(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

CORRECTED VERSION

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
14 May 2010 (14.05.2010)

PCT

(10) International Publication Number
WO 2010/053611 A9

(51) International Patent Classification:
F41H 7/00 (2006.01) *F41H 5/04* (2006.01)
F41H 5/02 (2006.01)

(21) International Application Number:
PCT/US2009/052379

(22) International Filing Date:
31 July 2009 (31.07.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/085,411 31 July 2008 (31.07.2008) US
12/259,790 28 October 2008 (28.10.2008) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,

[Continued on next page]

(54) Title: LIGHTWEIGHT MULTI-COMPONENT ARMOR

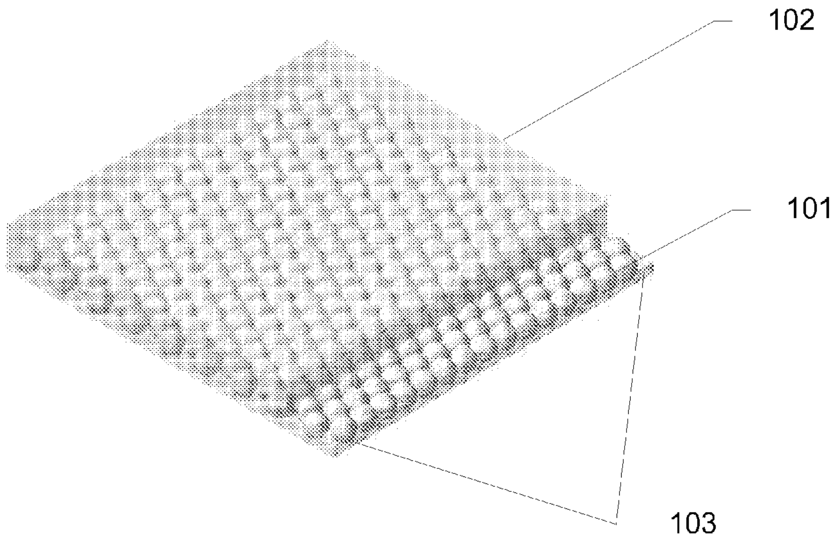

FIG. 1A

(57) **Abstract**: Devices and methods are disclosed which relate to a composite armor for providing protection to vehicles, vessels and the like, through use of material that is lightweight, strong, and durable. Exemplary embodiments provide an array of ceramic spheres within a ductile metal or polymeric material which distributes the impact of a projectile across a greater area. In certain exemplary embodiments, the present invention provides an armor plate for protection against projectiles and fragments. Energy from a projectile's impact upon a sphere of the array is spread throughout the array, dissipating the energy. By using small discrete spherical units within the layer, the ability of the layer to withstand multiple hits is improved.

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MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

— *of inventorship (Rule 4.17(iv))*

Published:

— *with international search report (Art. 21(3))*

— *with information concerning authorization of rectification of an obvious mistake under Rule 91.3 (b) (Rule 48.2(i))*

(88) Date of publication of the international search report: 1 July 2010

(48) Date of publication of this corrected version: 29 July 2010

(15) Information about Correction: see Notice of 29 July 2010

LIGHTWEIGHT MULTI-COMPONENT ARMOR

[0001] This application claims priority to U.S. Patent Application Serial No. 12/259,790, filed October 28, 2008, which claims priority to U.S. Provisional Patent Application Serial No. 61/085,411, filed July 31, 2008, the contents of both of which are hereby incorporated by reference herein in their entirety into this disclosure.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention relates to armor. More specifically, the present invention relates to light armor devices.

Background of the Invention

[0003] Military vehicles are commonly fortified with armor to protect soldiers from threats such as enemy fire. Vehicles such as tanks are heavily armored with metal plates to withstand a variety of dangers. However, many other types of vehicles, such as automobiles, jeeps, light boats, or aircraft need lower weight armor in order to maintain their mobility. Additionally, an armor to be carried by soldiers must be very light weight to allow ease of movement. This armor must still perform satisfactorily despite its low weight, and at a minimum maintain the ability to stop small arms fire. Armor design must take into account the weight, cost, and effectiveness of the materials used.

[0004] Conventional structural and vehicle armor calls for the use of rigid plates of ballistic material. Depending on the application, metals, polymer fibers, glasses, or ceramic materials are utilized to stop ballistic threats and fragments from explosive devices. For protection against high-velocity rounds, metals such as steel are used when cost is a primary factor. Such armor usually comprises a thick layer of alloy steel, which is intended to provide protection against heavy and explosive projectiles such as small arms, mines, and improvised explosive devices. Unfortunately, armors based on steel have considerable weight penalties, which limit mobility of any vehicle bearing the armor. Thus, due to its weight, such armor is not suitable for light vehicles and is certainly not suitable for being worn and/or carried by a soldier.

[0005] For applications requiring low weight armors, ceramic materials have been the material of choice. They offer high hardness to deform and blunt incoming projectiles, at less than half the weight of steel. However, ceramic-based armors typically suffer from poor multiple hit capabilities. A ballistic impact on a ceramic material generally causes brittle fracture of the material near the impact location. Due to the mechanics of brittle fracture, the damaged region can extend over the entire component area. As a result, performance is significantly degraded against subsequent ballistic impacts.

[0006] The cost of material is also a heavy consideration in creating armor. It is not feasible to spend excessive amounts of money on exotic materials which would limit the amount of armor that can be purchased on a fixed budget. In order for the production of armor to be effective and financially feasible, the design and materials used must provide the most protection for a reasonable cost.

[0007] Thus, it would be ideal to have the ability to provide armor made of material that has the advantages of lightweight materials as well as the strength of steel or heavy-weight material. What is needed is a lightweight armor capable of maintaining its effectiveness for multiple hits while not being prohibitively costly.

SUMMARY OF THE INVENTION

[0008] The present invention presents a composite armor for providing protection to persons, vehicles, vessels and the like, through use of material that is lightweight, strong, and durable. The present invention provides an array of ceramic spheres within a ductile metal or polymeric material which distributes the kinetic energy and momentum from the impact of a projectile across a greater area. In certain exemplary embodiments, the present invention provides an armor plate for protection against projectiles and fragments. Energy and momentum from a projectile's impact upon a sphere of the array is spread throughout the array, dissipating the energy and dispersing the momentum over a greatly increased area. By using small discrete spherical units within the layer, the ability of the layer to withstand multiple hits is improved.

[0009] The array of spheres can be configured in many ways to provide contact points between the spheres. Exemplary embodiments of the present invention provide for ballistic materials on the outside of the armor to prevent injuries due to spall as well as to catch projectile fragments. Further embodiments of the present invention are integrated into helmets or body armor to provide protection to individual soldiers.

[0010] In one exemplary embodiment, the present invention is a multi-component armor device, comprising a layer composed of a first material, and an array of spheres contained within the first material. The array of spheres allows for contact between the spheres such that kinetic energy from an impact to one sphere is distributed to neighboring spheres.

[0011] In another exemplary embodiment, the present invention is a multi-component armor device, comprising an array of spheres of a first material, and a second material encompassing and containing the array of spheres. The array of spheres comprises a plurality of layers of spheres and each sphere has the ability to yaw the angle of a projectile and distribute the kinetic energy across many spheres, spreading the momentum of the projectile across a greater area.

[0012] In a further exemplary embodiment, the present invention is a method for protecting a vehicle with armor, the method comprising providing armor made of one layer of material incorporating an array of spheres of a second material, and attaching the armor on the vehicle.

[0013] In yet another exemplary embodiment, the present invention is a method of manufacturing a multi-component armor comprising aligning an array of spheres in a first layer such that they are in contact with adjacent spheres, and casting a second material into a mold containing the array of spheres such that the second material encompasses the array.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] **FIG. 1A** shows a side perspective view of armor layers, according to an exemplary embodiment of this invention.

[0015] **FIG. 1B** shows a side cut view of armor layers, according to an exemplary embodiment of this invention.

[0016] **FIG. 2** shows a dense pack arrangement of spheres, according to an exemplary embodiment of the present invention.

[0017] **FIG. 3A** shows a top view of a lattice arrangement of ceramic spheres, according to an exemplary embodiment of the present invention.

[0018] **FIG. 3B** shows a side view of a lattice arrangement of ceramic spheres, according to an exemplary embodiment of the present invention.

[0019] **FIG. 4** shows a projectile striking a ceramic sphere in a layer of ceramic spheres, according to an exemplary embodiment of the present invention.

[0020] **FIG. 5** shows armor with a layer of ballistic material on one side, according to an exemplary embodiment of the present invention.

[0021] **FIG. 6** shows multi-component armor attached to a vehicle, according to an exemplary embodiment of the present invention.

[0022] **FIG. 7A** shows multi-component armor incorporated into a helmet, according to an exemplary embodiment of the present invention.

[0023] **FIG. 7B** shows multi-component armor incorporated into a vest, according to an exemplary embodiment of the present invention.

[0024] **FIG. 8A** shows the manufacture of multi-component armor using compression molding, according to an exemplary embodiment of the present invention.

[0025] **FIG. 8B** shows the use of injection molding to form a polymer matrix material around an array of spheres, according to an exemplary embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0026] The present invention presents exemplary embodiments of a composite armor for providing protection to persons, vehicles, vessels and the like, through use of material that is lightweight, strong, and durable. The present invention provides exemplary embodiments of an array of ceramic spheres within a ductile metal or polymeric material which distributes the kinetic energy and momentum from the impact of a projectile across a greater area. In certain exemplary embodiments, the present invention provides an armor plate for protection against projectiles and fragments. Energy and momentum from a projectile's impact upon a sphere of the array is spread throughout the array, dissipating the energy and dispersing the momentum over a greatly increased area. By using small discrete spherical units within the layer, the ability of the layer to withstand multiple hits is improved.

[0027] The array of spheres can be configured in many ways to provide contact points between the spheres. Exemplary embodiments of the present invention provide for ballistic materials on the outside of the armor to prevent injuries due to spall as well as to catch projectile fragments. Further embodiments of the present invention are integrated into helmets or body armor to provide protection to individual soldiers. The present application provides an alternative to the armor described in co-pending patent application, U.S. Serial No. 12/068,591, entitled, "Multilayer Armor and Method of Manufacture Thereof," filed on February 8, 2008, the content of which is hereby incorporated by reference herein in its entirety.

[0028] "Sphere", as used here and throughout this disclosure, refers to the general shape of the individual components composed of ceramic or another hard material. The individual components need not be perfectly spherical. Spheres may have imperfections, such as commercial grinding spheres.

Other materials may also be used, such as, for example, ordinary glass marbles, though the hardness would likely be less and the performance not as desirable as other materials such as alumina. Alternatively, the “sphere” components may be spheroidal, such that they have some curvature of part of their surface, preferably the part facing potential impact, and may be straight edged or other shaped on other parts of the component. Other shapes are also possible as long as they possess the same properties as described within this disclosure.

[0029] Various techniques of making multi-component armor are possible according to the present invention. **Figure 1A** shows an armored plate comprised of an array 103 of hard spheres in a single layer array where each sphere 101 is in contact with three to six of its neighbors. Sphere 101 may be composed of ceramic or other similar material and acts as a hard surface capable of deforming and blunting impinging projectiles. Spheres that present an angled or curved surface to the projectile may also act as yaw inducers within the armor panel.

[0030] In exemplary embodiments of the present invention, sphere 101 is composed substantially of a ceramic, for example, aluminum oxide (alumina). This material has excellent wear characteristics and has high-temperature properties and compressive strength. Alumina spheres may be those commercially available, such as, for example, commercial grinding spheres. The alumina spheres in the present invention may be one of a variety of sizes, depending upon the desired weight of the armor and the perceived threat the armor is designed to sustain. For example, one half inch diameter spheres may be used for protection from small arms fire. Many ceramic materials other than alumina can be used for the spheres, including but not limited to silicon carbide, silicon nitride, boron carbide, etc., as would be known to one having ordinary skill in the art after consideration of the present disclosure.

[0031] Ceramic sphere array 103 is further encapsulated in a ductile matrix material 102. This ductile matrix is made of a material that can be cast onto and around the sphere array and can be made of, for example, castable aluminum or other low melting point metals, or, alternatively, of a castable polymeric material. Aluminum provides an acceptable matrix material as it is lightweight, has a low melting point, and is not very reactive. The thickness of the matrix once cast should be enough to immobilize sphere array 103, with ceramic sphere array 103 oriented centrally or towards or close to or adjacent the panel strike face. The strike face is the outer side of the armored plate which receives the impact from a projectile. In embodiments of the present invention using two layers of spheres, a matrix slightly thicker than a single sphere, with the matrix spanning the midpoint of the first layer to the midpoint of the second layer, may be appropriate. The amount of matrix material on the backside of the array is optimized according to the threat and whether or not there are ballistic fibers embedded within the matrix.

[0032] In various embodiments, the matrix material may be a polymer. Such polymer should have desired properties where, when in contact with the ceramic spheres, the polymer produces a strong and lightweight protective barrier to projectiles. Such polymer should preferably be a combination of polyethylene and nylon. The ideal properties of the polymer are such that the polymer is easily castable/moldable and tough, such that it tears when the material fails rather than fracturing. With the use of polymer matrix material, the polymer can be cured to create crosslinking in the layer, increasing the ballistic protection. One non-limiting example of a polymer which may be used is available from INETEGRICO. But others may also be used as would be apparent to one having ordinary skill in the art.

[0033] **Figure 1B** shows a side cut view of exemplary armor layers, according to an embodiment of this invention. In this embodiment, an array of ceramic spheres 103 is oriented towards the panel strike face. This alignment may help prevent a matrix material 102 from opening gaps in ceramic sphere array 103 after the impact of a projectile. Matrix material 102 provides for a durable foundation to hold ceramic spheres 101. When encapsulated into a ductile material, the impact resistance of ceramic sphere array 103 is improved, leading to a reduction in premature damage to the ceramic prior to a ballistic event. This improves ballistic performance and improves product lifetime. The additional thickness of matrix material 102 incorporated into the armor panel improves the ballistic protection and reduces back-face spalling from the ceramic. Compared to conventional products, the present design leads to an improvement in protection and weight compared to a matrix similar in size to the encapsulated spheres. The additional thickness also allows for limited machining of the back face of the panel, easing integration onto a military or other platform. Thus, the advantages of a ceramic strike face can be realized, with a robust armor panel capable of multiple-hit protection.

[0034] In exemplary embodiments of the present invention utilizing a polymeric matrix material, fibrous materials may also be placed within the matrix. These fibers, such as KEVLAR pulp, which have beneficial ballistic properties, are suspended within the polymeric material to provide increased protection. The fibers further slow down and deflect a projectile striking the armor. Other embodiments contain nanoparticles, such as carbon nanotubes, within the polymeric material to alter physical and chemical properties of the matrix.

[0035] Optionally, an additional layer of material, positioned outside of the spheres, may be incorporated onto the strike face of the panel. This additional layer may be comprised of any materials acceptable for use as the matrix material, but the matrix material and the outer layer are not necessarily the same material. The outer layer reduces spall off the strike face and improves integration of the ceramic spheres. The incorporation of this additional layer also eases manufacturing when spheres of small outer diameter are used, especially those under 12.5 mm. At small sphere sizes, production of high quality casting is sometimes difficult due to poor fluid penetration through the small gaps between spheres. Thus, the additional layer of material serves to maintain the integrity of the array of spheres, as well as serve as an added layer of protection against ballistic impact.

[0036] Ceramic spheres are arranged such that energy is distributed throughout the array of spheres, and thus the individual impact on a particular locus is diminished. A hit to a single sphere transfers energy and momentum to surrounding spheres, spreading the energy and momentum across a larger area, and incrementally dissipating the energy and momentum through the multiple inelastic collisions executed. By spreading the energy and momentum across a larger area, the armor has the ability to dissipate energy from the impact and slow and/or stop projectiles. Different array configurations are possible based upon the desired armor weight as well as perceived threats.

[0037] **Figure 2** shows a dense pack arrangement of spheres, according to an exemplary embodiment of the present invention. In this embodiment, each sphere is in contact with six other spheres in the layer, with the exception of spheres on the edge of the armor plate which may be in contact with fewer than six. When a projectile strikes a sphere 201, the projectile's kinetic energy is transferred to the struck sphere 201. Sphere 201 in turn transfers this energy to the spheres it is in contact with. These spheres, in turn, further spread the energy to spheres surrounding them. The result is the energy being spread over a larger area, and the projectile is stopped. Additionally, because the spheres are round, a perpendicular hit straight onto a sphere is much less likely than a glancing, nonperpendicular hit. Especially for these nonperpendicular, glancing hits, the curvature of the spheres causes a projectile to yaw, changing the magnitude and direction of the momentum as well as dissipating some of the kinetic energy. A dense pack arrangement is especially useful in armor utilizing a single layer of ceramic spheres because it allows the highest number of contact spheres for any struck sphere. Use in multiple layers will create more contact points with even more spheres, further dissipating the energy and momentum in different directions and among the different layers.

[0038] **Figures 3A** and **3B** show an arrangement of ceramic spheres according to an exemplary embodiment of the present invention. In this embodiment, two layers of spheres are arranged in a lattice structure. In this lattice arrangement, each sphere is in contact with four other spheres in its layer.

[0039] **Figure 3A** shows a top view of a lattice arrangement of ceramic spheres, according to an exemplary embodiment of the present invention. This view shows an approximate placement of a second layer 332 beneath a first layer 331. Each sphere 301 is in planar contact with four other spheres and close to eight other spheres on the same layer. With second layer of spheres 332, each sphere is in direct contact with eight total spheres combined. This allows for a maximum number of contact points based upon the array of the layer. Second layer 332 allows a struck sphere to transfer kinetic energy and momentum to more spheres and in more directions. Any number of layers of spheres may be used, depending on necessary limitations, such as cost and weight. Multiple layers allow contact with a greater number of spheres. The multiple layers allow kinetic energy and momentum to spread to more spheres, with the successive collisions dissipating the kinetic energy and momentum into three dimensions. Kinetic energy and momentum are dissipated along each layer, perpendicular to the layers, as well as directions in between.

[0040] **FIG. 3B** shows a side view of a lattice arrangement of ceramic spheres, according to an exemplary embodiment of the present invention. This view shows how first layer of spheres 331 rests in the valleys of second layer 332. Again, this allows each sphere to be in contact with the maximum number of spheres from the other layer.

[0041] The armor redistributes the kinetic energy of the projectile via elastic scattering, with the tightly nested spheres propagating the energy and momentum from the impact location laterally along the armor layer or layers through collisions with neighboring spheres. The spheres redirect projectiles that penetrate the outermost armor layer via successive inelastic collisions, which dissipate energy and momentum from the projectile. The more kinetic energy dissipated laterally across the surface of the layers, the less energy is communicated to the structure underneath the armor. Due to their spherical shape, it is highly unlikely that the spheres can be impacted by the projectile so as not to deflect the initial trajectory of the projectile. In exemplary embodiments of the present invention, a layer of ballistic fibers, such as KEVLAR, is placed between the layers of spheres to catch projectiles and fragments.

[0042] **Figure 4** shows an exemplary projectile 440 striking a surface having a ceramic sphere 401 in a layer of ceramic spheres, according to an exemplary embodiment of the present invention. In this embodiment, due to the curvature of a struck sphere, the struck sphere 401 transfers the kinetic energy and momentum into the layer of spheres through multiple collisions. This causes the kinetic energy and momentum received from projectile 440 to spread to surrounding spheres. These spheres, in turn, spread the kinetic energy and momentum to spheres in contact with them, and so on. Because the kinetic energy and momentum is now spread to multiple spheres, rather than just one, the amount of kinetic energy and momentum of any one sphere is greatly reduced. Thus, rather than all of the kinetic energy and momentum being transferred to a single sphere or point and possibly causing failure of the armor, the energy and momentum is spread across the armor, stopping the projectile. This figure only shows a small portion of the layer of ceramic spheres. The actual layer can be of any size with any number of spheres.

[0043] The shape of the embedded spheres may help in mitigating projectile penetration by increasing the likelihood of deflection of a projectile from the projectile's initial path. This deflection makes the projectile travel a longer path through the armor, promoting more collisions, and thus dissipating more energy and momentum. By using small discrete spherical units within the layer, the ability of the layer to withstand multiple hits is improved.

[0044] In any type of armor, spall may occur as a projectile impacts the armor. These pieces of material, which can come from either side of the armor, can injure people nearby. To prevent or reduce spall, a layer of ballistic material can be attached as either or both a front and backing of the armor. This material catches fragments of the projectile as well as fragments of the armor.

[0045] **Figure 5** shows armor with a layer of ballistic material 550 on one side, according to an exemplary embodiment of the present invention. In this embodiment, a ballistic material, such as materials that are designed to withstand some impact, such as but not limited to KEVLAR, is coupled to a matrix material 502. This coupling may be done during the manufacture of the armor matrix or added later, such as by gluing, welding, nailing, etc. With the ballistic material backing, as a projectile hits the armor from underneath as shown in Figure 5, fragments that are not completely stopped by the matrix material 502 and spheres 501 will contact ballistic material 550. Ballistic material 550 catches these fragments, preventing them from striking the protected body.

[0046] **Figure 6** shows a multi-component armor attached to a vehicle 661, according to an exemplary embodiment of the present invention. In this embodiment, panels of armor 660 are coupled to vulnerable areas of vehicle 661. Panels 660 are attached to prevent injury to passengers as well as damage to the vehicle itself. For example, panels 660 may be attached to doors and the roof to prevent projectiles from striking passengers. Panels may be attached to the hood and underside of vehicle 661 to prevent damage to the engine and fuel tank as well as other mechanical and electrical components of the vehicle, and so on. The number of layers and the size of ceramic spheres 601 used in the armor depend upon the desired characteristics of the armor. These desired characteristics depend upon the expected threat as well as weight and cost considerations. Larger spheres can be used to deflect and dissipate energy from larger projectiles.

[0047] Many field tests have proven the efficacy of the present invention as embodied in the various exemplary embodiments. For example, testing showed that an embodiment of the present invention comprising a panel of two layers of 0.5 inch spheres in a polymeric matrix could stop 9mm ammunition rounds. The panel was tested against a series of ballistic threats to gauge the ballistic integrity, with a witness plate of 1inch aluminum placed behind the panel, with no standoff, for each shot to gauge the level of performance of the panel against each threat. A 9mm full metal jacket threat was stopped within the structure of the armor panel with only slight deformation of the back face.

[0048] In further testing, two panels of identical construction were comprised of a dual layer of nested 0.5 inch alumina spheres bound in a polymer matrix with a 0.25 inch integrated spall liner of aramid material. These panels were each subjected to ballistic threats to assess ballistic integrity. Each panel underwent a series of tests against 7.62X51mm armor-piercing steel core rounds, with a total of four rounds. The shots were fired from a REMINGTON

700 firearm at a distance of 100 meters and a speed of approximately 2600-2700 feet per second. Each shot was placed through a chronograph to record velocities. A witness plate of 1 inch aluminum was placed at an eight inch standoff to gauge the remaining energy in the event of total perforation of the panel.

[0049] The performance of the armor panel against each of the shots was similar. The shots placed on the panels created an entry point approximately 0.35 inches, slightly larger than the actual projectile. None of the four shots placed on the two panels resulted in total perforation of the panel. All shots penetrated the first few layers of the aramid fiber material. The aramid fiber spall liner retained the projectile and all fragments with no sign of any perforation, but showed deformation of approximately 0.5 inches.

[0050] **Figures 7A** and **7B** show further uses of multi-component armor plates for individual soldiers, police, etc. Embodiments of the present invention utilize polymers as well as other lightweight materials. Along with relatively lightweight ceramic spheres, the armor plates are light enough to be carried and worn by soldiers in combat or police in everyday operations. Smaller spheres may further reduce the weight of the armor without losing adequate protection.

[0051] **Figure 7A** shows a multi-component armor incorporated into a helmet 770, according to an exemplary embodiment of the present invention. In this embodiment, the armor plate is molded in the shape of helmet 770. Contact between spheres 701 is maintained in order to allow the dispersion of kinetic energy and momentum from a projectile striking helmet 770. Materials used for helmet 770, as well as the size of spheres 701 used, may be adjusted based upon the desired weight, protection, and size of helmet 770. For example, half inch spheres may be used within a polymeric matrix with a total thickness of one inch. This would allow protection without becoming too bulky or heavy for use. Alternatively, the multi-component armor can be coupled to the outside of an existing helmet. This allows for attachment and removal based upon the level of threat faced.

[0052] **Figure 7B** shows a multi-component armor incorporated into a vest 771, according to an exemplary embodiment of the present invention. In this embodiment, plates of armor fit into pouches or compartments in vest 771. These pouches are located on the front, back, and sides of vest 771 to provide soldiers with protection against projectiles. Locating armor plates within pouches allows plates to be replaced in the event they are struck by a projectile, even though the majority of the plate would be unharmed. It also allows for plates to be exchanged or removed, depending upon the threat level and type. Materials and size of plates used, including the size of spheres 701, will depend on the threat as well as weight restrictions such that the soldier may still properly perform any necessary function while wearing the armor. In further embodiments, the armor may be molded into a continuous vest. A continuous vest allows contact between more spheres from the front to the back of the vest, allowing energy and momentum to disperse further as well as preventing gaps in protection.

[0053] Manufacturing of the armor is accomplished in many ways, depending upon the matrix material as well as the results desired. In one method of manufacture, the ceramic spheres are arranged vertically in a sand mold. Molten aluminum is poured into the mold such that it fills the mold and surrounds each of the spheres, with the exception of the contact points between spheres. In another method of manufacture, the ceramic spheres are heated within a mold and molten aluminum is poured in to fill all gaps in the mold. In further methods, the ceramic spheres are attached to each other before being cast in aluminum. This attachment may be in the form of strings, wires, glue, cement, etc. In embodiments of the armor using a polymeric material, a pressure mold or a vacuum mold may be used to ensure all gaps in the mold are filled. Polymeric materials are generally compressible, moldable, and have lower melting points, allowing these manufacturing methods. Methods such as compression molding or injection molding may be used in the manufacture of the armor. In compression molding, pressure is applied to force the material into contact with all mold areas, and heat and pressure are maintained until the molding material has cured.

[0054] **Figure 8A** shows the manufacture of multi-component armor, according to an exemplary embodiment of the present invention. In this embodiment, a compression mold 880 may be used to form a matrix material around an array of spheres. Spheres 801 are placed into a lower portion 881 of mold 880, filling a layer of mold 880. Mold 880 is shaken such that spheres 801 arrange themselves into a dense pack arrangement. This shaking can be accomplished manually or in an automated process. In embodiments comprising multiple layers of spheres, subsequent layers are added to mold 880 after the preceding layer has been arranged. Shaking mold 880 allows the subsequent layers to arrange into a multiple layer dense pack arrangement. A molten polymeric material 882 is then added to lower portion 881 of mold 880 and an upper portion 883 of mold 880 is brought down to lower portion 881, compressing polymer 882 and forcing it into the gaps of the arrangement of spheres. Mold 880 may contain a heating system to maintain polymer 882's molten state until the gaps in mold 880 are filled. In exemplary embodiments, a backing, such as KEVLAR, is also placed into mold 880 below spheres 801 to integrate the backing into the armor. When polymeric material 882 has solidified, mold 880 is opened and the armor is removed by an ejector pin 884.

[0055] Alternatively, **Figure 8B** shows the use of injection molding to form a polymer matrix material around an array of spheres, according to an exemplary embodiment of the present invention. In this embodiment, spheres 801 are placed into a vertical mold 885, approximately filling mold 885. Mold 885 is then shaken, either manually or automatically by machine, so that spheres 801 align themselves into a dense pack arrangement. Additional spheres may then be added to mold 885 to fill any gaps created during settling of spheres 801. With spheres 801 in the desired arrangement, a molten polymer is injected into mold 885 through an opening 886. The molten polymer continues to be injected until all gaps in mold 885 are filled. The polymer and spheres 801 are held in mold 885 until the polymer has solidified. At this point mold 885 is opened and ejector pins remove the newly formed armor from mold 885.

[0056] As described elsewhere in this disclosure, the material used to house the spheres in this invention may be metallic or polymeric or a hybrid. An ideal metal to use would be aluminum, due to its highly beneficial manufacturing and weight properties. Foamed aluminum may also be used, providing structural support with very little weight while maintaining air gaps between the armor and the object or person to be protected. Polymeric materials may also be used to set a foundation for the spheres. An ideal polymer to use in various embodiments of the present invention would be one that has properties as described elsewhere in this disclosure. Combinations of metals and polymers may also be used, along with fibers interspersed throughout the matrix with the ideal combination dependant upon the threat. For heavier threats, the bulkiness of the armor layer can be reduced by including metal within the layer. One having ordinary skill in the art would be cognizant of materials not specifically listed or described herein that could be also used in the present invention.

[0057] The foregoing disclosure of the exemplary embodiments of the present invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many variations and modifications of the embodiments described herein will be apparent to one of ordinary skill in the art in light of the above disclosure. The scope of the invention is to be defined only by the claims appended hereto, and by their equivalents.

[0058] Further, in describing representative embodiments of the present invention, the specification may have presented the method and/or process of the present invention as a particular sequence of steps. However, to the extent that the method or process does not rely on the particular order of steps set forth herein, the method or process should not be limited to the particular sequence of steps described. As one of ordinary skill in the art would appreciate, other sequences of steps may be possible. Therefore, the particular order of the steps set forth in the specification should not be construed as limitations on the claims. In addition, the claims directed to the method and/or process of the present invention should not be limited to the performance of their steps in the order written, and one skilled in the art can readily appreciate that the sequences may be varied and still remain within the spirit and scope of the present invention.

WHAT IS CLAIMED IS:

1. A multi-component armor device, comprising:

a layer composed of a first material; and

an array of spheres contained within the first material,

wherein the array of spheres allows for contact between the spheres such that kinetic energy from an impact to one sphere is distributed to neighboring spheres.

2. The device of claim 1, wherein the first material is metal.

3. The device of claim 2, wherein the metal comprises aluminum.

4. The device of claim 1, wherein the first material comprises a polymer.

5. The device of claim 1, wherein the array of spheres is composed of a second material different than the first material.

6. The device of claim 5, wherein the second material comprises ceramic.

7. The device of claim 6, wherein the ceramic is aluminum oxide.

8. The device of claim 1, wherein the array of spheres comprises a

plurality of layers of spheres wherein adjacent layers are in contact with each other.

9. The device of claim 1, wherein the array of spheres is lined up such that each sphere in a single plane of spheres is in contact with three to six other spheres.

10. The device of claim 1, wherein a thickness of the layer of first material is such that it just encompasses the array of spheres.

11. The device of claim 1, further comprising an additional layer of a third material adjacent to the layer of first material, wherein the third material has ballistic resistant properties.

12. The device of claim 1, wherein the first material is formed into the shape of a helmet.

13. The device of claim 1, wherein the first material is formed into a plate and is coupled to a vehicle.

14. A multi-component armor device, comprising:

an array of spheres of a first material; and

a second material encompassing and containing the array of spheres;

wherein the array of spheres comprises a plurality of layers of spheres and each sphere has the ability to yaw the angle of a projectile impacting on the array of spheres and distribute the kinetic energy across many spheres, spreading the momentum of the projectile across a greater area.

15. The device of claim 14, wherein the first material comprises ceramic.

16. The device of claim 15, wherein the ceramic is aluminum oxide.

17. The device of claim 14, wherein the array of spheres are lined up such that each sphere is in contact with three to ten other spheres.

18. The device of claim 14, wherein the adjacent layers of the plurality of layers of spheres are in contact with each other.

19. The device of claim 14, further comprising an additional layer of a third material adjacent to the array of spheres, wherein the third material has ballistic resistant properties.

20. A method for protecting a vehicle with armor, the method comprising:

providing armor made of one layer of a first material incorporating an array of spheres of a second material; and

attaching the armor on the vehicle.

21. The method of claim 20, wherein the first material comprises a metal.

22. The method of claim 21, wherein the second material comprises a ceramic.

23. The method of claim 20, wherein the array of spheres are lined up such that each sphere is in contact with three to six other spheres.

24. The method of claim 20, wherein the array of spheres is positioned in the interior of the layer of first material.

25. The method of claim 20, wherein the array of spheres is positioned adjacent one side of the layer of first material.

26. A method of manufacturing a multi-component armor comprising:

aligning an array of spheres in a first layer such that they are in contact with adjacent spheres; and

casting a second material into a mold containing the array of spheres such that the second material encompasses the array.

27. The method of claim 26, wherein the casting further comprises heating the array of spheres.

28. The method of claim 26, further comprising attaching the spheres to one another prior to casting.

29. The method of claim 28, wherein the spheres attach with one of string, wire, glue, and cement.

30. The method of claim 26, wherein the mold is one of a pressure and vacuum mold.

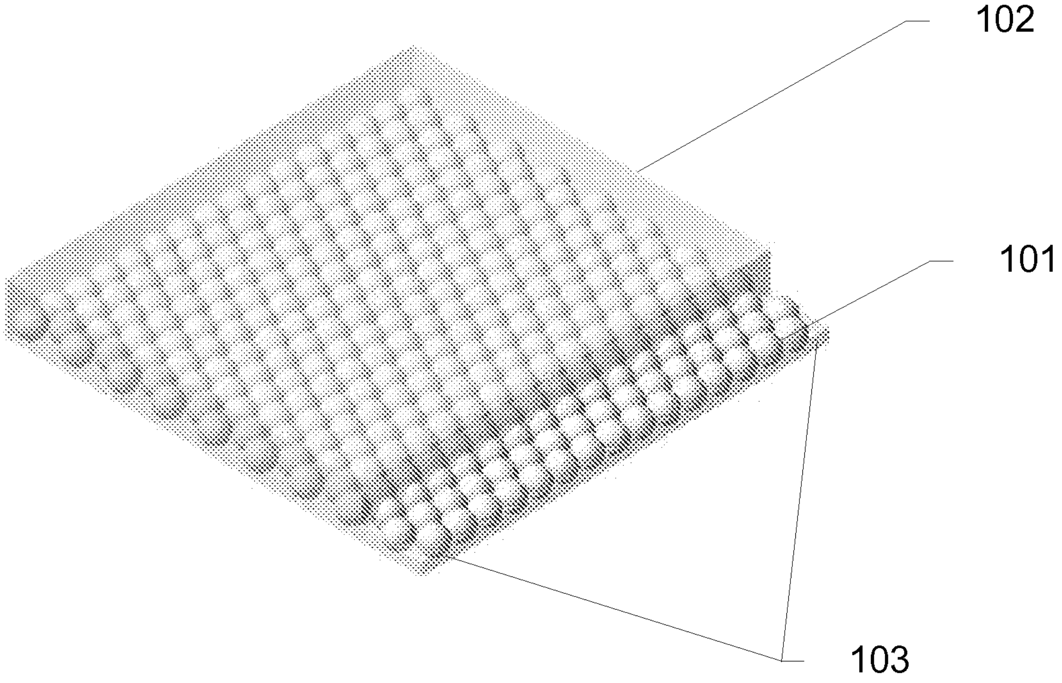

FIG. 1A

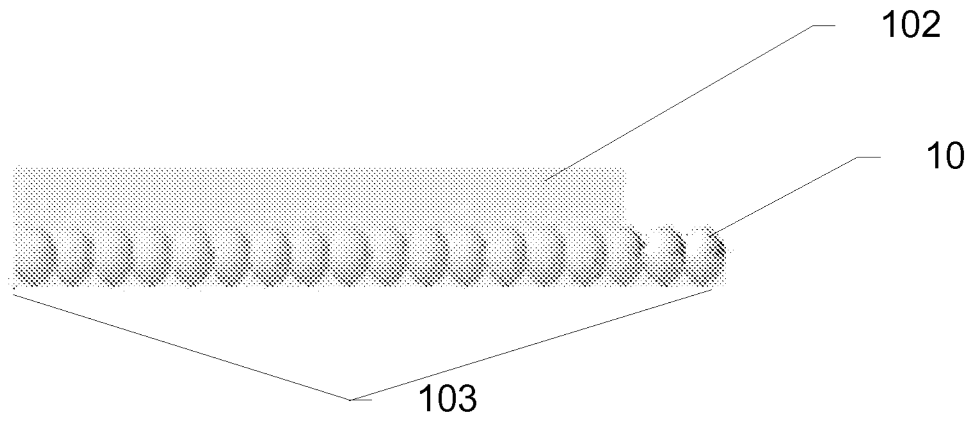

FIG. 1B

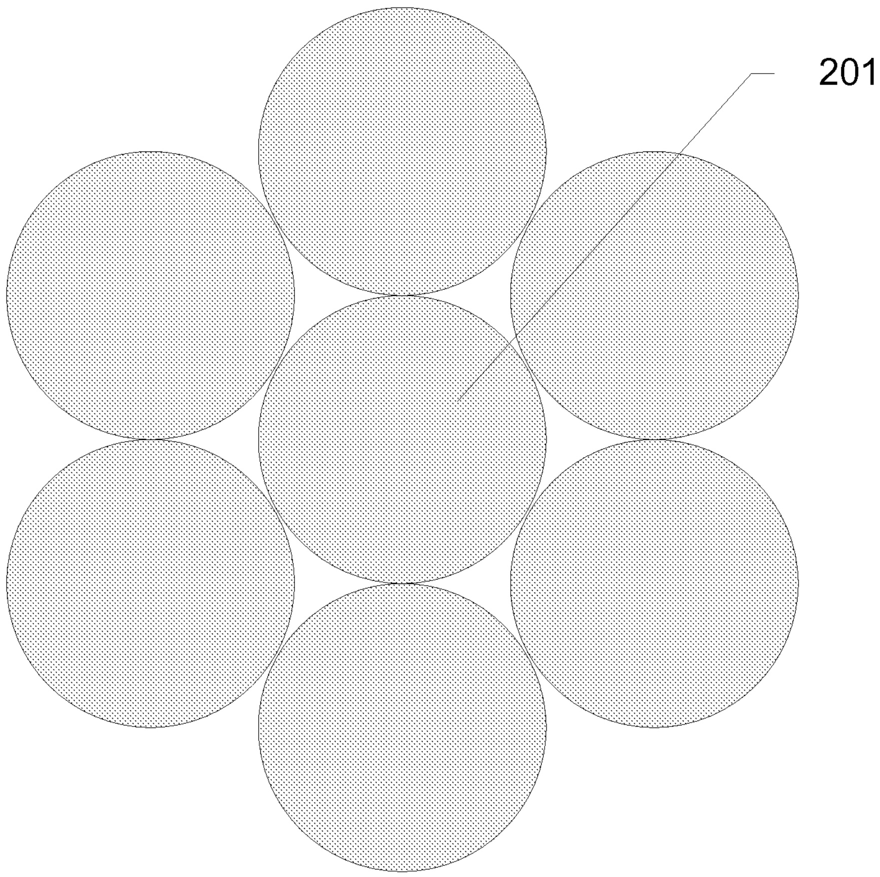

FIG. 2

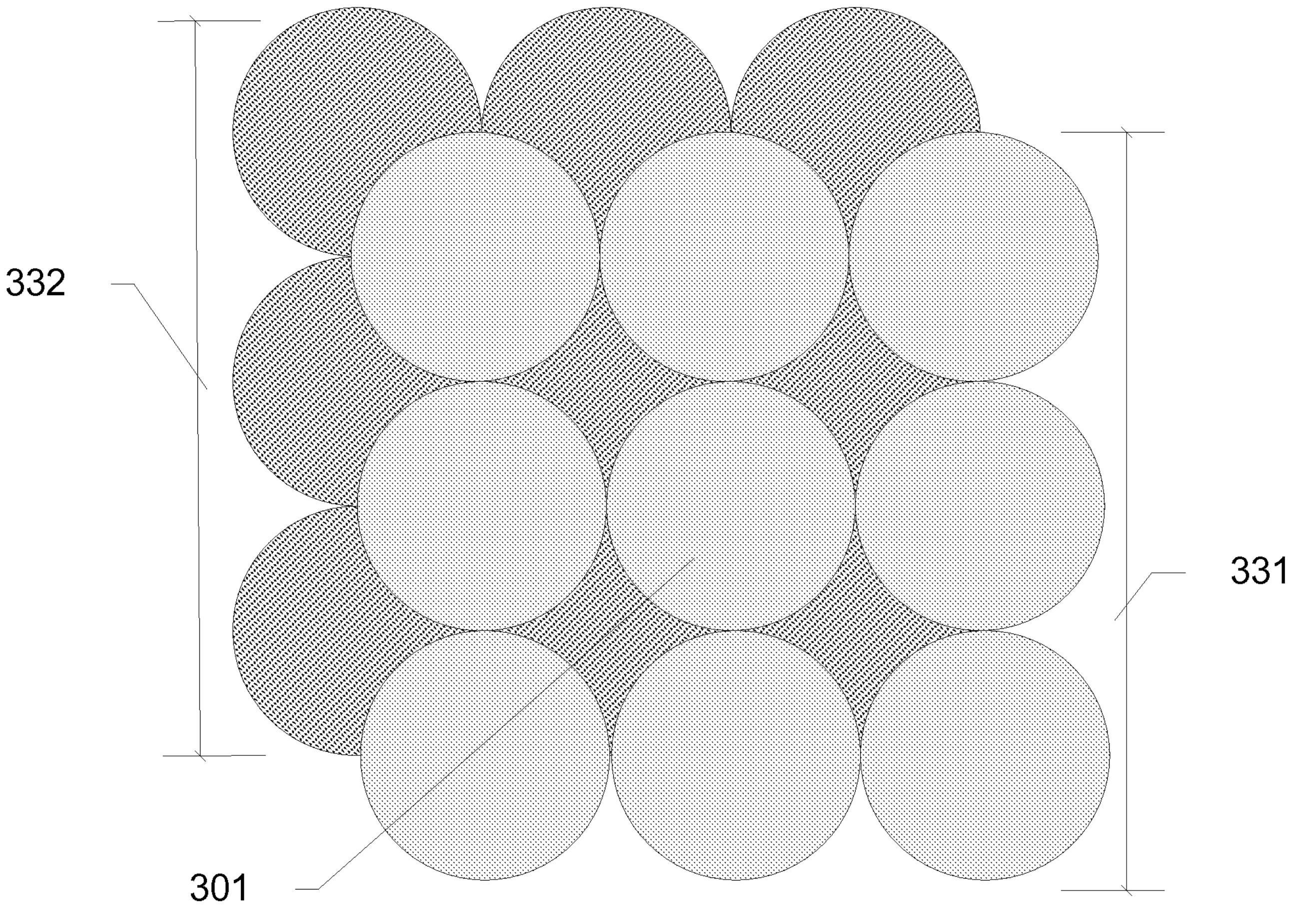

FIG. 3A

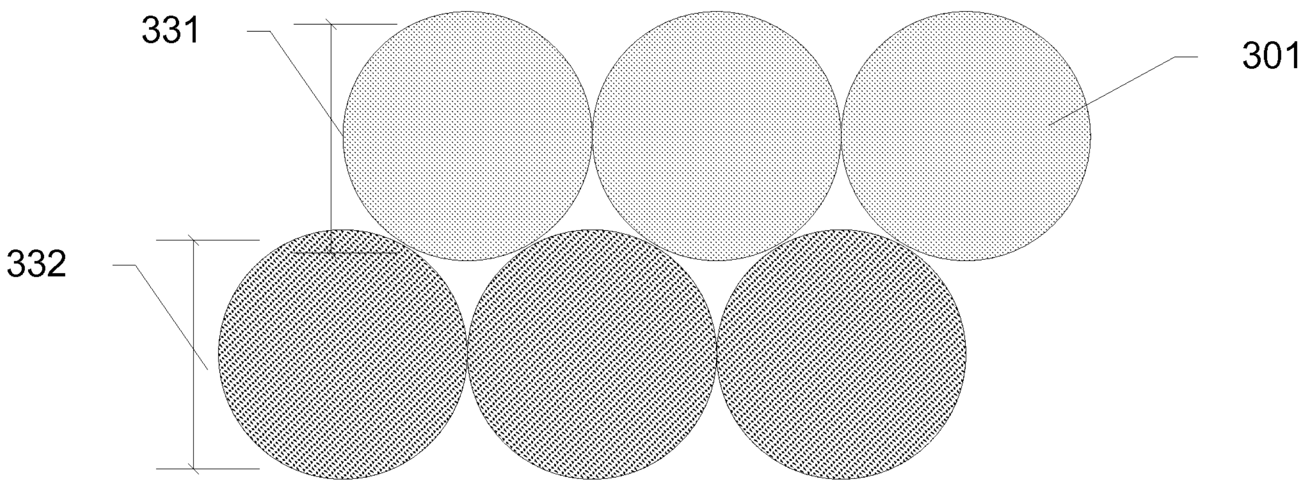

FIG. 3B

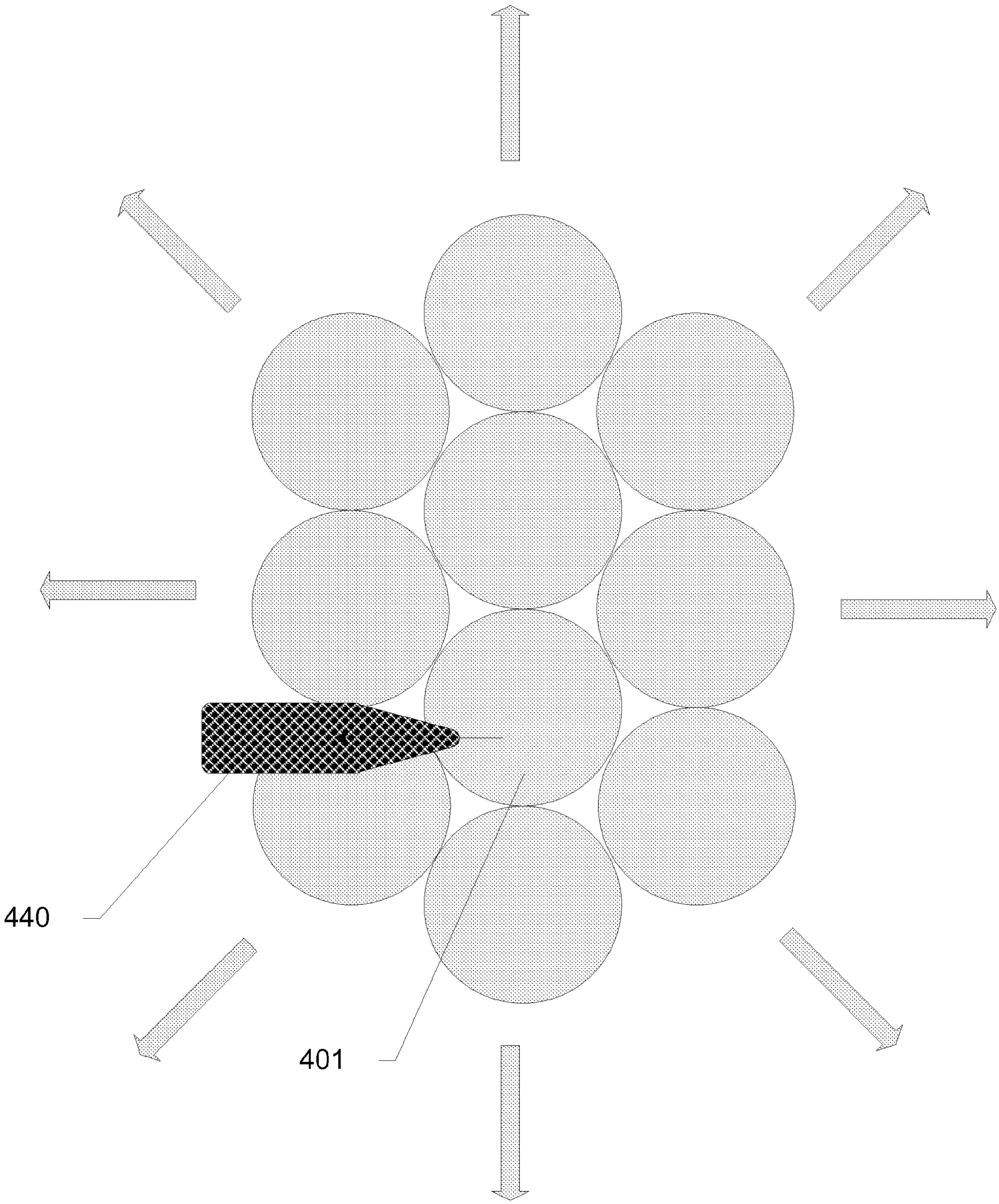

FIG. 4

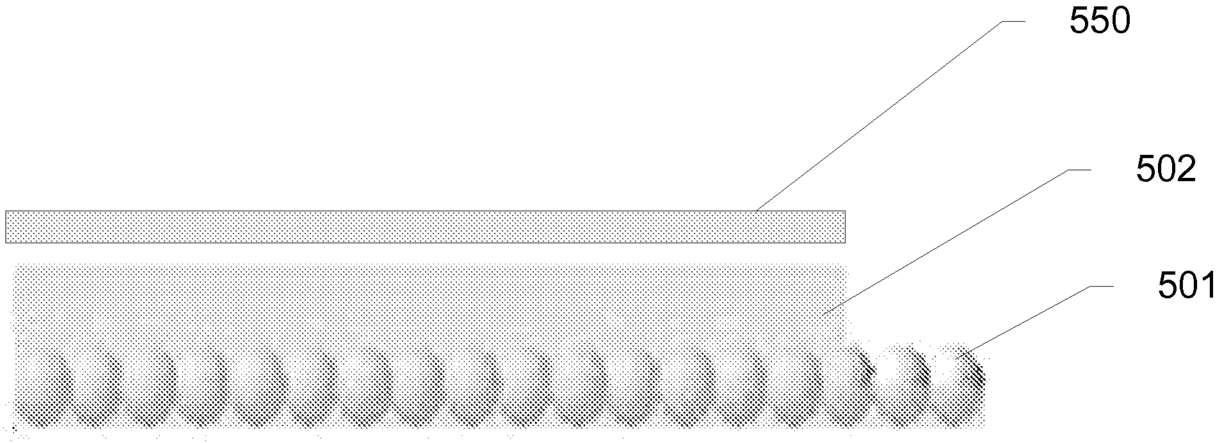

FIG. 5

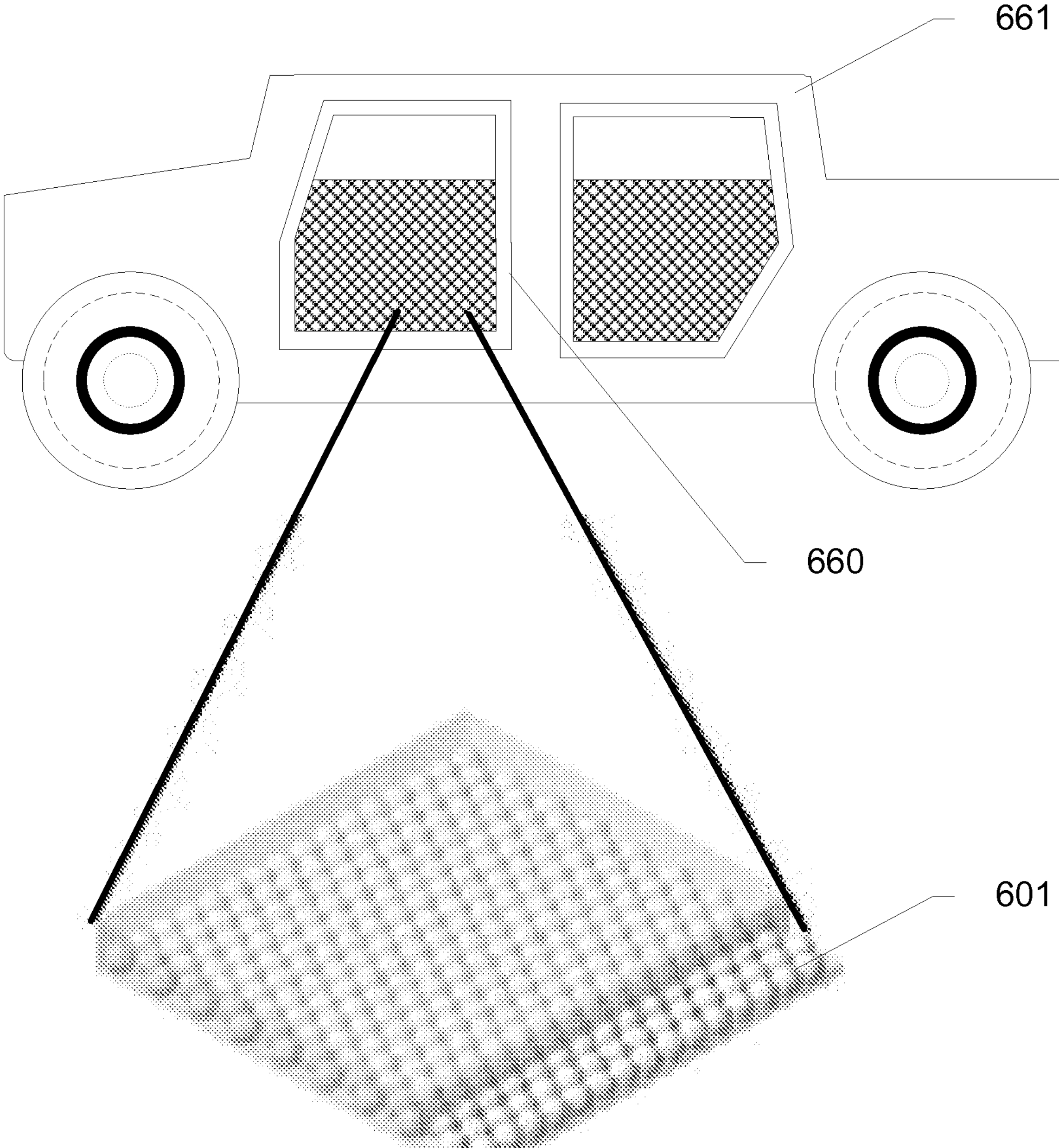

FIG. 6

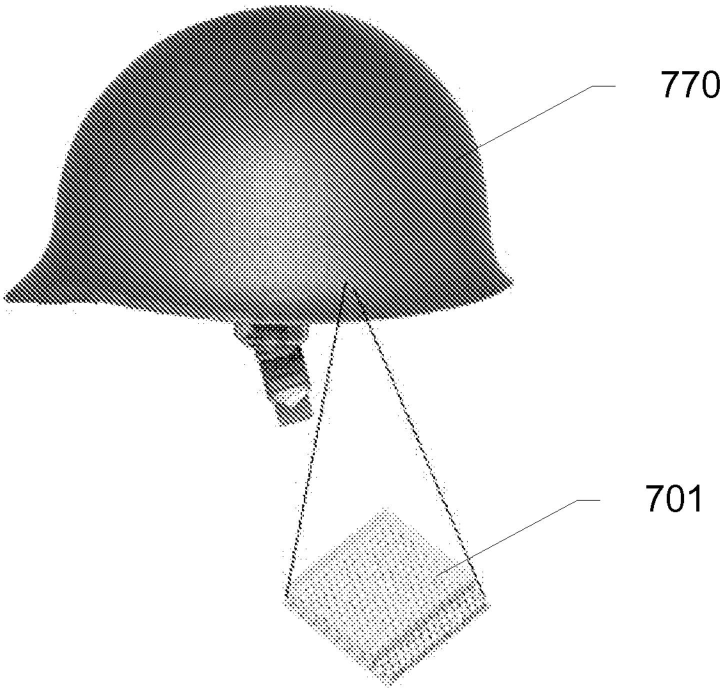

FIG. 7A

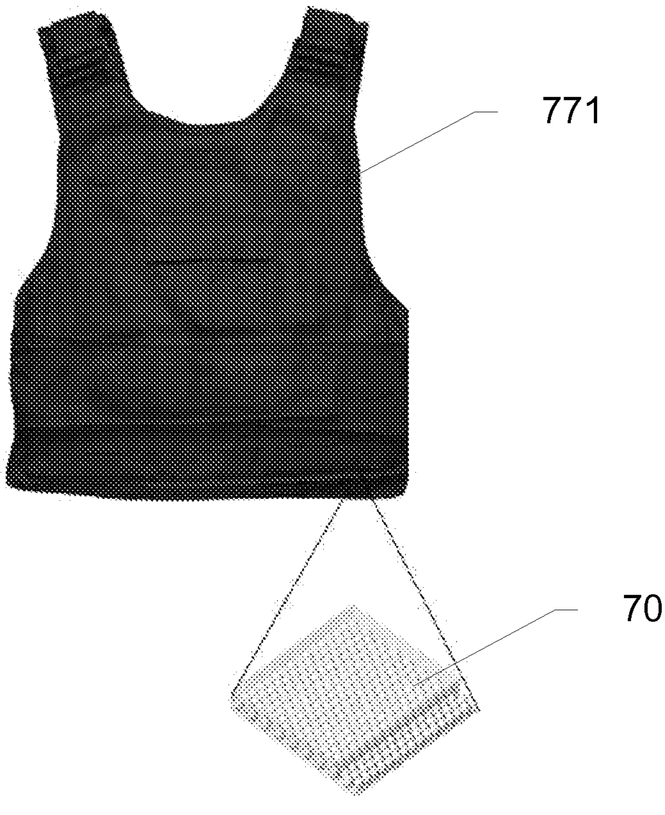

FIG. 7B

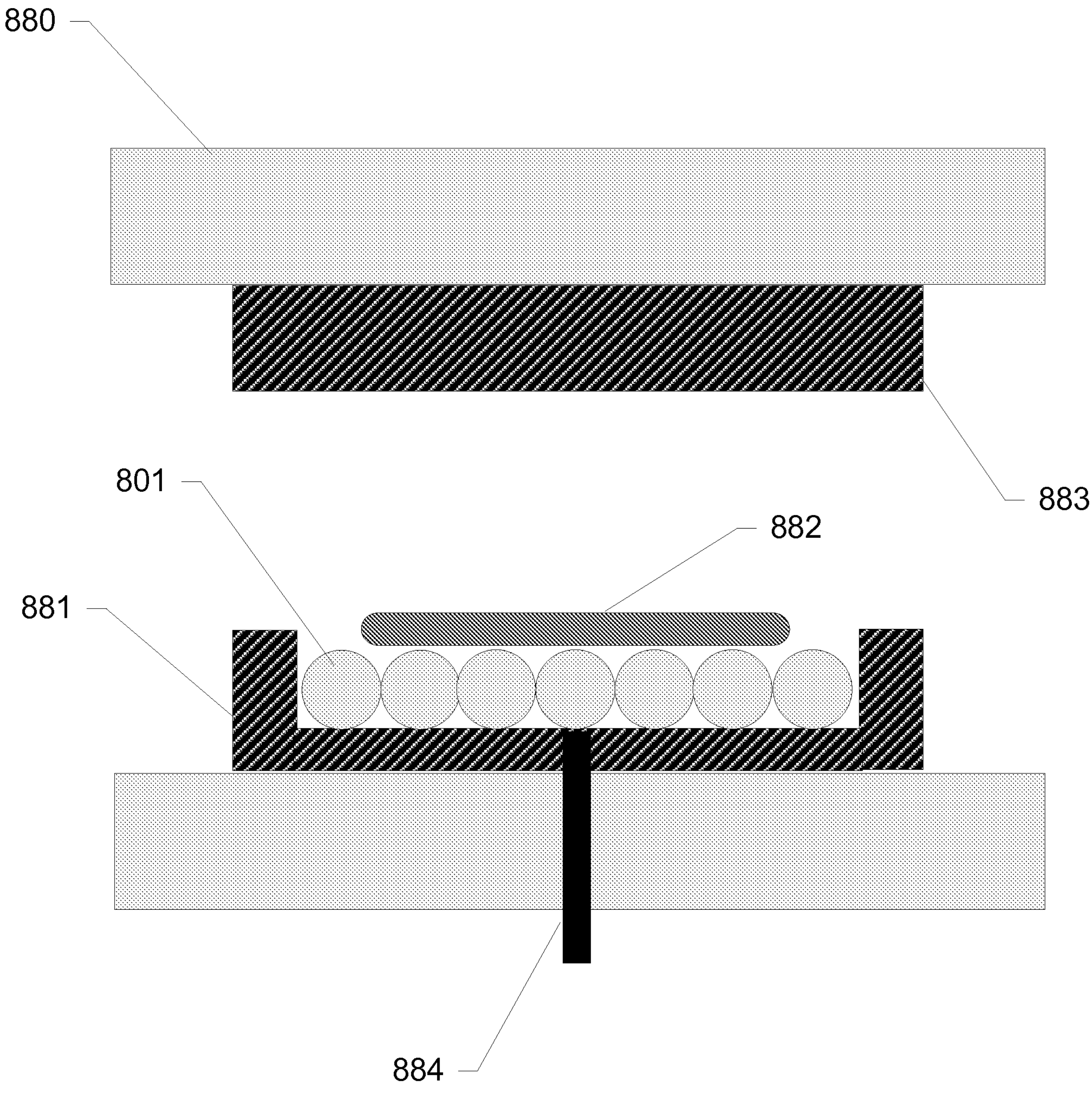

FIG. 8A

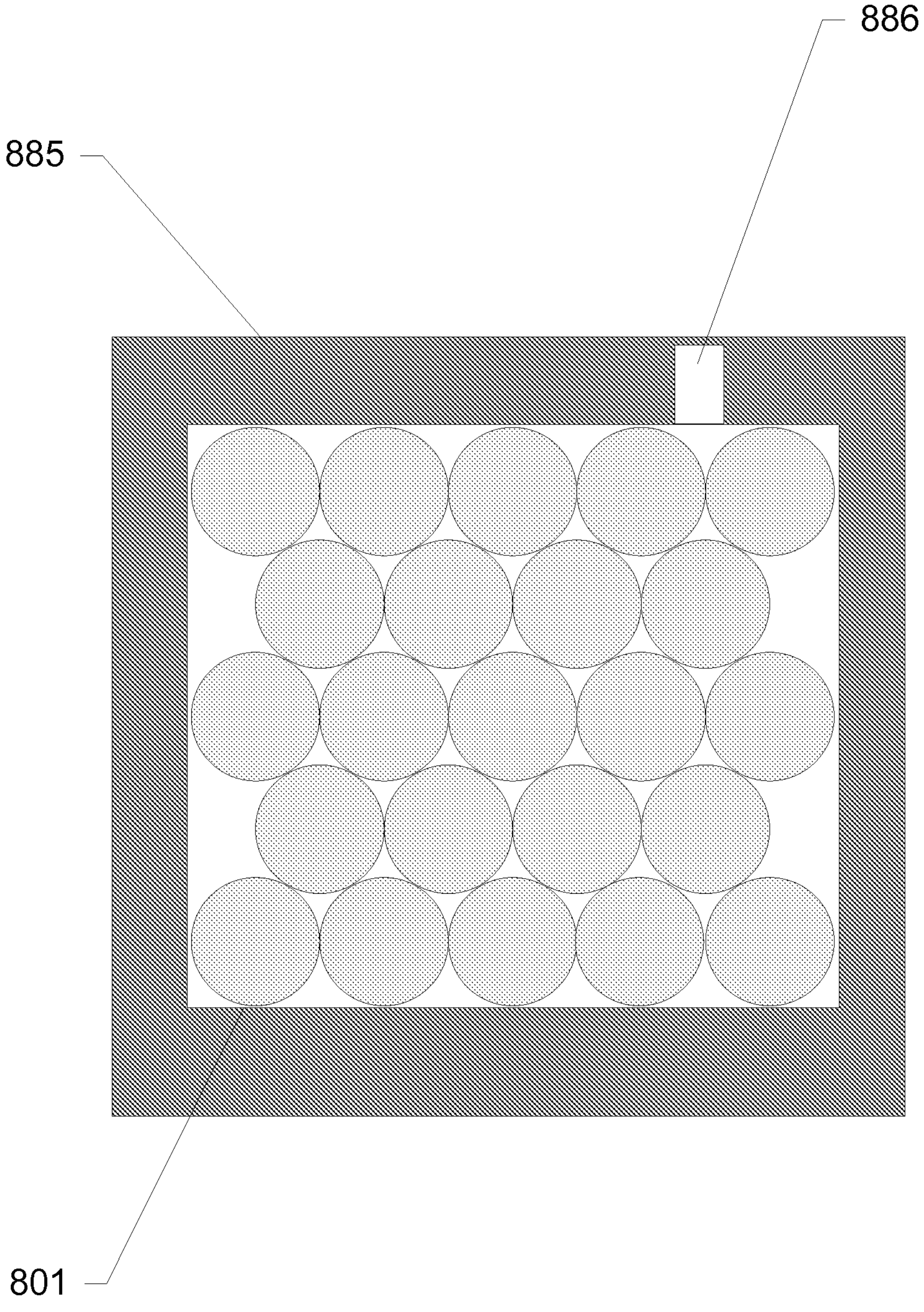

FIG. 8B

INCORPORATED BY REFERENCE (RULE 20.6)

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 09/52379

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - F41H 7/00; F41H 5/02; F41H 5/04 (2010.01)
USPC - 89/36.02, 36.07, 36.08
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
USPC: 89/36.02, 36.07, 36.08

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC: 89/36.01, 36.02, 36.07, 36.08
See Search Terms Below

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
pubWEST(PGPB,USPT,EPAB,JPAB); USPTO; Google Web
Search Terms Used: aluminium oxide, helmet, headgear, metal, layer, sphere, ball, ceramic, Cohen, adhesive, adher$3, glue, string, wire, cement, attach$3, armor, ballistic

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2008/0141852 A1 (WARREN et al) 19 June 2008 (19.06.2008) fig 1A, para [0026], [0028], [0035], [0037]-[0039], [0054], [0081]-[0082], [0100]-[0102]	1, 4-11, 13-20, 22-26 2-3, 12, 21, 27-30
Y	US 2004/0255768 A1 (RETTENBACHER et al) 23 December 2004 (23.12.2004) fig 3, 6, para [0033], [0048], [0052]-[0054], [0072]	2-3, 12, 21, 27, 30
Y	US 3,705,558 A (MCDOUGAL et al) 12 December 1972 (12.12.1972) col 2, ln 23-34	28-29

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 March 2010 (17.03.2010)	23 APR 2010

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774