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(54) **Ballistic armor**

(57) A ballistic structure (10) comprising a front pellet layer (12a) configured to face a ballistic threat and rear pellet layer (12b) therebehind, each of the pellet layers (12a,12b) comprising a plurality of pellets (14), which can be made of a ceramic material, having cylindrical bodies with their height axes in both layers (12a,12b) being parallel to each other, the pellets (14) being arranged in a honeycomb pattern within a binder matrix, the pellet layers (12a,12b) being codisposed such that all interior spaces (i.e., spaces which are surrounded on all sides by pellets) of each pellet layer (12a,12b) are entirely overlapped by an area of the other pellet layer (12a,12b) that is free of such spaces, the two layers (12a,12b) being by an intermediate layer (13) having such a width and being made of such a material as to allow the rear layer (12b) to rigidly support the front layer (12a).

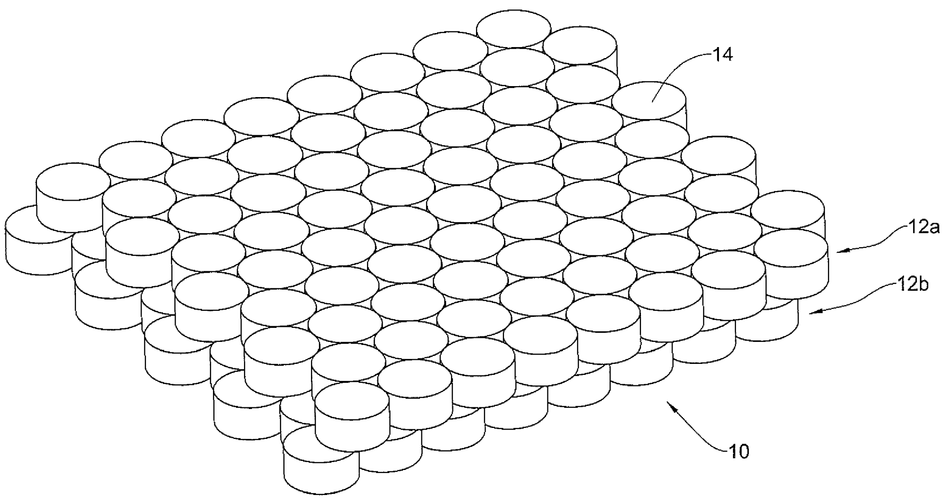

Fig. 1A

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Description

FIELD OF THE INVENTION

[0001] The present invention is directed toward composite ballistic armor, and especially to armor comprising layers of pellets made of high density material, to provide protection against incoming projectiles, for use as standalone armor or as add-on armor.

BACKGROUND OF THE INVENTION

[0002] Ballistic armor of the kind to which the present invention refers is disclosed, for example, in WO 2010/053611, and it comprises two armor layers of ceramic spheres, held within a matrix of polymeric material in order to distribute kinetic energy and momentum from the impact of a projectile across a greater area.

[0003] IL 163183 discloses another armor which comprises a plurality of longitudinal members in a tightly packed array, wherein the members are mutually spaced apart from one another forming a continuous gap in the array.

[0004] US 3,813,281 discloses a composite flexible armor comprising layers of rigid platelets separated by compressible foam material having gas cells therein. A high velocity projectile striking a platelet in one layer compresses and forces gas from the cells in the foam material to absorb and dissipate kinetic energy.

SUMMARY OF THE INVENTION

[0005] According to one aspect of the presently disclosed subject matter, there is provided a ballistic structure comprising a front pellet layer configured to face a ballistic threat and rear pellet layer therebehind, each of the pellet layers comprising a plurality of pellets, which can be made of a ceramic material, having cylindrical bodies with their height axes in both layers being parallel to each other, the pellets being arranged in a honeycomb pattern within a binder matrix, the pellet layers being co-disposed such that all interior spaces (i.e., spaces which are surrounded on all sides by pellets) of each pellet layer are entirely overlapped by an area of the other pellet layer that is free of such spaces, the two layers being by an intermediate layer having such a width and being made of such a material as to allow the rear layer to rigidly support the front layer.

[0006] Some of the pellets in each layer can be in contact with adjacent pellets of the same layer.

[0007] A majority of the pellets in each layer can be in contact with adjacent pellets of the same layer.

[0008] The pellets can comprise belts, so that each belt surrounds a corresponding pellet and configured for confinement thereof.

[0009] The belt member of the present invention may be made of a variety of materials so long as the belt member possesses a minimal amount of tensile strength, which is at least about 3 kg/mm^2. Possible materials include but are not limited to metal alloys such as Aluminum, Titanium and Steel alloys, composites such as glass, carbon and aramids, Kevlar™, high strength plastics such as Nylon, polycarbonates, and polyamids, High Density Poly-Ethylene (HDPE) within various resins, carbon fibers and the like. The various resins may include simple fabric, winded fabrics, or mats reinforcement resins.

[0010] The intermediate layer is configured to provide structural confinement to the front and rear layers.

[0011] The binder matrix can be rigid or flexible, in which case the entire structure can be flexible.

[0012] The distance between the pellets of each layer can be no greater than 0.3 mm.

[0013] The front and rear pellet layers, and the intermediate layer can be formed within a single binder matrix, or each of the front and rear pellet layers can be within a binder matrix separate from that which the other of the layers is within.

[0014] The ballistic armor can be formed such that the distance between the front and rear layers does not exceed 0.15 times the diameter of each pellet.

[0015] Centers of pellets in each of the pellet layers can overlap with points of contacts of pellets in the other of the pellet layers.

[0016] Each of the layers can be offset, relative to the other of the layers, along a row thereof by a distance equal to one half of the diameter of one of the pellets.

[0017] The intermediate layer can be made of ballistic fabric or metal or the material of said binder matrix.

[0018] The cylindrical bodies of the pellets can each have parallel height axes and be of the same diameter.

[0019] The binder matrix can be made of a thermoplastic material.

[0020] The pellets of the front pellet layer can be of a higher hardness than the pellets of the rear pellet layer.

[0021] The pellets can be made from a material selected from the group consisting of alumina, silicon carbide, boron carbide, ultra high-hardness steel, and cemented carbide.

[0022] The pellets can be made of a transparent material constituting a transparent ballistic structure. For example, the pellets can be made of a materiel selected from the group consisting of transparent soda-lime, transparent borosilicate, transparent aluminum oxide, transparent magnesium aluminum oxide (SPINEL), transparent sapphire and transparent aluminum oxynitride (ALON).

[0023] The binder matrix, configured for both attaching the pellet one to the other and for attaching the layers one to the other, can be made of a transparent material. For example, the binder matrix can be made of a termoset material selected from the group consisting of transparent polyurethane resin (PUR), transparent polyvinyl-butyral (PVB), phenoxy resin and phenolic resin, or of a thermoplastic material such as polycarbonates and polyamides.

[0024] The transparent ballistic structure can further comprising a backing layer made of materials selected from the group of termoset or thermoplastic as listed above. The material of the backing layer can be similar or different from that of the binder matrix.

[0025] According to another aspect of the presently disclosed subject matter, there is provided armor module comprising a ballistic structure as described above, and a casing, which can be rigid, enclosing the ballistic structure at least along sidewalls thereof extending between external surfaces of the module that are parallel to the pellet layers,

[0026] The casing can be made from a metal (such as aluminum) fiberglass, or Kevlar.

[0027] The armor module can further comprise at least one backing layer, which can comprise ballistic fabric. The ballistic fabric can be selected from the group consisting of aramid, fiberglass, and polyethylene,

[0028] The backing layer can comprise a hard layer, which can be made from a material selected from the group consisting of high-hardness steel, hard steel, aluminum, and titanium.

[0029] At least one sidewall of the casing can be formed with a projecting portion, wherein one of the front and rear pellet layers projects beyond the other and is accommodated within the projecting portion.

[0030] The height of the projecting portion can be substantially equal to that of the pellet layer accommodated therewithin.

[0031] The projecting portion can be formed such that its width is at least one half of the diameter of one of the pellets, and/or such that its width is no greater than three times the diameter of one of the pellets.

[0032] The ballistic structure can comprises semi-circular pellets disposed along edges of the front and rear pellet layers, wherein the edges are adjacent the sidewall formed with the projecting portion.

[0033] The armor module can be configured to defeat a WC projectile.

[0034] According to a further aspect of the presently disclosed subject matter, there is provided an armor assembly comprising a plurality of armor modules as describe above, wherein the modules are arranged such that projecting portions of adjacent modules overlap one another,

[0035] According to a still further aspect of the presently disclosed subject matter, there is provided a vehicle comprising a plurality of armor modules as described above.

[0036] According to a still further aspect of the presently disclosed subject matter, there is provided a vehicle comprising an armor assembly as described above.

[0037] According to a still further aspect of the presently disclosed subject matter, there is provided a vehicle comprising the transparent ballistic structure as described above.

[0038] One or more ballistic structures can constitute one or more windows of the vehicle.

[0039] One or more windows can be selected, for example, from the group consisting of side windows, back windows and turret windows.

[0040] According to a still further aspect of the presently disclosed subject matter, there is provided a flexible armor comprising a ballistic structure as described above, within a flexible enclosure.

[0041] The flexible armor can further comprise one or more flexible fabric layers between the rear pellet layer and the flexible enclosure.

[0042] The fabric layers can be sewn together and/or at least partially attached to each other by a flexible adhesive.

[0043] The flexible armor can further comprise at least one flexible hinge configured for bending the flexible armor between two adjacent rows thereof, which can facilitate bending of the flexible armor through 180°. The hinge can be made of a strip of flexible material attached to the two adjacent rows of each pellet layer. The hinges can be made of a fabric or elastomeric material, such as aramid, polyester, or rubber.

[0044] According to a still further aspect of the presently disclosed subject matter, there is provided a method for producing a ballistic structure as described above, the method comprising:

- providing a front fabric layer and plurality of pellets;
- arranging the front fabric layer in the form of a cavity having a generally horizontal bottom and generally vertical side walls;
- arranging some of the pellets in the cavity on the bottom to form a front pellet layer;
- arranging other of the pellets on top of the front pellet layer to form a rear pellet layer; and
- applying binder material to the pellets and the fabric layers in such a way (for example by heating and/or applying pressure to the binder matrix) so as to simultaneously form a matrix, which constitutes with the pellets the ballistic structure, and to bind the front layer thereto.

[0045] The method may further comprise introducing an intermediate layer between at least a portion of the front and rear pellet layers.

[0046] The method may further comprise providing a casing, wherein the front fabric layer is arranged within the casing.

[0047] The method may further comprise producing an armor module as described above.

BRIEF DESCRIPTION OF THE DRAWINGS

[0048] In order to understand the presently disclosed subject matter and to see how it can be carried out in practice, embodiments will now be described, by way of non-limiting examples only, with reference to the accompanying drawings, in which:

Fig. 1A is a schematic perspective view of a ballistic structure comprising two layers of pellets for use in a ballistic armor according to the presently disclosed subject matter;

Fig. 1B is a schematic plan view of the arrangement of pellets in the ballistic structure illustrated in Fig. 1A;

Fig. 1C is a schematic plan view of one layer of the ballistic structure illustrated in Figs. 1A and 1B;

Fig. 1D is a schematic side view of the ballistic structure illustrated in Figs. 1A and 1B, according to one example thereof;

Figs. 1E and 1F are schematic perspective and plan views, respectively, of according to one modification of the ballistic armor according to the presently disclosed subject matter.

Fig. 2 is a schematic perspective view of a pellet of the ballistic structure illustrated in Figs. 1A and 1B;

Fig. 3 is a schematic enlarged perspective view of a portion of the ballistic structure illustrated in Figs. 1A and 1B, shown with a projectile impinging thereupon;

Fig. 4 is a schematic perspective view of a vehicle with add-on armor according to the presently disclosed subject matter;

Fig. 5 is a schematic cross-sectional view taken along line V-V is Fig. 4;

Fig. 6 is a schematic perspective view of a vehicle with standalone armor according to the presently disclosed subject matter;

Fig. 7A through **7C** are alternative schematic cross-sectional views taken along line VII-VII is Fig. 6;

Fig. 8A is a schematic side cross-sectional view of an example of an armor module;

Fig. 8B is a schematic side view of an armor assembly made of several of the armor modules illustrated in Fig. 8A;

Fig. 8C is a schematic plan view of an arrangement of pellets within the armor module illustrated in Fig. 8A;

Fig. 9 is a schematic illustration of a person illustrating one placement of a body armor;

Fig. 10A is a schematic illustration of a body armor;

Fig. 10B is a schematic cross-sectional view of the armor illustrated in Fig. 10A;

Figs. 10C is a schematic top view of a pellet layer of a the body armor illustrated in Figs. 10A and 10B, according to a modification;

Fig. 10D is a schematic side view of the body armor illustrated in Figs. 10A and 10B, according to the modification illustrated in Fig. 10C; and

Figs. 11A through **11C** illustrate a method of producing the ballistic structure illustrated in Figs. 1A and 1B.

DETAILED DESCRIPTION OF EMBODIMENTS

[0049] As illustrated in Figs. 1A and 1B, there is provided a ballistic structure, which is designated by **10.** The structure **10** is shown as comprising two pellet layers **12a, 12b** (collectively referred to by **12**) of cylindrical pellets **14,** which will be hereinafter referred to as front and rear pellet layers, respectively. In Fig. 1B the rear layer **12b** is shown in broken lines. It should be noted that the structure **10** can comprise more than two pellet layers, at least two of which (not necessarily its rear and front layers) are configured as the pellet layers **12a** and **12b,** as described herein.

[0050] As best seen in Fig. 2, each of the pellets **14** is formed with a cylindrical portion **16** having a circular cross-section of a diameter, which is the same for all the pellets in both layers **12.** According to the example illustrated in Fig. 2, the cylindrical portion **16** constitutes the entire pellet **14** having flat (planar) front and rear ends **18a, 18b** flat; however, it will be appreciated that the pellets can be formed with other features, such as domed ends on one or both ends. Such a structure can be as disclosed, for example, in the Applicant's IL 169230, or any other suitable structure.

[0051] The pellets **14** can be made of any high density material used in ballistic protection, for example, against small-arms fire such as ball-type and armor-piercing projectiles, such as ballistic ceramics. Preferably the material can be alumina, silicon carbide. However, other material can be used, for example, the boron carbide, ultra high-hardness steel (UHH), cemented carbide (hard metal), or any other suitable material. The materials of the pellets **14** of the two layers can be different from each other. In particular, the pellets **14** of the front pellet layer **12a** can be harder than those of the rear pellet layer **12b.** However, it will be appreciated that the reverse can be the case, and the pellets both layers **12** can be made of the same material. In addition, while each layer **12** typically comprises pellets **14** made of a single material, each can comprise pellets made of different materials.

[0052] The two layers **12a** and **12b** of the pellets **14** can be held together in one common binder matrix or can each comprise its own matrix and be assembled, so that the pellets heights define a common thickness of the two layers. In any case, the two layers are held and/or assembled so as that their movement relative to each other is prevented at least in the directions perpendicular to their thickness direction.

[0053] The material of the matrix can be any suitable solid or flexible adhesive material, including, but not limited to, a plastic adhesive, including thermosetting and thermoplastic materials, such as for example, polyurethane, polyester, and epoxy.

[0054] The pellets **14** can be made of a transparent material, such as glass and held in a transparent binder matrix, allowing to obtain an essentially transparent ballistic armor structure for ballistic protection of those parts of armored vehicles where at least some amount of vision is required.

[0055] A transparent binder matrix, which can be made of a castable transparent polymer resin, can be used to adhere the pellets **14** to each other and to attach the armor and to a surface to be protected, such as, for example, a window of a vehicle.

[0056] In case the ballistic structure **10** is further provided with an intermediate layer between the layers **12a** and **12b,** as will be further described with reference to Fig.1D, the intermediate layer will also be made of a transparent material.

[0057] Each layer in the transparent ballistic structure as described above, can be produced, for example, in accordance with "Pellets-in-PUR (polyurethane resin)" concept, as described by Carton and Brooks in "Innovative Transparent Amour Concepts" (26th International Symposium on Ballistics, Miami, FL, September 12-16, 2011).

[0058] The transparent ballistic armor further comprises a transparent backing layer, made of a material similar or different of that of the binder matrix.

[0059] The transparent ballistic structure can be a stand-alone product configured to replace an existing transparent surface.

[0060] Although the pellets of each layer are shown to be in contact with each other, it will be appreciated that this does not necessarily need to be the case.

[0061] The pellets **14** can be coated, e.g., with a material improving their adhesion to the matrix (such as for example the primer as disclosed in the Applicant's IL 169230) or to provide the pellets with some other desired properties.

[0062] Each pellet **14** can be formed as a core surrounded by a belt member **81** configured for confining the pellet and made of a rigid material different from that of the core.

[0063] The belt member **81** mounted on the pellets **14,** as shown in Figs. 1E and IF. The belt member **81** is a thin-walled tube whose circular inner and outer perimeters conform to the shape of the pellet **14.** Each belt member **81** surrounds one pellet **14** to form a single unit **83.** The units **83** are arranged in each layer of the armor as described above, with the belt members being in direct contact with each other. Examples of possible forms of belt members are described in detail in the Applicant's. EP 1363101 and their description, together with the description of the armor including such belt members, is incorporated herewith by reference.

[0064] It will be appreciated that in the above described arrangements, and other similar arrangement wherein the pellets **14** or the pellet units (each including a pellet and a belt member mounted thereon as described above) are designed to be in contact with adjacent pellets or pellet units, respectively, should be considered as 'being in contact' even though they are not in direct contact each with another, as an artifact of the manufacturing process.

[0065] The pellets are arranged to form a "honeycomb" pattern, wherein most of the pellets **14** (expect for those on the periphery) are surrounded by six adjacent pellets. As illustrated in Fig. 1C, when arranged in the "honeycomb" pattern, the pellets **14** form three sets **19, 20** and **21** of parallel rows **19a, 19b, ... 19n; 20a, 20b, ... 24n;** and **21a, 21b, ... 21n,** respectively, each of which defines with the rows of other sets an angle of 60°.

[0066] With reference to Figs. 1B and 1C, the pellet layers **12a** and **12b** are codisposed such that, in the plan view of the ballistic structure, each layer is offset, relative to the other layer, along the rows of the set **20** thereof by a distance equal to that of half of the diameter of a pellet **14.** It will be appreciated that the term "offset" when used herein the specification and claims refers to an arrangement of two identical layers, wherein one has been translated from a position wherein elements of each the layer lie in full registration with corresponding elements of the other.

[0067] With this arrangement, though the rows of set **20** of the rear layer are fully aligned with the rows of set **20** of the front layer, the pellets **14** in these rows in one of the layers are offset as described above, relative to the pellets **14** of these rows in the other layer, the rows of the sets **19** and **21** of the one of the layers being thus off-set relative to the corresponding rows of the other. Staggering the front and rear layers **12a** and **12b** as described above results in points of contact **24** between adjacent pellets **14** in the rows of the set **20** in one of the layers overlapping centers **26** of the pellets in the corresponding rows in the other layer (it will be appreciated that as in the plan-view depiction of Fig. 1B, the points of contact **24** are coincident with the centers **26,** both reference numerals are directed toward the same point in the figure); whilst points of contact of the pellets **14** in the rows of each one of the sets **19, 21** in one of the layers overlap with the points of contact of the pellets in the rows in the other set **21, 19** of the other layer.

[0068] The above described arrangement ensures that all spaces **22** between adjacent pellets **14** of each pellet layer are overlapped by the area of the other layer that is free of such spaces.

[0069] As shown for example in Fig. 1D, the pellets of the layers **12a** and **12b** can be spaced by an optional intermediate layer **13** or by the material of the binder matrix. The intermediate layer can be constituted by one or several plies of a material different from the material of the pellets and of the binder matrix, e.g., a fabric material such as aramid or fiberglass, and/or by a metal layer such as aluminum.

[0070] The intermediate layer **13** can support the front and rear pellet layers **12a, 12b,** for example by providing structural confinement. In addition, it can reduce shockwave propagation between the front and rear pellet layers **12a, 12b.**

[0071] With the thickness of the intermediate layer **13** being $\boldsymbol{S}$ (Fig. 1D), advantageous results have been obtained with $0 < \boldsymbol{S} \leq 0.3\boldsymbol{D}$, in particular $0.1\boldsymbol{D} \leq \boldsymbol{S} \leq 0.3\boldsymbol{D}$. With such thickness, the intermediate layer, on the one hand, provides close disposition of the two layers to one another allowing the rear layer **12b** to rigidly support the front layer **12a,** and on the other hand, can still provide the above structural confinement of the layers. It will be appreciated that the terminology "rigidly supporting", when used herein the specification and claims (for example to describe the relationship between the rear armor layer **12b** vis-à-vis the front hard armor layer **12a**), indicates that any displacement of the supported layer toward the supporting layer resulting from the impact of a projectile is resisted by the supporting layer, or that the supporting layer is displaced in tandem therewith (however, due at least in part to the disposition of the pellets **14** in the different layers, the movement of pellets due to displacement of each of the layers **12** will differ from one another).

[0072] The ballistic structure **10** as described above can provide a high degree of ballistic protection, with a relatively low weight. For example, it can provide a degree of protection equal or similar to that provided by a similarly designed armor having a single layer of pellets, while having a weight per unit area which is about 80%-90% thereof. In particular, it has been surprisingly uncovered that, to provide the same degree of protection in an armor having such single layer of pellets, the pellets need to have a height greater than the total height the two layers described above.

[0073] In addition, the ballistic structure **10** can provide protection not available when a single layer of pellets is used. In such single layer structure, as illustrated in Fig. 3, an impinging projectile **28,** which can be, e.g., of a ball-type or comprising a material that is harder than that from which the pellets are made, which strikes the ballistic structure **10** having spaces **22** between adjacent pellets **14** can at least partially penetrate the front pellet layer **12a.** For example, a WC (tungsten carbide) projectile, which is harder than some ceramics used to manufacture ballistic pellets, striking one of the spaces **22** of the front pellet layer **12a,** can penetrate and/or produce spall which would penetrate therethrough. In addition, a deformable lead-core projectile striking one of the spaces **22** of the front pellet layer **12a** can deform and penetrate the layer via the space. By providing the rear pellet layer **12b** positioned in relation to the front pellet layer **12a** as described above, penetrations, *inter alia* as described above, are fully protected against.

[0074] The ballistic structure **10** as described above with reference to Figs. 1A through 3 is normally to be utilized as a part of an armor module which further comprises at least a backing layer, so that the structure **10** is directed to break or at least shatter incoming projectiles, whilst the backing layer is directed to stop its fragments from reaching a body to be protected. As will be described below, the armor module can further comprise at least one front layer made of a ballistic material, such as high-hardness steel or a ballistic fabric such as aramid, polyethylene, fiberglass, or any other suitable material. Alternatively or additionally, the module can comprise a wrapping made of a flexible material as listed above, or a rigid casing made for example of metal, which tightly holds all layers of the armor together.

[0075] It will further be appreciated that although the ballistic structure **10** is described above as comprising individual pellets **14,** the pellet layers **12** may be constructed using various other structures which give rise to protected areas surrounded by spaces, without departing from the scope of the presently disclosed subject matter, *mutatis mutandis.* Examples of such armor are described, for example, in EP 2 023 072, and in PCT application PCT/EP10/058520.

[0076] The ballistic structure **10** can be utilized as part of an add-on armor. As illustrated in Fig. 4, one or more add-on armor modules **30** can be mounted on a vehicle **32** to protect it from ballistic threats. The add-on armor modules **30,** together with the sidewall of the vehicle to be protected thereby, are designed to defeat one or more known ballistic threats. Thus, when designing the add-on armor module **30,** relevant parameters, including material, thickness, etc., of the sidewall of the vehicle are taken into account.

[0077] As illustrated in Fig. 5, the add-on armor module **30** comprises a ballistic structure **10** as described above with reference to Figs. 1 through 3 within a casing **34.** The casing **34** can be made of any suitable material, such as aluminum, fiberglass, or Kevlar. A fabric layer can be provided in front of the front pellet layer **12a** of the ballistic structure (henceforth referred to a front fabric layer **36**), between the front and rear pellet layers **12a, 12b,** and/or behind the rear pellet layer **12b.** The front fabric layer **36** can at least partially wrap around the other layers within the casing **34,** e.g., extending along the sides of the structure and partially covering its rear. Binder matrix material can permeate at least some of the fabric layers. The fabric layers can be made of any suitable ballistic fabric, including, but not limited to, aramid, polyethylene, and fiberglass. In addition, a backing **44,** e.g., made of fabric layers such as aramid, fiberglass or polyethylene, or of metal such as steel, aluminum, titanium, can be provided behind the pellet layers **12.** A metal casing cover **37,** for example made of the same material as is the casing **34,** can be provided at the rear end of the add-on armor module **30.** The metal casing cover **37** can be provided for constructional purposes (e.g., to keep the module planar) and/or to protect the module from adverse environmental conditions, and does not need to significantly contribute to the ballistic performance of the module **30.**

[0078] It will be appreciated that the add-on armor module **30** as described above with reference to Figs. 4 and 5 can be used in conjunction with an additional liner (not illustrated) attached to the inside of the vehicle directly behind the armor, in order to stop fragments and deformed projectiles from entering the vehicle.

[0079] It will be appreciated that in the accompanying figures, different layers are represented by different types of lines of varying thicknesses. However, the thicknesses of these lines do not necessarily correspond to the thicknesses of the layers which they represent. Thus, for example, several fabric layers can be represented in the accompanying figures by several spaced apart lines, which total thickness approaches that of the ballistic structure, which in reality the ballistic structure can be much thicker than the fabric layers.

[0080] Alternatively, the ballistic structure **10** as described above with reference to Figs. 1 though 3 can be utilized as part of a standalone armor. As illustrated in Fig. 6, one or more standalone armor modules **38** can be mounted on a vehicle frame **40** to assemble a vehicle, designated by **42,** protected from ballistic threats. The standalone armor modules **38** are designed to defeat one or more known ballistic threats.

[0081] As illustrated in Figs. 7A through 7C, the standalone armor module **38** is designed similarly to the add-on armor module described above with reference to Fig. 5. In particular, it comprises a ballistic structure **10** as described above with reference to Figs. 1 through 3 within a metal casing **34.** The casing **34** can be made of any suitable material, such as aluminum. A front fabric layer **36** can be provided in front of the front pellet layer **12a** of the ballistic structure. In addition, a backing **44,** which contribute to the overall ballistic performance of the standalone armor module **38,** are provided behind the rear pellet layer **12b.**

[0082] Binder matrix material can permeate the backing **44.** The fabric layers can be made of any suitable ballistic fabric, including, but not limited to, aramid, polyethylene, and fiberglass.

[0083] As illustrated in Fig. 7A, the backing **44** can be constituted by several fabric backing layers **46.** The fabric backing layers **46** can be made of any suitable ballistic fabric, including, but not limited to, aramid, polyethylene, and fiberglass. As illustrated in Fig. 7B, the backing **44** can be constituted by one or more hard metal layers **48.** The hard metal layers **48** can be made of aluminum, high-hardness steel, titanium, or any other suitable material. As illustrated in Fig. 7C, the backing **44** can be constituted by a combination of both the fabric and hard armor metal layers **46, 48.** The number and/or thickness of the backing **44** is to be determined by the designer based on the ballistic requirements of the standalone armor module **38,** such that the module can, by itself, defeat the ballistic threat for which it is designed.

[0084] As illustrated in Fig. 8A, both the add-on armor module **30** and standalone armor module **38** can be formed at one or more side edges **50** thereof with a projecting portion **52** disposed adjacent and level with one of the pellet layers **12** of the ballistic structure **10** within the module. (It will be appreciated that the representation of the ballistic structure in Fig. 8A is schematic, and that it may be provided according to any example of the presently disclosed subject matter, including, but not limited to, those described with reference to any one of Figs. 5 and 7A through 7C.) The projecting portion **52** constitutes the top or bottom portion of the sidewall **50,** being in fact a continuation of one of the layers **12** projecting past the other layer, in the plan view of the module. The projecting portions **52** allow several modules **30, 38** to be conveniently arranged side-by-side as illustrated in Fig. 8B to form an assembly **75,** which can constitute at least a portion of a vehicle sidewall, and/or can allow modules to be replaced easily. It also ensures complete ballistic coverage in the area wherein adjacent modules 30, **38** border one another by providing for an overlap between front and rear pellet layers **12a, 12b** of adjacent modules. It is formed so as to accommodate the ballistic structure **10** when formed with one of the pellet layers **12** projecting farther than the other at least one edge thereof, as illustrated in Fig. 8C. The projecting portion **52** can be made of incomplete pellets **56** having the same height as the pellets **14** of the layer of which it constitutes a continuation, in order to provide continuous coverage. The incomplete pellets **56** can be semi-circular, having a circular side facing adjacent pellets of the corresponding layer, and a straight side facing to the exterior of the layer.

[0085] The width ***W*** of the projecting portion **52** in the plan view of the structure **10** can be no less than about half the diameter of a pellet **14,** e.g., when made of semi-circular pellets, and can be up to about three times the diameter of a pellet, although it can be even wider. In any event, the width ***W*** of the projecting portion **52** should be designed so as to support an arrangement of modules **30, 38** as illustrated in Fig. 8B.

[0086] Providing modules **30, 38** such as described above provides several advantages. For example, the armor assembly **75** can be assembled to any desired size from prefabricated parts, In addition, in the event that several pellets are damaged, e.g., due to impact of projectiles, the module containing the damaged pellets can be easily replaced, without having to replace the entire assembly.

[0087] The ballistic structure **10** can be used as part of a flexible body armor. As illustrated in Fig. 9, a body armor is designed to protect vital organs **58** of a wearer, and as such should cover at least the area indicated by **60.** In addition, such an armor should maintain a degree of flexibility in order to accommodate changes in the shape of the torso of the wearer, for example due to crouching, to accommodate firing/shooting position of the wearer, and other movements of the wearer.

[0088] As illustrated in Figs. 10A and 10B, a flexible body armor **62,** e.g., for use in a personal bullet-proof vest, is provided comprising a flexible enclosure **64** containing therewithin ballistic structure **10** as described above with reference to Figs. 1 through 3 and a fabric layer **66.**

[0089] The flexible enclosure **64** can be formed as a sack of dimensions suitable to accommodate therewithin the ballistic structure **10** and fabric layer **66,** as well as any other layers or elements which can be provided. It can be made of any suitable material which provides ballistic protection, such as aramid. Alternatively, it can be made of a material which offers no ballistic protection, such as polyester, cotton, etc. Appropriate accessories (not illustrated), such as snaps, buttons, straps, etc., can be provided in order to fasten, adjust, etc. the body armor **62** on the wearer.

[0090] The pellet layers **12** of the ballistic structure **10** can be free to change shapes relative to one another, e.g. when bended, without moving parallel to each other. Such an arrangement imparts flexibility to the layers.

[0091] This can be accomplished by providing them substantially free of bonds directly therebetween (they may, however, be attached along at least portions of their peripheries, and/or they can be both attached to a single element along at least a portion of their peripheries). Such an arrangement allows the pellet layers **12** to remain adjacent one another while remaining flexible. This can also be accomplished by attaching them together at select portions of their adjacent surfaces. For example, the pellet layers **12** can be connected to one another along a line running along a centerline thereof. Although the areas of the pellet layers **12** which are close to the point or area of attachment have limited movement with respect to one another, overall, the ballistic structure **10** can together retain a high degree of flexibility.

[0092] In addition, the binder matrix is made out of a flexible material.

[0093] As such, and as illustrated in Fig. 10A, the body armor **62** is configured to bend about several axes **68,** which imparts an overall flexibility suitable therefor, as described above.

[0094] The fabric layer **66** can comprise a plurality of sub-layers **70** of ballistic fabric. The ballistic fabric can be aramid, polyethylene, fiberglass, or any other suitable material. The sub-layers **70** can be sewn together and un-pressed, in order to maintain a high degree of flexibility of the fabric layer **66.**

[0095] According to a modification illustrated in Figs. 10C and 10D, the body armor **62** can be provided with flexible hinges **65,** for example if the binder matrix does not provide sufficient flexibility, for example along axis **67.** Fig. 10C illustrates a pellet layer **12** with the footprints of hinges **65** attached thereto indicated by their outlines; the footprint of the hinge attached to the front side of the pellet layer (and its associated axis) being indicated by a solid line (and being slightly elongated for clarity), and the footprint of the hinge attached to the rear side of the pellet layer (and its associated axis) being indicated by a broken line.

[0096] The hinges **65** can be made of a flexible material, for example a fabric such as aramid or polyester, or an elastomer such as natural or artificial rubber, or of any other suitable material. The flexible material of the hinges can be more flexible than the binder matrix. According to the illustrated example, each hinge comprises a strip of material attached to ends of two adjacent rows of pellets **14.** Such an arrangement can allow bending of the body armor **62** through an angle up to 180° (i.e., the final disposition of the two adjacent rows represents a rotation of 180° from the original, un-bended, disposition thereof). In the event, for example, that the hinges **65** are made out of an elastomeric material, the hinges can allow bending up to 180° in one direction, and somewhat in the other direction. The degree of bending allowed in the other direction depends on a several factors including, but not limited to, the material of the hinge **65** and the distance between adjacent pellets **14** in the pellet layer **12..**

[0097] In order to facilitate bending of the ballistic structure **10,** hinges **65** can be provided in corresponding rows in adjacent pellet layers **12,** i.e., a hinge can be provided on rows of the rear pellet layer **12b** below those on which a hinge is provided on the front pellet layer **12a,** in order to allow both pellet layers to bend together, such as illustrated in Fig. 10D.

[0098] A single row of pellets **14** can be attached to a hinge **65** on its front and rear sides, with the front-facing hinge being attached to an adjacent row on one side thereof, and the rear-facing hinge being attached to an adjacent row on the other side thereof. It will be appreciated that the binder matrix between adjacent rows of pellet **14** attached to a single hinge **65** can be broken or weakened to allow for the bending.

[0099] The hinges **65** can be attached during formation of the pellet layers **12** or thereafter.

[0100] It will be appreciated that an armor similar in design to the body armor **62** can be provided in shapes which make it suitable for other uses, such as wrapping part of vehicles or articles to provide ballistic protection therefor.

[0101] The ballistic structure **10** can be manufactured as follows:

[0102] The pellets **14** are prepared by cleaning with a surface preparation chemical agent. They are then coated with one or more coats of primer, such as Silan, or any other suitable bonding agent. The coating can be accomplished by spraying the pellets **14** with the primer, or by immersion thereof in a bath of the primer. The spraying can be accomplished by standing the pellets **14** on their rear ends **18b,** spraying the primer thereon, and allowing them to dry. This coats all surfaces except the rear ends **18b.** When the pellets **14** are later arranged for production with their rear ends facing upward, as described below, the primer is applied to the rear ends **18b,** thereby ensuring that the entire surface of each pellets **14** is coated therewith. Alternatively, the entire surface of the pellets **14** can be coated prior to their arrangement for production. The primer can be applied manually or in an automated fashion.

[0103] A non-limiting description of a process which can be employed for manufacturing armor as above will be presented below with reference to Figs. 11A through 11C.

[0104] As illustrated in Fig. 11A, a mold **72,** which can be made of aluminum or other similar material, is provided, having dimensions corresponding to those of the armor module **30, 38** or body armor **62.** A cover **74,** associated with the mold, can be provided. It has dimensions which are slightly smaller than those defined by the interior of the mold **72.** A front fabric layer **36** is optionally arranged in a generally horizontal position within the casing **34** and the mold **72,** and the edges thereof are arranged along sidewalls thereof, defining a cavity **76.** As seen in Fig. 118, the pellets **14** are arranged within the cavity **76** in a honeycomb arrangement to form the front pellet layer **12a.** The sidewalls of the mold **72** are shifted until the pellets **14** are tightly packed. In the event that an armor module is being manufactured with a projecting portion **52** as described above with reference to Figs. 8A through 8C, incomplete, e.g., semi-circular, pellets are provided as necessary. The pellets can be placed in the mold as part of a semi-fabricated layer, for example as disclosed in the Applicant's IL 182511.

[0105] Binder material in powder or liquid form is introduced in the mold **72** to fill the gaps between the pellets and fully cover them, including the planar rear ends **18b** thereof. The binder matrix is adapted to bind the pellets **14** to each other and to the adjacent layers.

[0106] As seen in Fig. 11C, the optional intermediate layer **13** can be applied to the rear ends **18b** of the pellets **14.** In the event that the pellets **14** are formed with planar rear ends **18b,** and if the intermediate layer **13** is provided as a fabric layer, it can be easily and smoothly applied to the pellet array. This provides a better attachment of the intermediate layer **13** to the rear ends **18b** of the pellets **14,** thereby increasing the confinement therebetween, which increases the ballistic protection.

[0107] Subsequently, the rear pellet layer **12b** is formed on top of the intermediate layer **13** (if no intermediate layer is provided, then the rear pellet layer is formed immediately on top of the front pellet layer **12a**). In the event that one or more fabric backing layers are provided, suitable ballistic fabric is provided on top of the rear pellet layer **12b,** similar to that described with reference to the intermediate fabric layer **13.** If a backing **44** is provided, it is placed above the rear pellet layer **12b.**

[0108] Each of the fabric layers, if provided, can be pre-impregnated with the binder matrix.

[0109] As seen in Fig. 11C, if a front fabric layer **36** is provided, the edges thereof are wrapped around all of the layers above it. The casing cover **37** is placed on top. The cover **74** is placed at the rear. Heat and pressure are then applied by a press (not shown), which melt and press the powder, forming thereby the ballistic structure **10,** along with any other layers provided therewith. The cover **74** can be used to distribute the pressure the pellets. Alternatively, the entire mold with the pellets can be covered with a plastic bag and placed inside an autoclave (not shown). In the event that the binder material is a thermoset, and was therefore introduced as a liquid, enough heat and pressure needs to be applied to cure the binder material.

[0110] The heating expands the mold **72,** which allows the pellets **14,** which heretofore have been held in contact with one another, to separate slightly by the binder material, whether a thermoplastic or thermoset, at this stage in liquid form, drawn by the primer in-between the pellets **14.** When the binder material solidifies, there is produced a gap of 0.1 and 0.3 mm between adjacent pellets **14** at their closest points. This gap contains the primer and the binder material. The presence of the binder between adjacent pellets **14** improves ballistic protection of the armor upon impact by a projectile and lessening the effect of shattering pellets on those adjacent thereto.

[0111] It will be appreciated that the method of manufacture described above with reference to Figs. 11A through 11C can be modified when producing the ballistic structure **10** for use as part of a personal armor **62,** for example as follows:

- Only the layers **12** of the ballistic structure **10** are manufactured as described above. The fabric layers **66** of the personal armor **62** are added later.

- After pellets **14** are arranged within the mold **72** to form the front pellet layer **12a,** the binder material is introduced, then a plastic separation layer (not illustrated) is placed thereupon before pellets are arranged thereabove to form the rear pellet layer **12b.** The plastic separation layer serves to maintain the front and rear pellet layers **12a, 12b** separate from each other. Binder material is then applied to the rear pellet layer **12b,** and the cover **74** is placed thereupon.

[0112] The processes described above can be modified by manufacturing each pellet layer **12** separately.

Claims

1. A ballistic structure comprising a front pellet layer configured to face a ballistic threat and rear pellet layer therebehind, each of said pellet layers comprising a plurality of pellets having cylindrical bodies with their height axes in both layers being parallel to each other, the pellets being arranged in a honeycomb pattern within a binder matrix, said pellet layers being codisposed such that all interior spaces of each pellet layer are entirely overlapped by an area of the other pellet layer that is free of such spaces, the two layers being spaced by an intermediate layer having such a width and being made of such a material as to allow the rear layer to rigidly support the front layer.

2. A ballistic structure according to Claim 1, wherein some of said pellets in each layer are in contact with adjacent pellets of the same layer or a majority of the pellets in each layer are in contact with adjacent pellets of the same layer.

3. A ballistic structure according to Claims 1 or 2, wherein said intermediate layer is configured to provide structural confinement to the front and rear layers.

4. A ballistic armor according to Claims 1 to 3, wherein said pellets are made from a ceramic material.

5. The ballistic structure according to any one of the preceding claims, wherein centers of pellets in each of said pellet layers overlap with points of contacts of pellets in the other of said pellet layers and optionally each of said layers is offset, relative to the other of said layers, along a row thereof by a distance equal to one half of the diameter of one of the pellets.

6. The ballistic structure according to any one of the preceding claims, wherein said intermediate layer is made of ballistic fabric or metal or the material of said binder matrix.

7. The ballistic structure according to any one of the preceding claims, wherein the pellets are made of a transparent material and the binder matrix is made of a transparent material.

8. An armor module comprising a ballistic structure according to any one of the preceding claims, and further comprising a casing enclosing said ballistic structure at least along sidewalls thereof extending between external surfaces of the module that are parallel to the pellet layers, wherein the casing is optionally rigid, optionally made from a metal, fiberglass, or Kevlar, more optionally the metal is aluminum; the armor module optionally further comprising at least one backing layer, the backing layer optionally comprising ballistic fabric, the ballistic fabric being optionally selected from the group consisting of aramid, fiberglass, and polyethylene, said backing layer optionally comprising a hard layer, said being optionally made from a material selected from the group consisting of high-hardness steel, hard steel, aluminum, and titanium.

9. An armor assembly comprising a plurality of armor modules according to Claim 8, wherein said modules are arranged such that projecting portions of adjacent modules overlap one another,

10. A vehicle comprising at least one of the following: one or more ballistic structures according to Claims 1 to 7, a plurality of armor modules according to Claim 8, an armor assembly according to Claim 9,

11. A method for producing a ballistic structure according to any one of Claims 1 through 7, the method comprising:

● providing a front fabric layer and plurality of pellets;
● arranging the front fabric layer in the form of a cavity having a generally horizontal bottom and generally vertical side walls;
● arranging some of said pellets in the cavity on the bottom to form a front pellet layer;
● arranging other of said pellets on top of said front pellet layer to form a rear pellet layer; and
● applying binder material to the pellets and the fabric layers in such a way so as to simultaneously form a matrix, which constitutes with the pellets said ballistic structure, and to bind the front layer thereto.

12. A method according to Claim 11, wherein the matrix is formed by heating and/or applying pressure to the binder matrix.

13. A method according to any one of Claims 11 or 12, further comprising introducing an intermediate layer between at least a portion of the front and rear pellet layers.

14. A method according to any one of Claims 11 through 13, further comprising providing a casing, wherein said front fabric layer is arranged within said casing.

15. A method according to Claim 14 further comprising producing an armor module according to Claim 8.

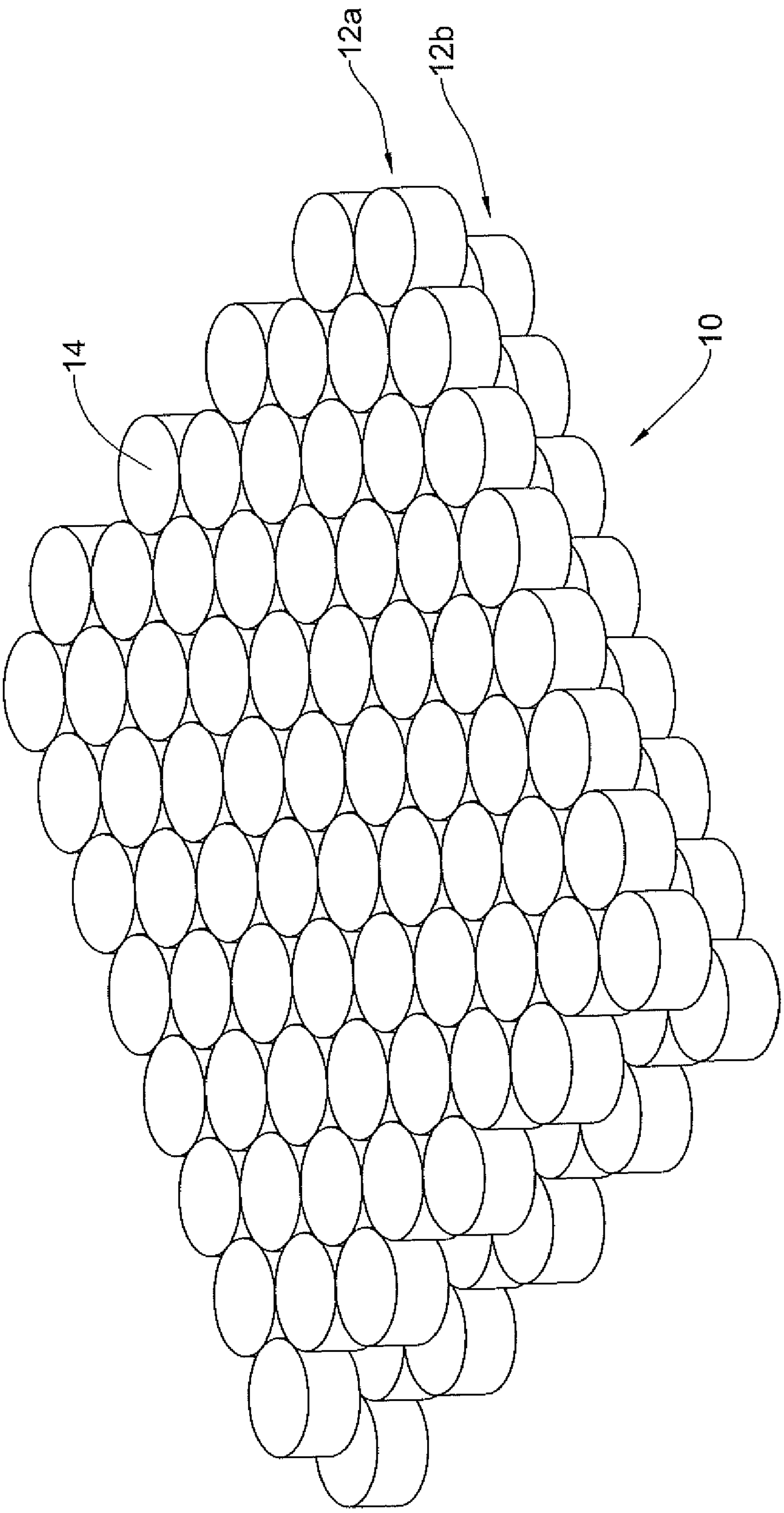

Fig. 1A

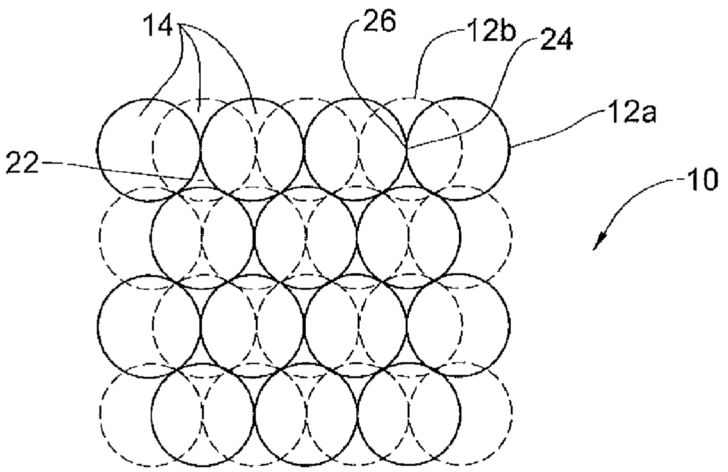

FIG. 1B

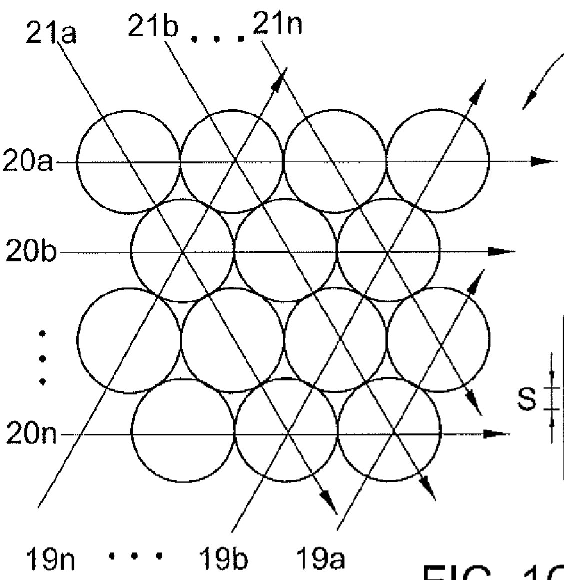

FIG. 1C

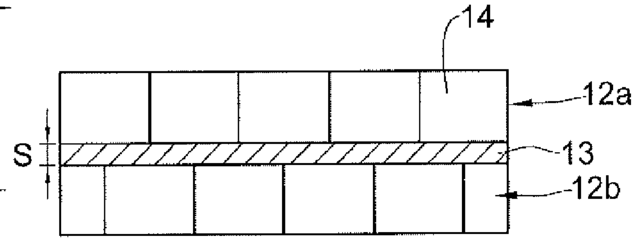

FIG. 1D

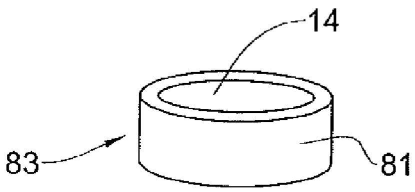

FIG. 1E

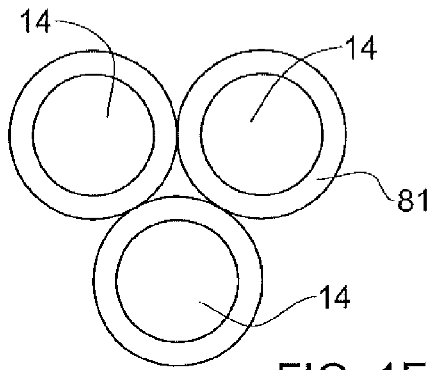

FIG. 1F

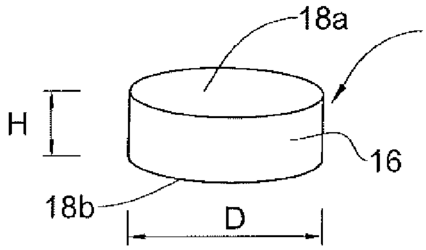

FIG. 2

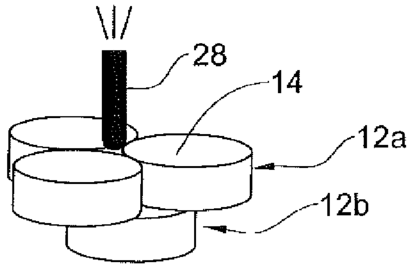

FIG. 3

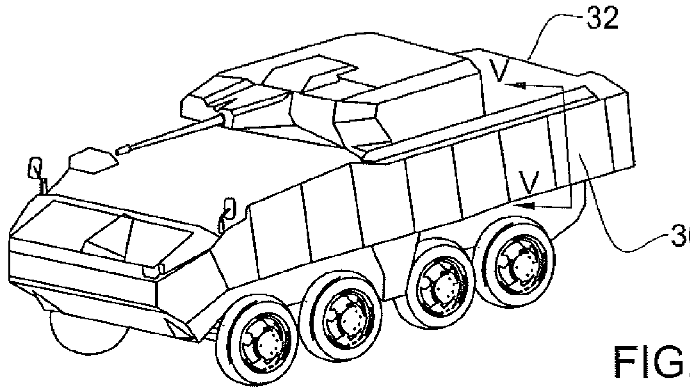

FIG. 4

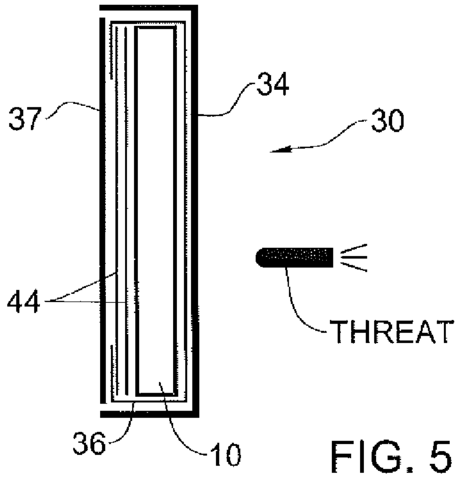

FIG. 5

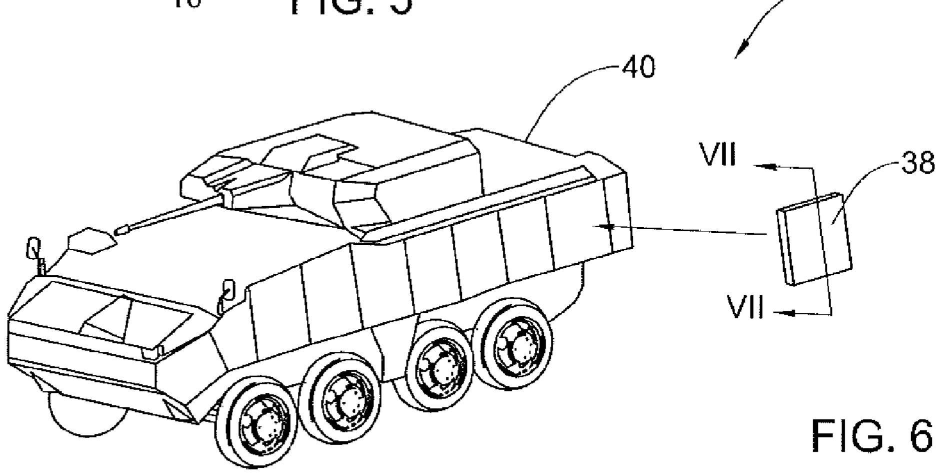

FIG. 6

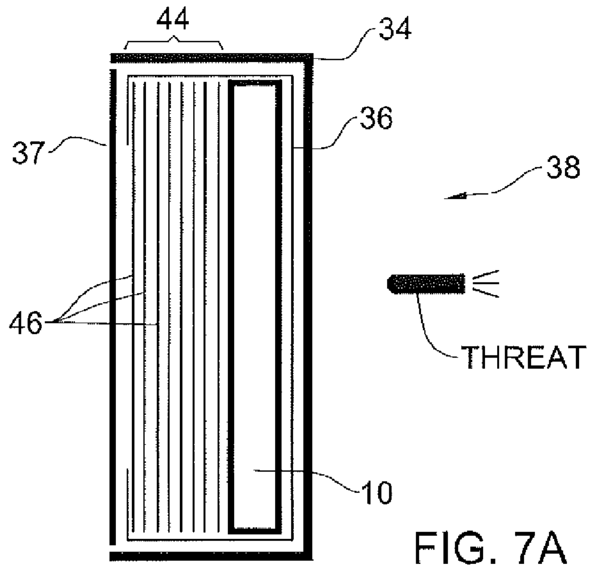

FIG. 7A

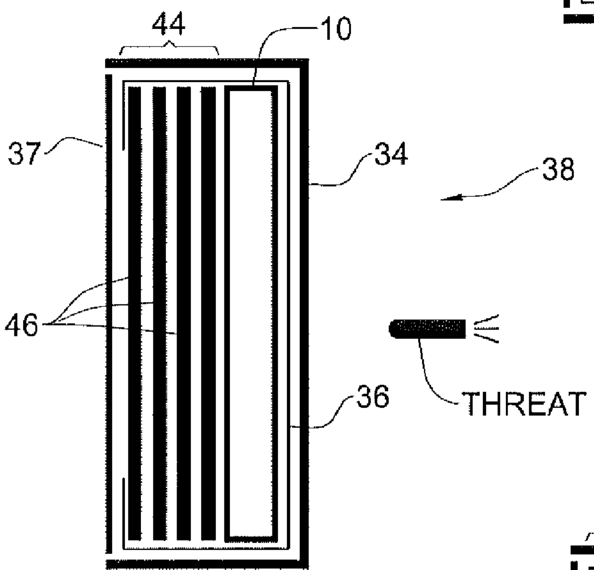

FIG. 7B

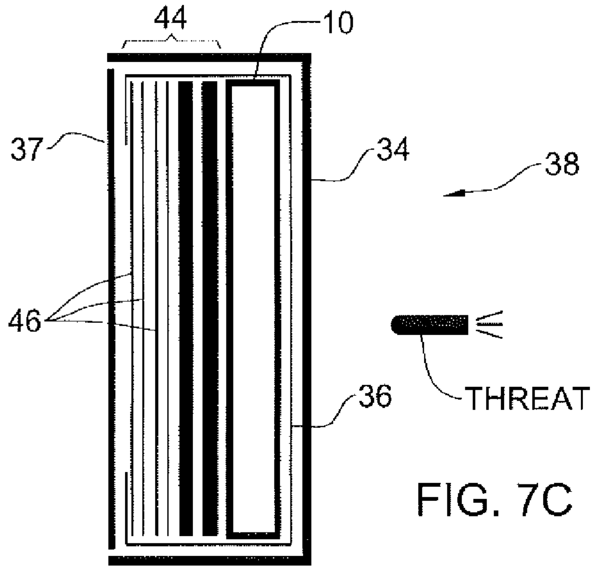

FIG. 7C

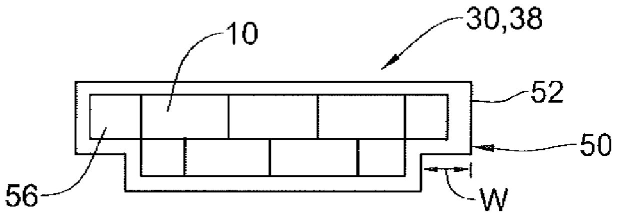

FIG. 8A

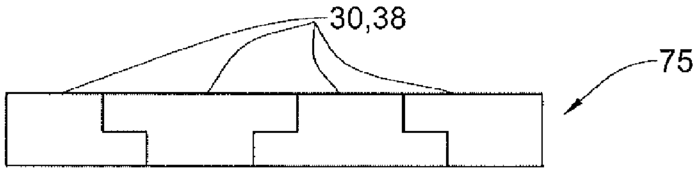

FIG. 8B

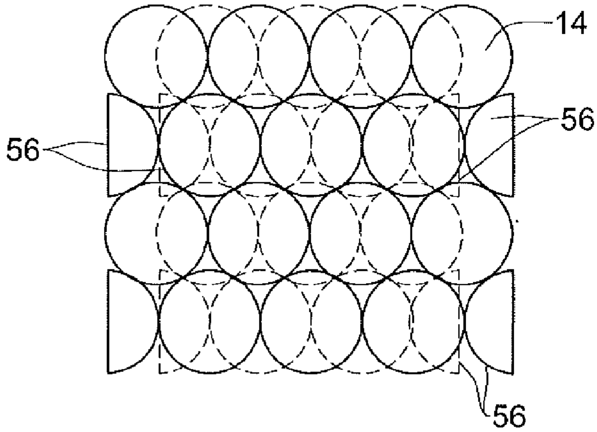

FIG. 8C

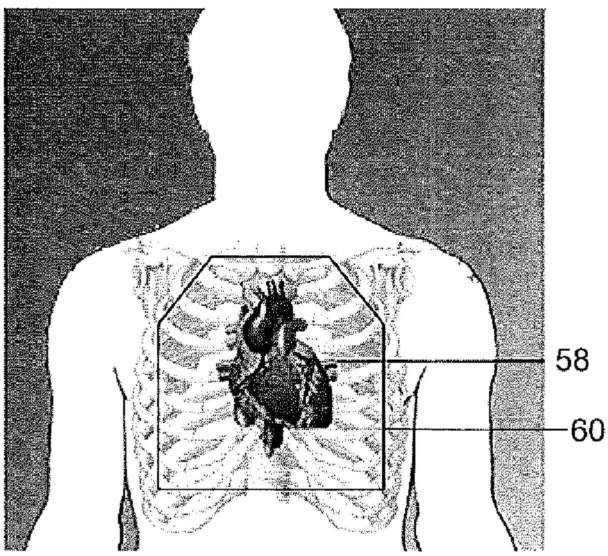

FIG. 9

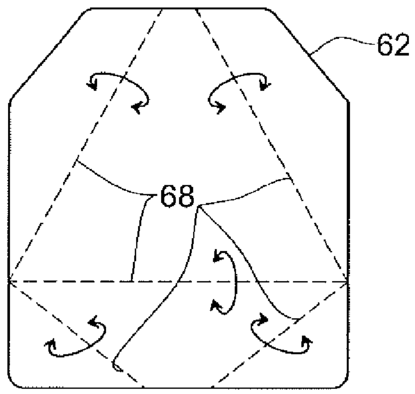

FIG. 10A

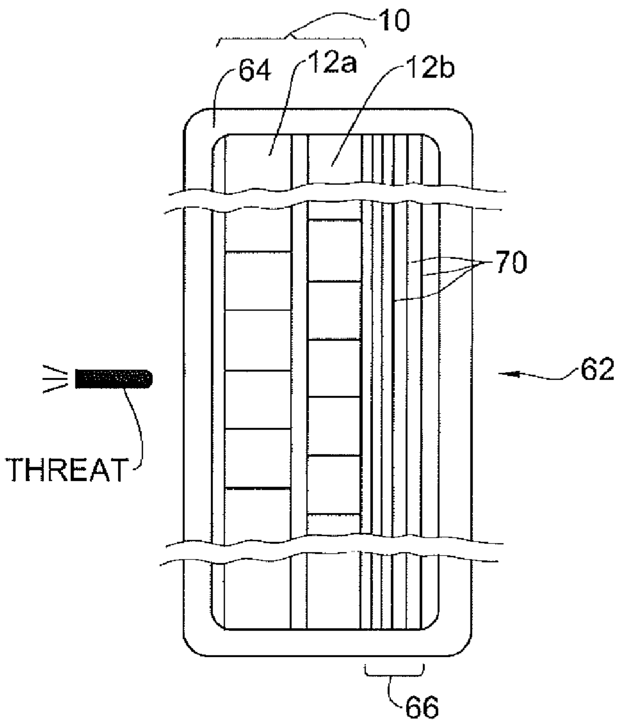

FIG. 10B

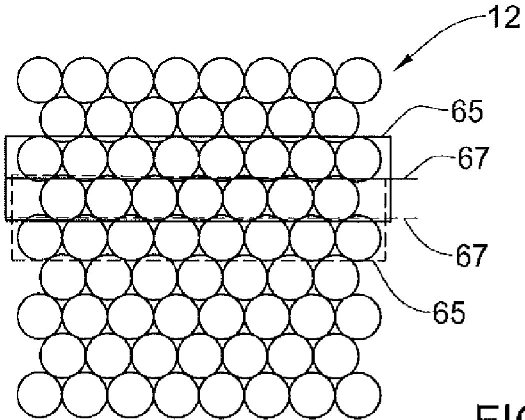

FIG. 10C

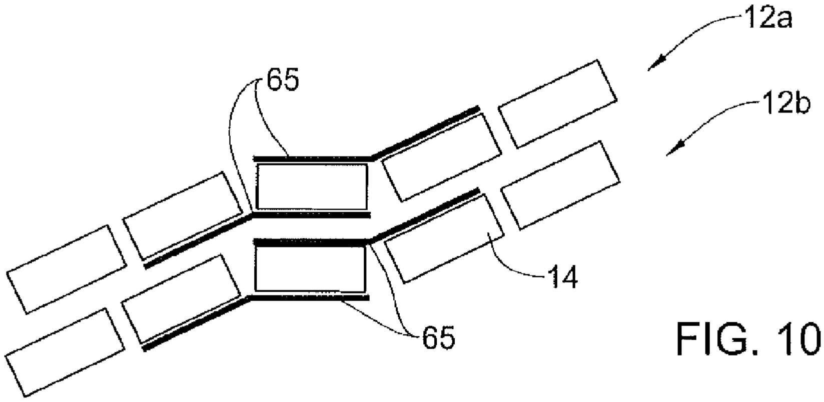

FIG. 10D

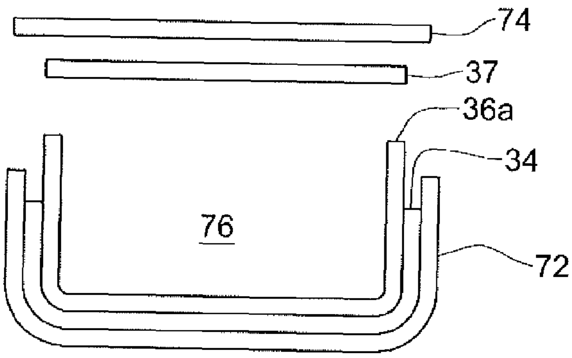

FIG. 11A

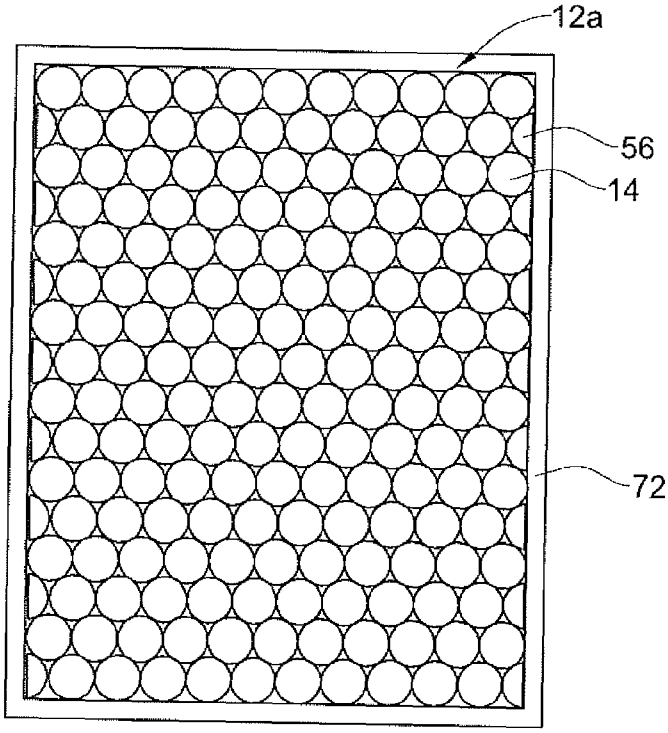

FIG. 11B

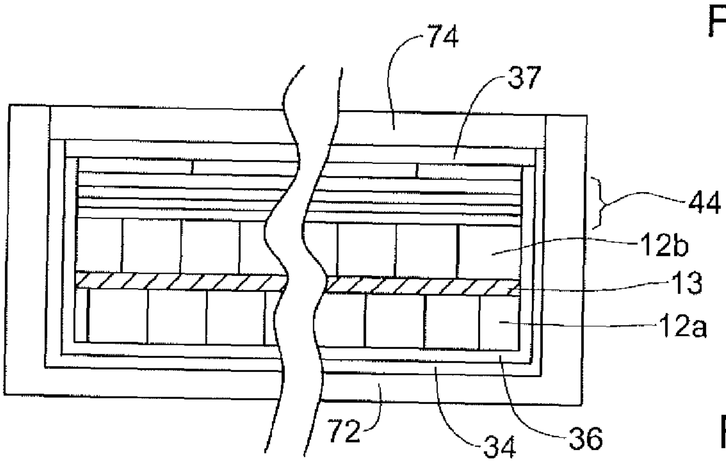

FIG. 11C

REFERENCES CITED IN THE DESCRIPTION

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