BALLISTIC ARMOR

FIELD OF THE INVENTION

The present invention is directed toward composite ballistic armor, and especially to armor comprising a layer of pellets made of high density material, to provide protection against armor-piercing projectiles, for use as stand-alone armor or as add-on armor.

BACKGROUND OF THE INVENTION

One of the major considerations when designing ballistic armor of the above kind is its weight. Since armor is meant to be carried by a vehicle or worn by a person, armor having a lower weight is preferred to armor of greater weight which provides the same ballistic protection.

Ballistic armor of the kind to which the present invention refers comprises an armor layer of ceramic tough pellets, adapted to absorb most of the energy of the impacting armor-piercing projectiles. The pellets are typically regularly arranged, and held within a matrix of thermoset or thermoplastic material. Such armor normally has high multi-hit capability, since damage to the armor is localized to one or a small number of pellets at the area of impact. The armor typically further comprises front and/or back layers attached to the armor layer.

US 5,763,813 discloses one example of such armor comprising an armor layer of ceramic pellets and a back layer, and the manufacture of the armor layer by use of a vertical mold. After the armor layer has been produced within the mold, the back layer is attached thereto.

In armor layers of the kind described above, the geometry of the pellets contributes to the ballistic protection capability of the layer. It is appreciated that

when pellets have domed ends facing a threat, the impact is better absorbed by the armor layer. Cylindrical pellets having such ends are disclosed, for example, in FR 2559254, EP 699687, DE 3940623, US 5,972,819, and EP 1,522,817. Cylindrical pellets disclosed in these publications have both of their ends domed with the same or different radii of curvature, or only the front end facing the threat being domed. The latter design is disclosed, for example, in US 5,972,819, as an alternative to the former configuration, though it is emphasized that the configuration with both domed ends is most preferred.

EP 1,522,817 discloses a composite armor plate for absorbing and dissipating kinetic energy from high-velocity projectiles. The plate comprises a single layer of pellets which are retained by a binder which may be aluminum, thermoplastic polymers or thermoset plastic, such that the pellets are held in direct contact with each other in a plurality of rows and columns. The pellets are made of ceramic material, and are substantially fully embedded in the binder. Each of the pellets is characterized by a cylindrical body having a first and second end faces, each projecting from the body and having an outwardly decreasing cross-sectional area, wherein the height of the end face disposed substantially opposite to an outer impact receiving major surface of the plate is less than 15% of the length of the diameter of the pellet body from which it projects.

SUMMARY OF THE INVENTION

The present invention refers to a number of measures directed to improve ballistic protection provided by a composite armor having a main armor layer comprising a plurality of pellets made of high density material and enveloped in a binder matrix and, preferably, having front and back layers. The pellets may be made of any high density ceramic used in ballistic armor, such as alumina. The binder matrix may be made of a thermoplastic material or a thermoset material. The front and back layers may be made of fibers, preferably in the form of a fabric, capable of absorbing the binder material.

According to one aspect of the present invention, there is provided a composite armor plate for ballistic protection of a body against a threat, comprising an inner, main armor layer of high density pellets in a binder matrix, and a front layer adapted for facing the threat, each pellet having a domed front face and a body portion merging with the front face along a perimeter line, the domed front face having a juncture point and being formed of sectors, each defined between two side edges have the form of arcs and a portion of the perimeter line extending between two spaced-apart points lying thereon, and constituting the sector's base edge, each side edge spanning between the juncture point and one of the spaced apart points; the shape of each sector being such that:

- the intersection of the sector and a first plane crossing said two side edges, has a form of a straight line extending therebetween; and
- the intersection of the sector and a second plane crossing said base edge, has a form of a convexly curved line;

wherein the front layer is made of a material other than the binder matrix and is bonded to at least the majority of the pellets at the domed front faces thereof.

When the pellets have an axis of symmetry (e.g., rotational symmetry) passing through the juncture point, the second plane may contain the axis of symmetry and the first plane may be substantially perpendicular to the second plane, being parallel to the axis of symmetry.

The second plane may substantially bisect each sector, i.e., bisect the angle formed between the two side edges defining it. The second plane may further be perpendicular to the base edge of each sector.

The juncture point may be the outermost point of the front face of the pellet, i.e., it is farther from the body portion than any other point of the front end.

The convexly curved line formed by the intersection of the sector with the second plane may be a circular arc having a first radius, and each of the side edges may be circular arcs having a second radius which is greater than the first

radius. Due to this geometry, the front face of the pellets may be seen as being fully disposed within an imaginary sphere having the second radius, except for the side edges defining this sphere.

The perimeter line may be defined by an inscribed circle lying in a plane, e.g., it may fully lie in the plane, and the side edges of the sectors may be oriented such that a line tangent to each of the side edge at the juncture point lies in a plane which is parallel to this plane.

The body portion may be in the form of a polygonal cylinder having a plurality of sides, each side merging with the domed face at the base edge of one of the sectors. Alternatively, the body portion may have any other shape, i.e., that of a circular or oval cylinder, and this shape, or dimensions of the body portion, may vary along its axis of symmetry. .

The polygonal cylinder may have a convex polygonal shape and may have any number of sides, e.g. have four sides, e.g. be a square cylinder, or six sides, e.g. be a hexagonal cylinder.

The main layer and front layer may be integrally formed, with the material of the binder matrix serving to bind the front layer to the main armor layer.

The pellets are preferably coated with primer which is adapted to facilitate binding of the binder material to the pellets. Hereinafter, the term "*primer*" is to be understood as a coating material adapted to facilitate binding of the binder material to the pellet.

The composite armor plate preferably has at least one additional layer made of a material different from the binder material, constituting a back layer of the plate. The main layer and the front and back layers may be integrally formed, with the binder material forming the matrix and serving to bind the front and back layers to the main armor layer. The back layer may be made from a ballistic fabric.

According to another aspect of the present invention, there is provided a method for producing a composite armor plate having a front face and side walls therebetween, the method comprising:

(a) providing a plurality of pellets, each of the pellets being formed as described above;

(b) providing a front layer;

(c) applying binder materialto the pellets and layer; and

(d) heating the binder material to simultaneously form a matrix, which constitutes with the pellets a main armor layer, and binds the front layer to the main armor layer, to form the front face of the plate.

The method may further comprise the steps of:

(e) arranging the front layer in the form of a cavity, having a generally horizontal bottom and generally vertical side walls, corresponding in shape and dimensions to the front face and side walls of the plate;

(f) arranging the pellets in the cavity; and

(g) introducing the binder material in the cavity

so that their domed front faces face the bottom of the cavity.

Herein the specification and claims, prepositions are to be understood in their broadest sense, including, but not limited to, a description of an element extending beyond the object of the proposition. (Thus, e.g., an element described being above or below a member, or between two members, may partially extend beyond one or more of the members.)

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may 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. 1 is a cross-sectional side view of a composite armor plate according to one aspect of the present invention;

Fig. 2A is a perspective view of a mold for use to manufacture the armor plate shown in Fig. 1;

Fig. 2B is a perspective view of the mold illustrated in **Fig. 2A** with a front layer of the armor plate disposed therewithin;

Fig. 2C is a top view of the mold and front layer as seen in **Fig. 2B**, with pellets arranged therein;

Fig 2D is a cross-sectional side view of the armor plate shown in Fig. 1, within the mold shown in Figs. 2A to 2C; and

Fig. 3A is a perspective view of an example of a pellet used to manufacture the composite armor plate illustrated in Fig. 1;

Fig. 3B is a perspective view of the pellet illustrated in Fig. 3A, a portion of which is cut away along plane B-B; and

Fig. 3C is a perspective view of the pellet illustrated in Fig. 3A, a portion of which is cut away along plane C-C.

DETAILED DESCRIPION OF EMBODIMENTS

Fig. 1 shows one example of a composite armor plate **10** according to the present invention. The plate **10** comprises a main armor layer **12**, with a front layer **14** attached in the main layer on one side thereof, to form a front face **11** and side walls **13** of the plate, and a back layer **16** attached to the main layer on its other side, to form a back face **15** of the plate.

The main armor layer **12** comprises an array of pellets **18** made of high density ballistic armor material, e.g., ceramic, such as alumina, silicon carbide, silicon nitride, and boron carbide. Each pellet comprises a cylindrical body **20**, a domed front end **22**, and a planar back end **24**.

The main armor layer **12** further comprises a binder matrix **26** which envelops the pellets and is adapted to retain the arrangement of the array. The matrix may be made of thermoplastic or thermoset material.

The front layer **14** is typically made from a ballistic fabric such as aramid (e.g., Kevlar™) or fiberglass. It may comprise several sheets of fabric, which may be made of different materials. It constitutes the front face **11** of the armor plate **10**, and wraps around the sides of the main armor layer **12**. This *inter alia* provides protection to the main armor layer **12** against moisture and chemical substances, and also functions as a spall liner, preventing exit of shrapnel that results from shattering of pellets upon impact thereon of a projectile. It further provides an aesthetic covering for the armor plate **10**.

The back layer **16** is made from a ballistic fabric such as aramid (e.g., Kevlar™), fiberglass, polyethylene, or other similar material. It may comprise several sheets of fabric, which may be made of different materials. All sheets may be unidirectional, however the one immediately adjacent the pellets is preferably not. The back layer **16** serves to stop projectiles and their fragments as well as shrapnel of pellets that may result from a ballistic projectile impacting the main armor layer **12**.

With reference to figures 2A through 2D, the plate **10** may be manufactured as follows:

The pellets **18** are prepared by washing with a surface preparation chemical agent. They are then coated with one or more coats of primer, such as Silan, or any other bonding agent for elastomers. The coating may be accomplished by spraying the pellets **18** with the primer, or by immersion thereof in a bath of the primer. The spraying may be accomplished by standing the pellets **18** on their planar back ends **24**, spraying the primer thereon, and allowing them to dry. This coats all surfaces except the back ends **24**. When the pellets **18** are later arranged for production with their back ends **24** facing upward, as described below, the primer is applied to the back ends **24**, thereby ensuring that the entire surface of each pellet **18** is coated therewith. Alternatively, the entire surface of the pellets may be coated prior to their arrangement for production. The primer may be applied manually or in an automated fashion.

As seen in Fig. 2A, a mold **28**, which may be made of aluminum or other similar material, is provided, having dimensions corresponding to those of the plate **10**. The side walls **30** of the mold may be shifted while remaining mutually perpendicular to adjacent walls. A cover **34**, associated with the mold, may be provided. It has dimensions which are slightly smaller that those defined by the interior of the side walls **30**. As seen in Fig. 2B, the front layer **14** is arranged in a generally horizontal position within the mold **28**, and the edges thereof are arranged along the side walls **30** of the mold, forming a cavity **32** having sides and a bottom to correspond, respectively, to the front face **11** and side walls **13** of the armor plate **10**. As seen in Fig. 2C, the pellets **18** are arranged within the cavity **32** in a honeycomb or other advantageous arrangement to form the main armor layer **12**, with their domed front ends **22** facing the bottom of the cavity **32**. The side walls **30** of the mold **28** are shifted until the pellets **18** are tightly packed.

The binder material is introduced in the mold **28** to fill the gaps between the pellets and fully cover them, including the planar back ends **24** thereof. In the event that pellets having a round cross-section are used, the binder can easily reach the front ends of the pellets **18**, which are presently disposed downwardly. Due to the domed shape of the front ends **22**, binder material covers the entire surface of the pellets and the entire surface area of the front layer **14**, increasing adhesion of the front layer to the main armor layer **12**. The binder matrix **26** is adapted to bind the pellets **18** to each other and to the adjacent layers.

The back layer **16** is applied to the planar back ends **24** of the pellets **18**. Due to flat shape of the pellets **18**, the back layer **16** may be easily and smoothly applied to the pellet array. This provides a better attachment of the back layer **16** to the back ends **24** of the pellets **18**, increasing the confinement.

Both the front and back layers may be provided with binder material associated therewith. In the event that the binder material is a thermoplastic, the material in powder form may be spread on the each layer before it is introduced

into the above process and heated enough so that it binds thereto, while still remaining in powder form. In the event that the binder material is a thermoset, the fabric may be pre-impregnated.

As seen in Fig. 2D, the edges of the front layer **14**, which, due to their arrangement in the mold cover the sides of the main armor layer **12**, are then wrapped around the back layer **16** near the edges of the plate. Heat and pressure are then applied, which melt the powder, forming thereby the integral plate **10**, with the matrix **26** constituting the main armor layer **12** together with the pellets **18**, and binding the front and back layers thereto. The cover **34** may be used to distribute the pressure the pellets. Alternatively, the entire mold with the pellets may be covered with plastic 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 needs to be applied to cure the binder material. This is usually at a lower temperature.

The heating expands the mold **28**, which allows the pellets **18**, 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 **18**. When the binder material solidifies, there is produced a gap of 0.1 and 0.3 mm between adjacent pellets **18** at their closest points. This gap contains the primer and the binder material. The presence of the binder between adjacent pellets **18** improves ballistic protection of the armor by reducing propagation of shockwaves through the armor upon impact by a projectile and lessening the effect of shattering pellets on their neighbors.

During the heating, the front layer **14** contracts, thereby at least partially conforming to the shape domed front ends **22**, as illustrated in Fig. 1. This increases the confinement of the front layer **14** to the pellets **18**, thereby increasing the ballistic performance of the armor.

As illustrated further in Fig. 2D, an optional final backing **36** is applied to the back of the armor. This layer provides a smooth appearance to the armor, and may mainly serve an aesthetic purpose. The gap **38** between the final backing **36** and the backing **16** may be filled in with any material, such as binder or other filler.

Experiments have shown that the plate as described above provides the same ballistic protection capabilities as a reference panel of the same design having higher weight and using pellets having two domed and at least the same height of the body portions.

In one such experiment, a plate according to the present invention and a reference panel were tested. The pellets in the plate were composed of 98% alumina, and each had a diameter of 12.7 mm, a total height of 8 mm, of which 6.5 mm was the height of the cylindrical body portion. The pellets in the reference panel were composed of 99.5% alumina, and each had a diameter of 12.7 mm, a total height of 11.5 mm, of which 7 mm was the height of the cylindrical body portion.

The plate and reference panel each comprised Kevlar™ and fiberglass layers on both ends thereof, and an aluminum panel was disposed therebehind. Ten rounds of 7.62x51 AP projectiles were fired at 840 m/s at both the plate and the reference panel. Each round passed through the respective armor, and the depth of the residual penetration (RP) into the aluminum panel was observed.

The results of the experiment demonstrated that the plate provided substantially the same level of ballistic protection as the reference panel, while weighing considerably less (27 kg/m^2 vs. 36.5 kg/m^2 for the reference panel).

Experiments further show that the plate as described above provides better ballistic protection capabilities than a reference panel having similar design wherein the front and back layers are not integrally formed with the main armor layer, namely they are attached to the main armor layer after its production.

Figs. 3A illustrates pellet, **18** used in the armor plate as described above. The pellet **18** has a body portion **102** formed as a hexagonal cylinder, a domed front face **104**, with a perimeter line **106** therebetween serving as the boundary between the body portion and the domed front face, and rear face **110**, the perimeter line **106** lying in a plane parallel to the rear face **110**.

The domed front face **104** comprises six identical sectors **108**, which meet at a common juncture point **112** formed at the intersection of the domed front face **104** and an axis of rotational symmetry **114** of the pellet.

Each sector **108** is defined between two convex side edges **116** and base edge **118** constituted by a portion of the perimeter line **106,** which extends between two spaced-apart points **120** thereon. Each of the side edges **116** is in the form of a circular arc of radius R1 extending between the juncture point **112** and one of the spaced-apart points **120**.

Each sector **108** is formed such that, when the pellet **18** is cut along a plane crossing the side edges **116** e.g., plane **P1** shown in Fig. 3B and represented by a line B-B in Fig. 3A, the intersection of this plane with the sector 108 is a straight line extending between the side edges **116**, as indicated at **125a** in Fig. 3B; when the pellet **18** is cut along a plane crossing the base edge **118** e.g. plane **P2** shown in Fig. 3C and represented byline C-C in Fig. 3A, the intersection of this plane with the sector 108 is a convexly curved line (albeit having a smaller radius R2 than that of the side edge **116**), as indicated at **125b** in Fig. 3C. Thus, each sector **108** can be described as having the shape of a triangular sheet which is curved in one direction only. The planes **P1** and **P2** are mutually perpendicular, with the latter being perpendicular to the base edge **118** and bisecting the sector **108**, and the former passing through points **117** on the side edges **116**, which are equidistant from the juncture point **112**.

The sectors 108 are oriented so that lines **122** which are tangent to their side edges **116** at the juncture point **112**, lie are parallel to the perimeter line **106**.

It will be appreciated that any cross-section of the sector **108** which is taken along a line which is non-parallel to line B-B in Fig. 3A will be a convexly curved line.

In the main armor layer **12** with the pellets **18,** the pellets are arranged with their planar side walls aligned and abutting each other, similar to shown in Fig. 2C.

The domed front face **104** having the design as described above improves adhesion of the front layer **14** to the pellets **18**, compared to that of a spherical domed front face, , while retaining the ballistic advantages of domed front face. This is due to, *inter alia*, the fact mentioned above that the shape of each sector **108** can be described as that of a sheet which is curved in one direction only, which is a shape to which sheets can naturally and easily be bent. Thus, each sector is formed so as to naturally conform to the front layer **14** without resulting in kinks therein, at least locally at each sector **108**. These kinks would reduce the amount of area of the front layer **14** which is in contact with the main armor layer **12**. Thus, by reducing the kinks in the front layer **14**, the overall adhesion of the main armor layer **12** thereto is increased, which results in an increased ballistic ability of the composite armor plate **10**.

The armor as described above may be used by itself (stand alone) or, more commonly, mounted to the exterior wall of a vehicle. In the latter case, the wall of the vehicle serves to augment the energy absorbing capability of the back layer, thereby lowering the necessary thickness of the armor. When mounted on a vehicle, an additional liner is typically attached to the inside of the wall, in order to stop fragments and deformed projectiles from entering the vehicle.

Those skilled in the art to which this invention pertains will readily appreciate that numerous changes, variations and modifications can be made without departing from the scope of the invention *mutatis mutandis*.

CLAIMS:

1. A composite armor plate for ballistic protection of a body against a threat, comprising an inner, main armor layer of high density pellets in a binder matrix, and a front layer adapted for facing said threat, each pellet having a domed front face and a body portion merging with the front face along a perimeter line, the domed front face having a juncture point and being formed of sectors each defined between two side edges having the form of arcs and a portion of the perimeter line, constituting the sector's base edge, extending between two spaced-apart points lying thereon, each side edge spanning between the juncture point and one of said spaced apart points; the shape of each sector being such that:

- the intersection of the sector and a first plane crossing said two side edges has a form of a straight line; and
- the intersection of the sector and a second plane crossing said base edge, has a form of a convexly curved line;

wherein said front layer is made of a material other than said binder matrix and is bonded to at least the majority of said pellets at said domed front faces thereof.

2. The composite armor plate according to Claim 1, wherein each pellet has an axis of symmetry passing through said juncture point, said first plane being substantially parallel to said base edge.

3. The composite armor plate according to Claim 2, wherein said second plane contains said axis of symmetry and substantially bisects said sector.

4. The composite armor plate according to any one of the preceding claims, wherein said second plane is substantially perpendicular to said base edge of the sector.

5. The composite armor plate according to any one of the preceding claims, wherein said juncture point is the outermost point of the front face of the pellet.

6. The composite armor plate according to any one of the preceding claims, wherein said convexly curved line is a circular arc having a first radius, and each of said side edges are circular arcs having a second radius which is greater than said first radius.

7. The composite armor plate according to any one of the preceding claims, wherein said perimeter line is defined by an inscribed circle lying in a plane, said side edges being oriented such that a line tangent to each of said side edges at the juncture point lies in a plane which is parallel to the plane.

8. The composite armor plate according to any one of Claims 2 through 7, wherein said body portion is in the form of a polygonal cylinder having a plurality of sides, each side merging with the domed face at said base edge of one of the sectors.

9. The composite armor plate according to Claim 8, wherein the polygon is a hexagon.

10. The composite armor plate according to any one of the preceding claims, wherein said main layer and said front layer are integrally formed, with the material of the binder matrix serving to bind the front layer to the front faces of the pellets in the main armor layer.

11. The composite armor plate according to any one of the preceding claims, wherein the pellets including their front faces are coated with primer which is adapted to facilitate binding of the binder matrix to the pellet.

12. The composite armor plate according to any one of the preceding claims, wherein the front layer is made from a ballistic fabric.

13. The composite armor plate according to Claim 12, wherein the binder material is absorbable by the fabric.

14. The composite armor plate according to any one of the preceding claims, further comprising a back layer.

15. A method for producing a composite armor plate having front and back faces and side walls therebetween, the method comprising:

(a) providing a plurality of pellets, each of said pellets having a domed front face and a body portion merging with the front face along a perimeter line, the domed front face having a juncture point and being formed of sectors each defined between two side edges having the form of arcs and a portion of the perimeter line, constituting the sector's base edge, extending between two spaced-apart points lying thereon, each side edge spanning between the juncture point and one of said spaced apart points; the shape of each sector being such that:

- the intersection of the sector and a first plane crossing said two side edges has a form of a straight line; and
- the intersection of the sector and a second plane crossing said base edge, has a form of a convexly curved line;

(b) providing a front layer;

(c) applying binder material; and

(d) heating the binder material to simultaneously form a matrix, which constitutes with the pellets a main armor layer, and binds the front layer to the front faces of the pellets in the main armor layer, to form said front face of the plate.

16. The method according to Claim 15, further comprising the steps of:

(e) arranging the front layer in the form of a cavity, having a generally horizontal bottom and generally vertical side walls, corresponding in shape and dimensions to the front face and side walls of the plate;

(f) arranging the pellets in the cavity; and

(g) introducing the binder material in the cavity so that the domed ends face the bottom of the cavity.

17. The method according to any one of Claims 15 and 16, wherein each pellet has an axis of symmetry passing through said juncture point, said first plane being substantially parallel to the base edge of the sector.

18. The method according to Claim 17, wherein said second plane contains said axis of symmetry and substantially bisects said sector.

19. The method according to any one of Claims 15 through 18, wherein said second plane is substantially perpendicular to said base edge of the sector.

20. The method according to any one of Claims 15 through 19, wherein said juncture point is the outermost point of the front face of the pellet.

21. The method according to any one of Claims 15 through 20, wherein said convexly curved line is a circular arc having a first radius, and said side edges are circular arcs having a second radius which is greater than said first radius.

22. The method according to any one of Claims 15 through 21, wherein said perimeter line is defined by an inscribed circle lying in a plane, said side edges being oriented such that a line tangent to each of said side edges at the juncture point lies in a plane which is parallel to the plane.

23. The method according to any one of Claims 17 through 22, wherein said body portion is in the form of a polygonal cylinder having a plurality of sides, each side merging with the domed face at said base edge of one of the sectors.

24. The method according to Claim 23, wherein the polygon is a hexagon.