the second layer and made of aluminium.

Figure 1

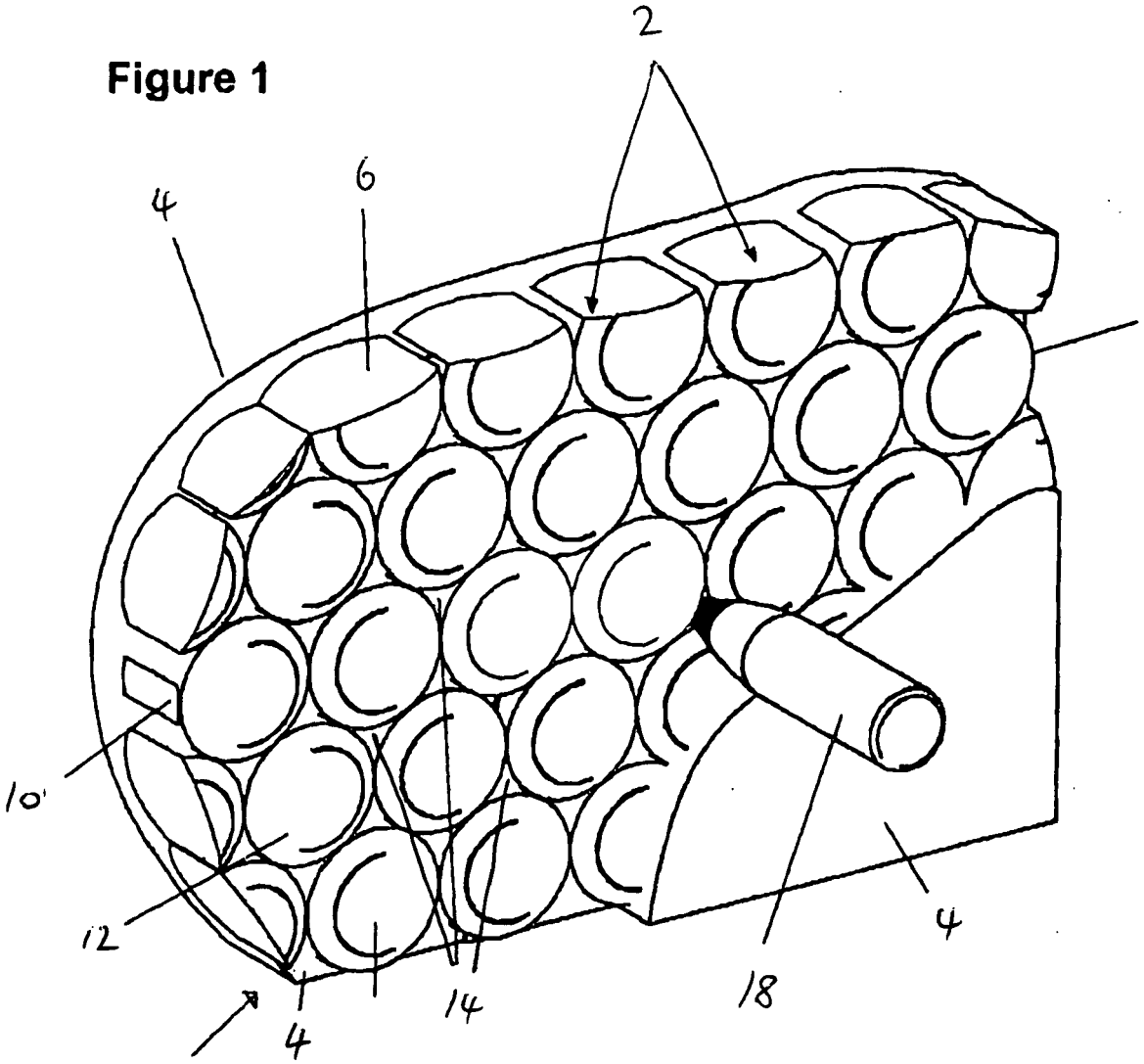


Figure 2a

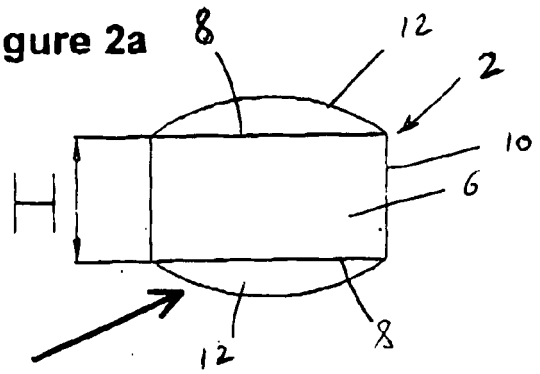


Figure 2b

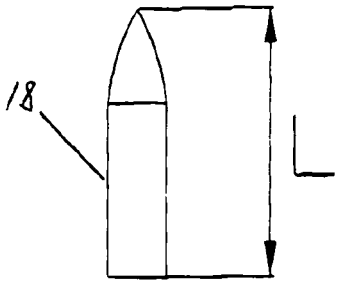


Figure 2c

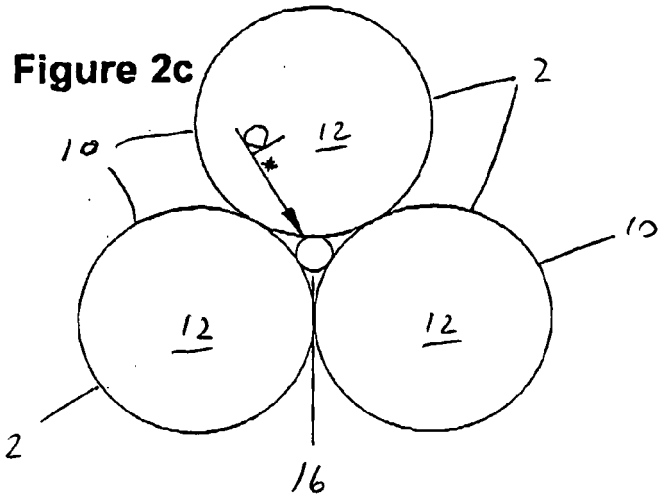
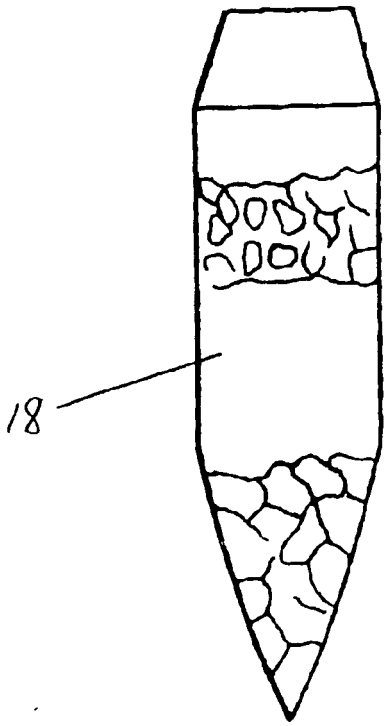


Figure 3



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