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(54) **ARMOR PLATE**

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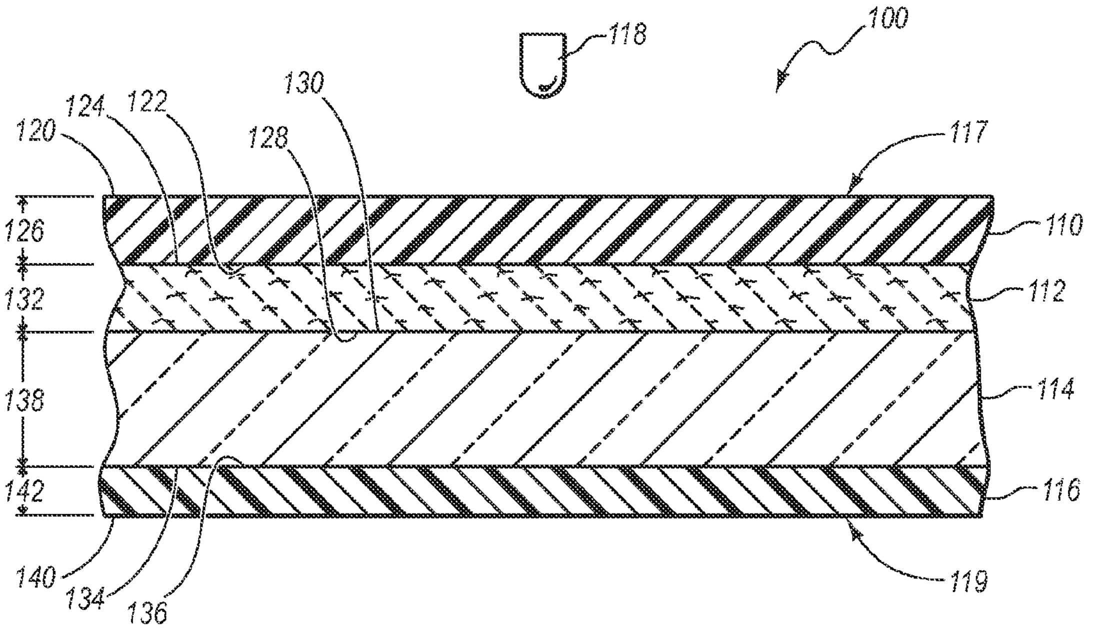
(57) **ABSTRACT**

An armor plate includes at least four layers configured to generate a compression wave that is dissipated in a fracture player. The armor plate includes a deformable layer of a material having an elongation before failure of 20% or more; a transparent ceramic layer adjacent the deformable layer; a transparent fracture layer adjacent the ceramic layer; and a transparent spall liner backing the fracture layer.



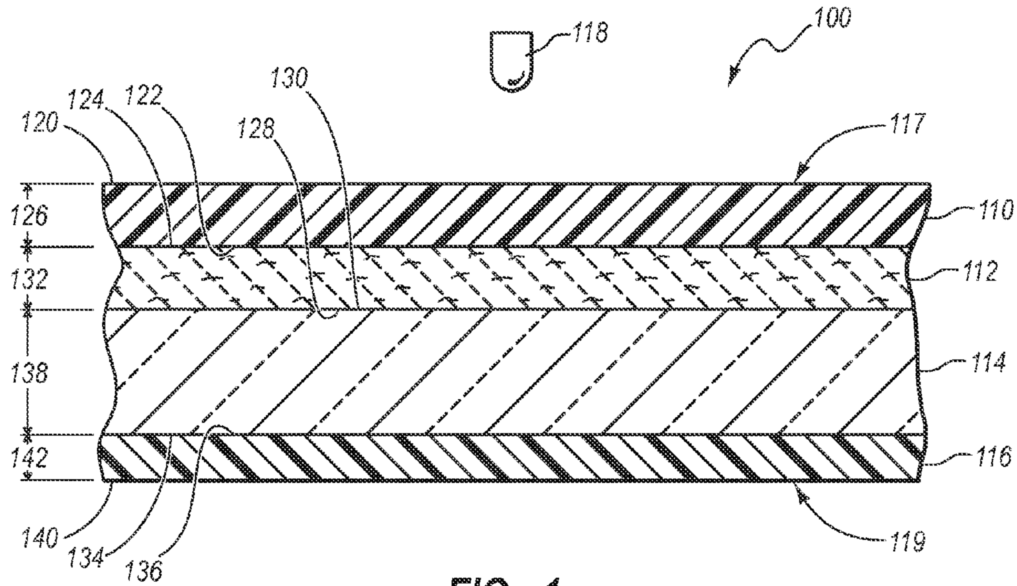

118
100
130
124 122
120
128
117
126
110
132
112
138
114
142
116
140
134
136
119

FIG. 1

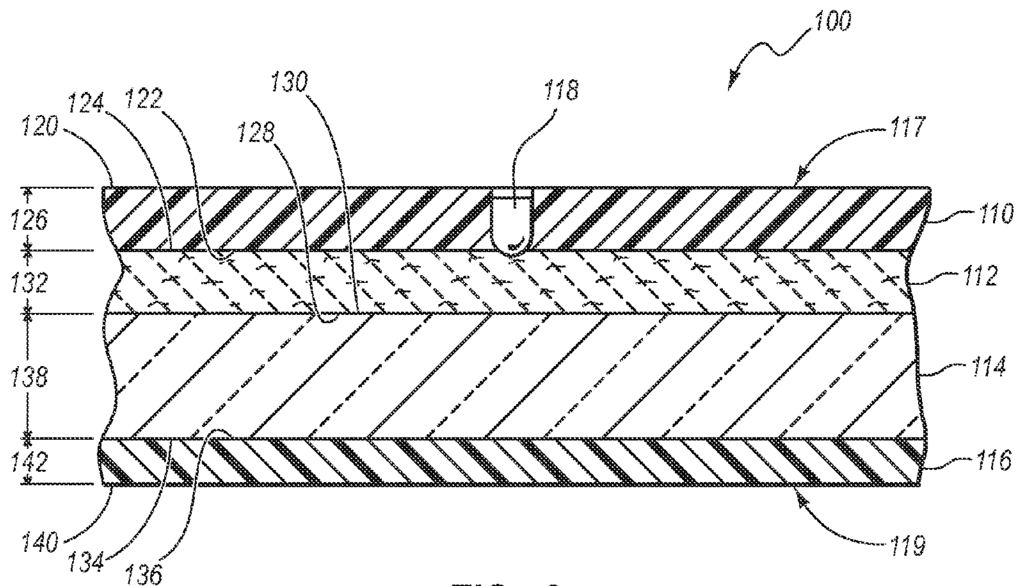

100
130
118
124 122
120
128
117
126
110
132
112
138
114
142
116
140
134
136
119

FIG. 2

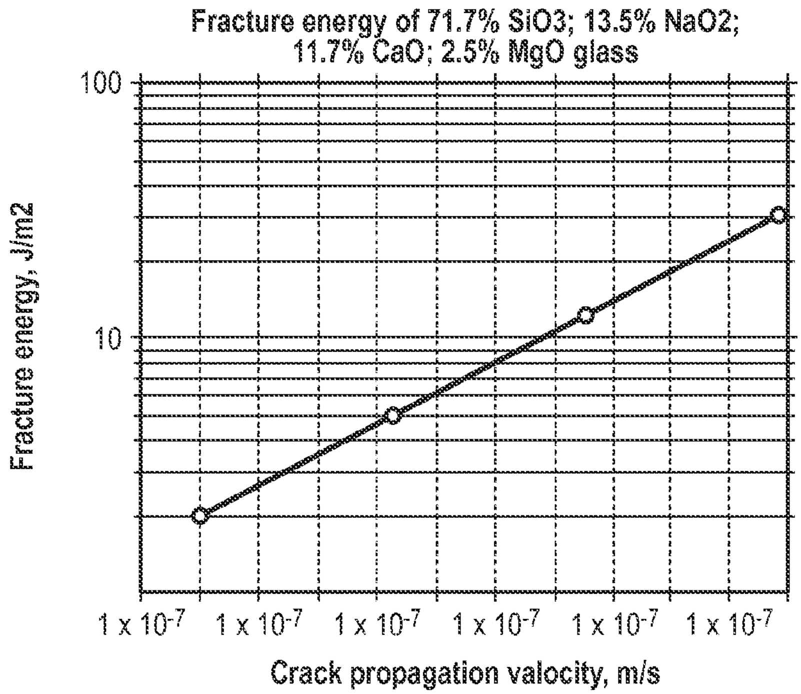

Fracture energy of 71.7% SiO3; 13.5% NaO2;
11.7% CaO; 2.5% MgO glass
100
10
Fracture energy, J/m2
1 x 10-7
1 x 10-7
1 x 10-7
1 x 10-7
1 x 10-7
1 x 10-7
Crack propagation valocity, m/s

FIG. 3

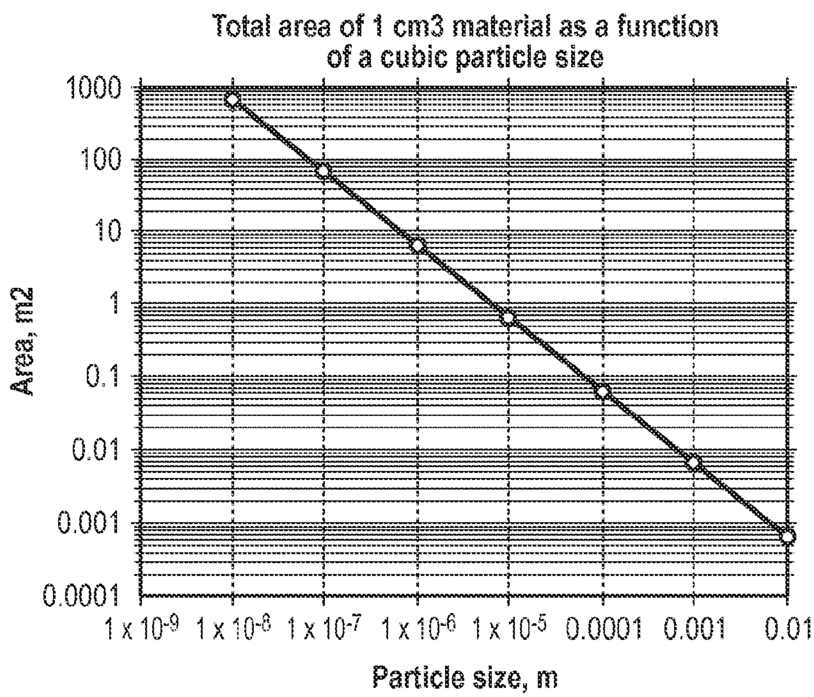

Total area of 1 cm3 material as a function
of a cubic particle size
1000
100
10
1
0.1
0.01
0.001
0.0001
Area, m2
1 x 10-9
1 x 10-8
1 x 10-7
1 x 10-6
1 x 10-5
0.0001
0.001
0.01
Particle size, m

FIG. 4

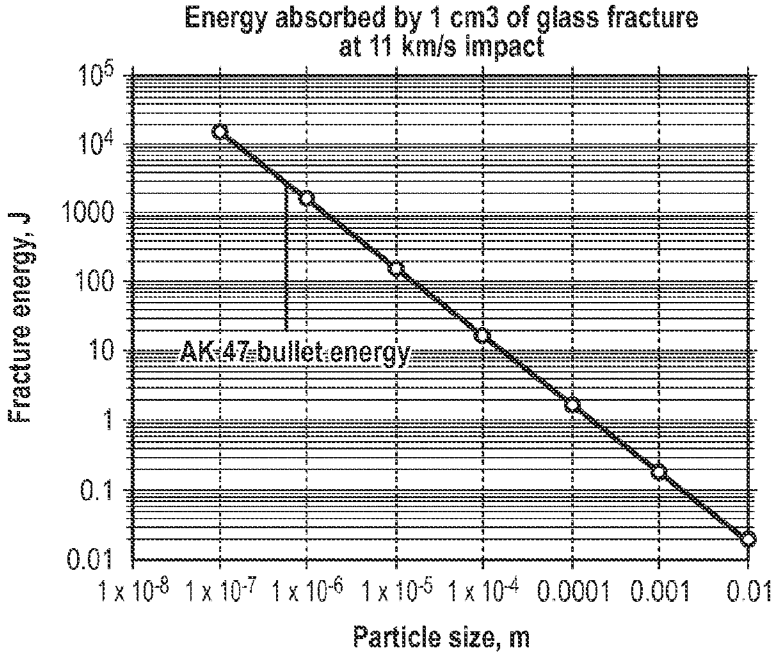

Energy absorbed by 1 cm3 of glass fracture
at 11 km/s impact
Fracture energy, J
10^5
10^4
1000
100
10
1
0.1
0.01
AK-47 bullet energy
1×10^{-8}
1×10^{-7}
1×10^{-6}
1×10^{-5}
1×10^{-4}
0.0001
0.001
0.01
Particle size, m

FIG. 5

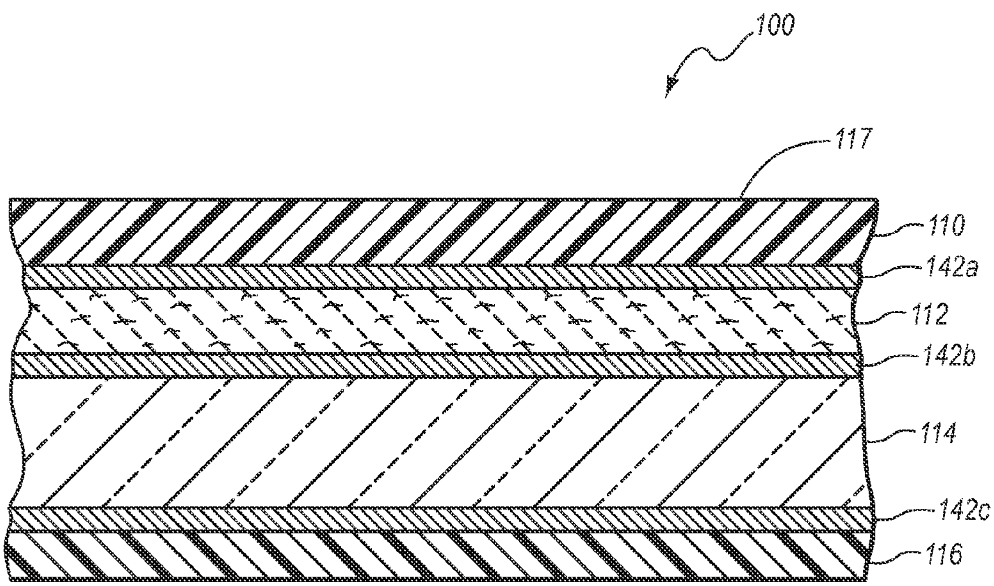

100
117
110
142a
112
142b
114
142c
116

FIG. 6

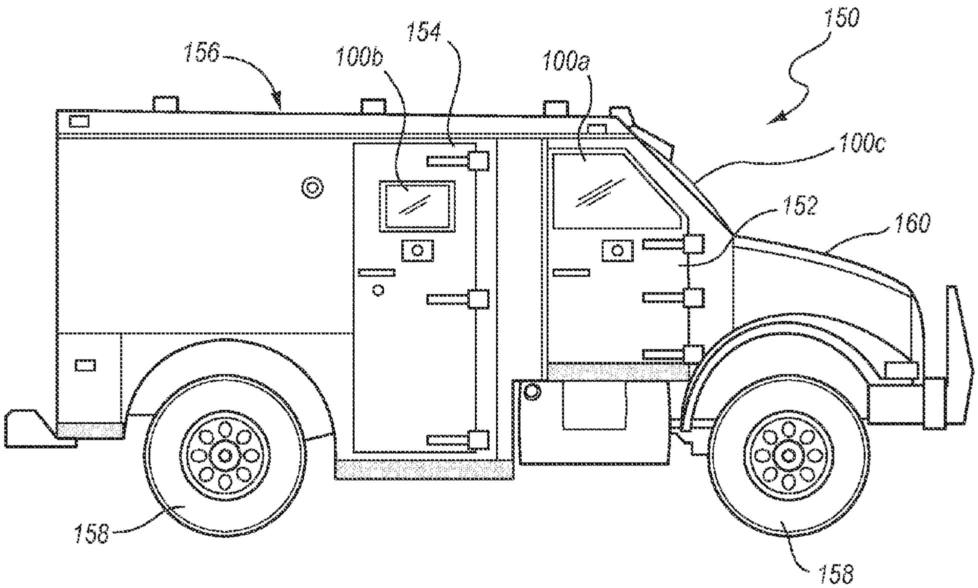

150
156
100b
154
100a
100c
152
160
158
158

FIG. 7

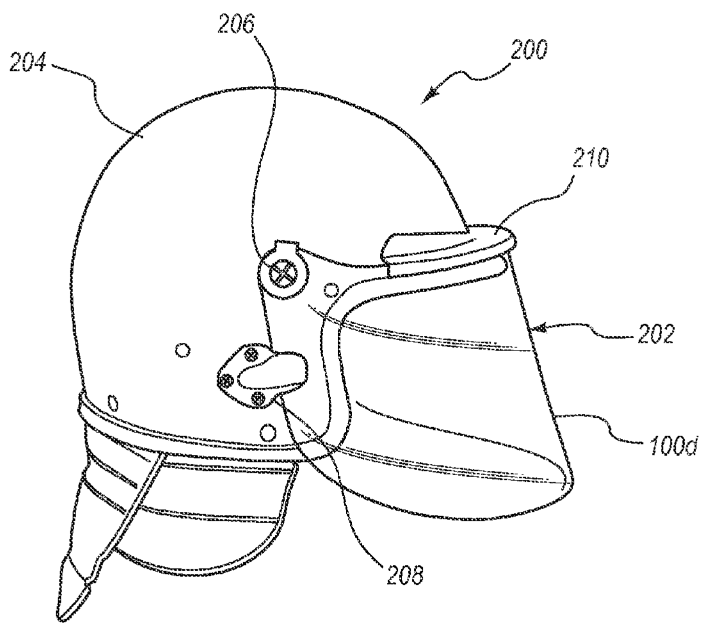

206
204
200
210
202
100d
208

FIG. 8

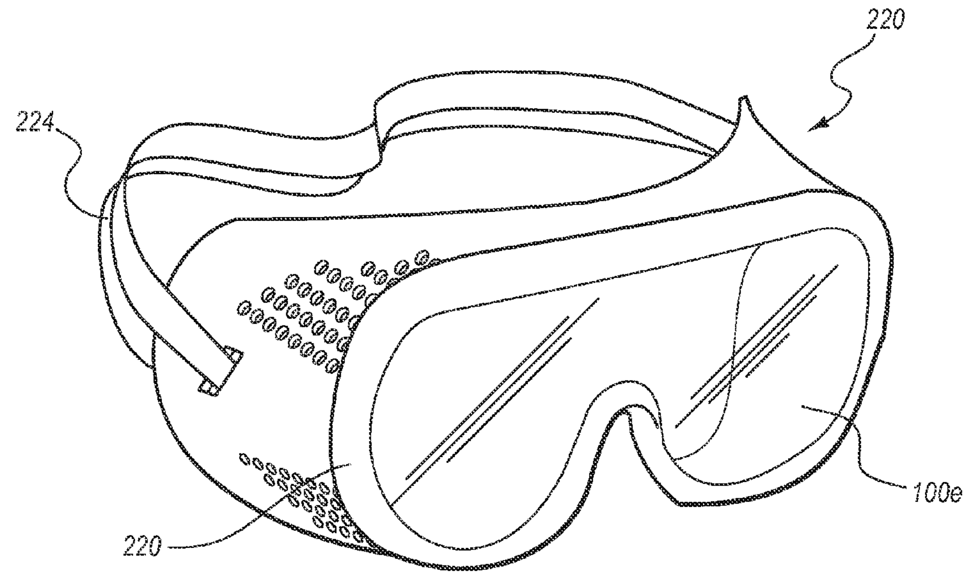


FIG. 9

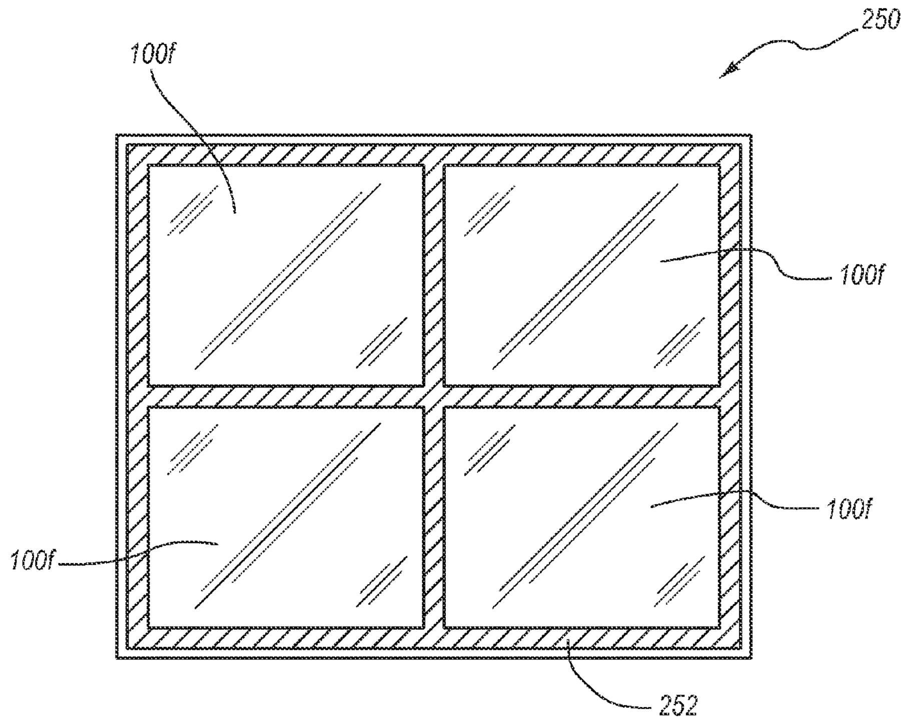


FIG. 10

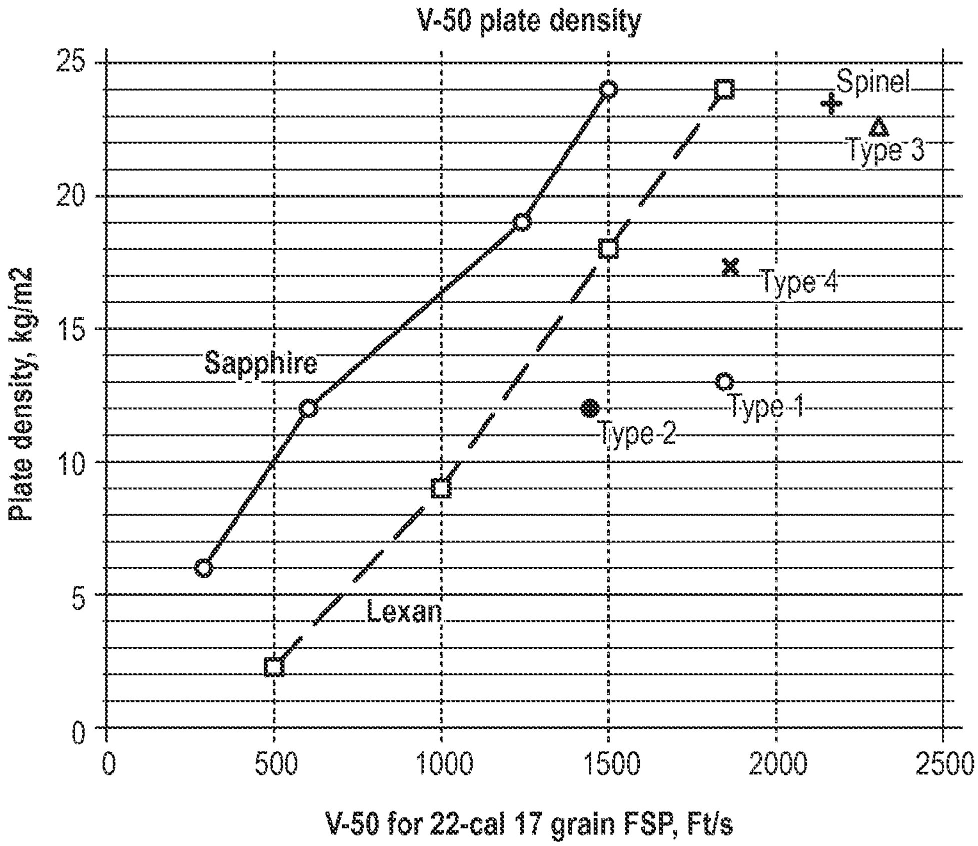

V-50 plate density
Plate density, kg/m2
25
20
15
10
5
0
0
500
1000
1500
2000
2500
V-50 for 22-cal 17 grain FSP, Ft/s
Sapphire
Lexan
Spinel
Type 3
Type 4
Type 1
Type 2

FIG. 11

ARMOR PLATE

GOVERNMENT LICENSE RIGHTS

[0001] The U.S. Government has a paid-up license in this invention and the right in limited circumstances to require the patent owner to license others on reasonable terms as provided for by the terms Contract No. N00173-07-C-2055 awarded by U.S. Naval Research Laboratory.

BACKGROUND OF THE INVENTION

[0002] 1. The Field of the Invention

[0003] The present invention relates to armor plates and articles of manufacture incorporating the armor plates.

[0004] 2. The Relevant Technology

[0005] Armor is a material or system of materials designed to protect from ballistic threats. Transparent armor, in addition to providing protection from the ballistic threat is also designed to be optically transparent, which allows a person to see through the armor and/or to allow light to illuminate the area behind the armor.

[0006] In the general field of ballistic armors, existing armor systems are typically comprised of many layers of projectile resistant material separated by polymer interlayers, which bond the projectile resistant materials. In a typical armor laminate the strike surface is a hard layer of projectile resistant material that is designed to break up or deform projectiles upon impact. The interlayer materials are used to mitigate the stresses from thermal expansion mismatches as well as to stop crack propagation into the polymers.

[0007] For most armor plates, efforts are usually made to make the armor plate light weight. This is particularly true of transparent armor plates, which are often used for protective visors and goggles. Currently existing military specification for protective visors and goggles requires that the lens should be able to stop 0.22-caliber 17 grain FSP projectile at 550-feet per second (fps). For comparison, most handguns give more than 1000 fps bullet velocity and rifles up to 3000 fps. To stop bullets from handguns one needs an inch thick polycarbonate plate and around two inches thickness for a rifle bullet.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. **1** shows a schematic of an armor plate according to one embodiment of the invention and a projectile about to strike the surface of the transparent armor plate;

[0009] FIG. **2** illustrates the schematic of FIG. **1** showing the projectile after impact;

[0010] FIG. **3** is a graph showing the fracture energy of the soda glass as a function of crack propagation velocity;

[0011] FIG. **4** is a graph showing the surface area of 1 cm^3 material volume as a function of particle size;

[0012] FIG. **5** is a graph showing fracture energy absorbed by 1 cm^3 of glass fracture as a function of particle size at 11 km/s impact;

[0013] FIG. **6** is a schematic of an armor plate with adjacent layers of material joined using an adhesive;

[0014] FIG. **7** illustrates an armored vehicle according to one embodiment of the invention incorporating the armor plate of FIG. **1**;

[0015] FIG. **8** illustrates a helmet according to an alternative embodiment of the invention incorporating the armor plate illustrated in FIG. **1**;

[0016] FIG. **9** illustrates a pair of goggles incorporating the armor plate illustrated in FIG. **1**; and

[0017] FIG. **10** shows a panel including a plurality of segments of the armor plate of FIG. **1**; and

[0018] FIG. **11** is a graph showing test results of armor plate manufactured according to the present invention.

DETAILED DESCRIPTION

[0019] The present invention relates to a composite armor plate and articles of manufacture incorporating the armor plate. The composite armor plate typically uses at least four layers of material that are configured to create a compression wave from the impact of a projectile and absorb the compression wave by fracturing one of the layers. The four-layer system of the invention can be made comparatively lighter, stronger, and/or thinner than armor materials using conventional laminates. In one embodiment, the armor plate can be transparent. Transparent armor plates can be incorporated into windows, helmets, goggles, and similar devices where transparency and/or translucency are desired. In other embodiments, the armor plate can include one or more layers that are opaque.

[0020] The four-layer system of the present invention can achieve a lighter, thinner armor by placing a deformable layer on the front side of a ballistic-resistant ceramic layer. The ceramic layer is in turn backed by a fracture layer and a spall liner. Upon ballistic impact, the deformable layer creates a compression wave that spreads out through the ceramic layer and is absorbed by the fracture layer. The spall liner backing the fracture layer catches the fracture layer as it disintegrates from the impact. The use of a deformable layer in front of the strong ceramic layer allows an intensive compression wave with a large surface area to be generated. When the large surface area compression wave strikes the fracture layer, the larger surface area results in comparatively better disintegration of the fracture layer, thereby absorbing a comparatively larger amount of energy. Depending on the plate geometry, projectile size and speed, orders of-magnitude increase in energy absorption can be achieved using a deformable layer and a fracture layer with a ceramic layer in between.

[0021] FIG. **1** illustrates an example armor plate **100** according to one embodiment of the invention. The armor plate **100** includes a transparent deformable layer **110**, a transparent ceramic layer **112**, a fracture layer **114**, and a spall liner **116**.

[0022] Armor plate **100** has a strike surface **117** upon which a bullet **118** or any other type of projectile impinges. Armor plate **100** also includes a back surface **119** opposite the strike surface **117**. Strike surface **117** is configured to receive the initial impact of bullet **118** and back surface **119** is configured to be the surface closest to the object for which the armor plate provides protection. For example, where armor plate **100** is used as a window in an armored vehicle, strike surface **117** is positioned outside the vehicle and back surface **119** communicates with the interior of the vehicle.

[0023] In one embodiment, the deformable layer **110** has a first side **120** configured to be strike surface **117** upon which bullet **118** impinges. Deformable layer **110** is configured to generate a compression wave from the impact of bullet **118**. In one embodiment the deformable layer **110** comprises a material having an elongation before failure of at least 20%. Materials having an elongation before failure of at least 20% typically generate an intense compression wave upon ballistic impact. In a more preferred embodiment, the deformable layer may include a material having an elongation before failure of at least about 50%, even more preferably about

100% or more. Examples of suitable transparent materials that can be used for the deformable layer **110** include, but are not limited to, polycarbonate, polyurethanes, elastic acrylic polymers, and combinations of these. Examples of nontransparent deformable materials that can be used include aluminum, titanium, and combinations of these.

[0024] Deformable layer **110** also has a backside **122** that opposes first side **120**. Backside **122** is adjacent ceramic layer **112**. As will be discussed below in greater detail, backside **122** may be adhered to or otherwise bonded directly to ceramic layer **112** or alternatively backside **122** may be held in direct contact with ceramic layer **112** without being bonded thereto. For example, deformable layer **110** and ceramic layer **112** can be adhered using a resin such as, but not limited to, poly(vinylbutiral) or secured together by fixing the layers within a frame and/or clamping.

[0025] The thickness of deformable layer **110** may be selected to enhance the generation of the compression wave. In one embodiment the deformable layer **110** has a thickness in a range from about 0.5 mm to about 10 mm, more preferably about 1 mm to about 4 mm. Opposing faces **120** and **122** can be disposed in parallel alignment so that the thickness is constant where the faces can be angled relative to each other so that the thickness varies one or both of faces **120** and **122**. Faces **120** and **122** can also be contoured, such as curved, so that they are not planar.

[0026] In a preferred embodiment, deformable layer **110** is a single layer of a homogeneous material. However, in some embodiments the deformable layer **110** may be made from a plurality of sub-layers that together are highly deformable (e.g., the sub-layers together have an elongation before failure of at least about 20%).

[0027] Ceramic layer **112** is positioned adjacent to and between deformable layer **110** and fracture layer **114**. Ceramic layer **112** has a front side surface **124** and an opposing backside surface **128**. Backside surface **128** is adjacent fracture layer **114**. Ceramic layer **112** can be adhered to or otherwise bonded to deformable layer **110** and/or fracture layer **114** similarly to the connection between ceramic layer **112** and deformable layer **110**.

[0028] Ceramic layer **112** is made from a strong, ballistic-resistant material having a high sound velocity. The ceramic material will typically have a sound velocity in a range from about 2-50 km/s, more specifically 4-30 km/s, or even more specifically 8-20 km/s. Ceramic layer **112** may also be transparent. Examples of suitable transparent material include sapphire, aluminum oxinitride (AlON), spinel, AlN, alumina, and combinations of these. Nontransparent materials can also be used. Examples of nontransparent materials include, but are not limited to, silicon carbide, boronitride, boron carbide, diamond, and combinations of these. These materials and similar materials with a high sound velocity are advantageous for allowing the compression wave generated in the deformable layer **110** to spread out as it travels through ceramic layer **112** and for providing toughness in a thin layer.

[0029] The thickness **132** of ceramic layer **112** is typically selected to provide maximum strength while minimizing weight. Ceramics such as sapphire, aluminum oxynitride (AlON), and spinels typically need to have a minimal thickness before they will outperform plastic materials (e.g., about 0.25 mm). After this minimal thickness ceramics tend to provide better protection than plastics, but with increased weight, as the density of transparent ceramics are 2 to 3 times higher than the density of plastics. Thus, even where cost is not an issue, practical weight restrictions in some cases will limit the thickness of ceramic layers.

[0030] Even when relatively thick ceramic layers can be used, a thick ceramic layer tends to transfer impact velocity to the substrate (e.g. the frames of protective eyewear), which may not be able to handle increased forces and the whole system must be strengthened, again with weight increase. Thus in some embodiments of the invention it is desirable to minimize the thickness of the ceramic layer **112**. In one embodiment, the thickness may be less than 10 mm, more preferably less than about 6 mm, even more preferably less than about 4 mm, and most preferably less than about 2 mm. In one embodiment of thickness **132** can be in a range from about 0.5 mm to about 6 mm, more preferably about 0.8 mm to about 4 mm, and most preferably from about 1 mm to about 2 mm.

[0031] In one embodiment of the invention ceramic layer **112** may be a continuous and/or homogeneous layer of the ceramic material. However in an alternative embodiment ceramic layer **112** may include a plurality of sub-layers of the ceramic material. The sub-layers may be the same or different ceramic materials and may be bonded or adhered together as previously discussed with respect to the connection between deformable layer **110** and ceramic layer **112**.

[0032] Fracture layer **114** is adjacent to and between ceramic layer **112** and spall liner **116**. Fracture layer **114** has a front side **130** and an opposing backside **134**. Backside **134** may be adhered to or bonded to a front surface **136** of spall liner **116** any manner similar to the connection between deformable layer **110** and ceramic layer **112** as discussed above.

[0033] Fracture layer **114** is configured to receive a compression wave that has traveled through ceramic layer **112**. Fracture layer **114** is configured to at least partially disintegrate upon receiving the compression wave. Fracture layer **114** is selected to have a low fracture toughness and high surface energy, which will maximize fracture absorption energy, typically at the expense of impact resistance. Typically, a lower fracture threshold will give better energy absorption and less momentum transfer to the armor plate supporting structure. In one embodiment, fracture layer **114** can be made from a brittle transparent material. Examples of suitable materials include glass, soda glass, transparent silicates, and combinations of these. Examples of nontransparent materials include nontransparent silicates. Within a given glass type, absorbed fracture energy can be manipulated by tempering the glass.

[0034] Fracture layer **114** is selected to have a lower impact resistance than ceramic layer **112**. However, fracture layer **114** is configured to absorb substantial amounts of energy through fracturing. If desired, fracture layer **114** can even be configured to absorb more energy than ceramic layer **112**. To achieve high energy absorption by fracture layer **114**, armor plate **100** is configured to cause a relatively large volume of fracture layer **114** to fracture into fine particles.

[0035] The energy absorbed by fracture layer **114** depends on the velocity of the crack propagation and the fractured grain size. FIG. **3** shows fracture energy as a function of crack propagation velocity for soda glass (extrapolated from J. O. Atwater. "Fracture energy of glass" DTIC report #640848, 1966). With an intense shock wave, crack propagation velocity is pinned to the speed of sound in the brittle material of fracture layer **114**. In the case where ceramic layer **112** is made of sapphire, the speed of sound is 11.2 kmfs and at the sapphire-glass interface crack propagation velocity will be the same. This corresponds to 30 J/m^2 surface energy for a soda-lime glass, or almost fifteen times more than for a slow impact event.

[0036] In order to absorb large amount of energy, fractured particle size must be sufficiently small. The absorbed energy increases exponentially with a decrease in the diameter of the fractured particle size do to the increase in surface area. FIG. **4** is a graph showing surface area as a function of the particle size. FIG. **5** shows the energy absorbed by 1 cm^3 of glass fractured at 11 km/s impact. To illustrate the potential energy absorption of fractured glass, the energy of an AK-47 bullet is plotted on the graph of FIG. **5**. As shown in FIG. **5**, 1 cm^3 of glass is, in principle, capable of absorbing all the energy from a rifle bullet if the fractured grain size is smaller than about 1×10^{-7}. The armor plate **100** of the present invention provides for substantial energy absorption in fracture layer **114** by generating a compression wave in deformable layer **110** and spreading the compression wave in ceramic layer **112**.

[0037] The thickness of fracture layer **114** can be selected to provide adequate volume for absorbing a compression wave generated in deformable layer **110**. With reference now to FIG. **1**, in one embodiment the thickness **138** of fracture layer **114** can be in a range from about 0.5 mm to about 10 mm, more specifically about 1 mm to about 5 mm.

[0038] Fracture layer **114** is backed by spall liner **116** to stop (i.e. catch) the fractured glass particles. Spall liner **116** has a front surface **136** that is adjacent fracture layer **114**. In one embodiment, a back surface **140** of spall liner **116** is configured to be the back surface **119** of armor plate **110**.

[0039] When a bullet strikes armor plate **100** and fracture layer **114** is pulverized, the disintegrated particles will be small, but can still carry residual momentum. Spall liner **116** is made from a material capable of capturing the fine particles generated from fracture layer **114**. In one embodiment spall liner **116** may have relatively high elasticity such that spall liner **116** can expand to absorb the momentum of the fractured particles without rupturing. Examples of suitable materials that can be used to make spall liner **116** include polymers such as polycarbonate; woven ballistic fibers including para-aramids (e.g., Kevlar), ultra-high strength polyethylene fiber (e.g., Spectra and Dyneema), poly(p-phenylene-2,6-benzobisoxazole) (PBO), and/or boron fibers; polyurethane; and combinations of these. In one embodiment, spall liner **116** can be made from a transparent material such as polycarbonate or Dynema. Alternatively, spall liner **116** can be nontransparent.

[0040] The thickness of spall liner **116** is selected to ensure sufficient strength to withstand the residual momentum of the fractured particles from fracture layer **114**. Typically the thickness of spall liner **116** may be in a range from about 0.5 mm to about 10 mm, more specifically between about 1 mm and 4 mm.

[0041] FIG. **2** illustrates how armor plate **100** dissipates momentum from bullet **118**. FIG. **2** shows bullet **118** penetrating front surface **117** of armor plate **100**. At the initial phase of a ballistic impact deformable layer **110** deforms, creating the equivalent of local compression. The compression wave then spreads out at a velocity close to the speed of sound in ceramic layer **112**. As bullet **118** moves through ceramic layer **112** it generates a lattice wave by moving dislocations, thereby transforming an additional portion of the projectile energy into acoustic waves. The intensity ratio of the compression wave to the lattice waves generated by moving dislocations depends on the thickness of the deformable layer **110** and ceramic layer **112** relative to the projectile diameter and the properties of the materials used for deformable layer **110** and ceramic layer **112**. The approach taken in making existing body armor typically relies on the theory that moving dislocations can last for a relatively long time, thereby spreading total wave generation over time and making the impact less intense. In reality this scenario is difficult to achieve, as deformation needed to absorb significant energy typically is outside of acceptable armor plate thickness for most applications. Hard ceramic plates efficiently convert impact energy into the compression wave. This compression wave fractures a portion of the ceramic, absorbing energy. High impact strength of the ceramics results in the energy absorption in a fixed volume. As a result, thin ceramics do not work well. Also, only a strong wave can fracture ceramics. Lower intensity waves go unaffected, contributing to the momentum transfer to the substrate, which is especially undesirable for a wearable armor.

[0042] In contrast, the proposed invention takes a counter-intuitive approach. Armor plate **100** includes a soft material in front ceramic layer **112** (i.e., deformable layer **110**). Instead of mitigating a shock wave, deformable layer **110** and ceramic layer **112** are amplifying the shock wave. As a projectile moves through deformable layer **110**, pressure on ceramic layer **112** builds up, effectively accumulating the compression wave. Lattice wave generation also lasts longer.

[0043] The speed of sound in deformable layer **110** may be selected to be relatively small. When the compression wave reaches ceramic layer **112**, for example sapphire, it accelerates to the speed of sound (e.g., from 3 km/s to 11 km/s), thus becoming more intense. The compression wave also spreads out. When the compression waves hits the fracture layer **114** it is close in intensity to the impact point, but can be spread out over the area two orders of magnitude larger than the projectile cross-section area.

[0044] When a brittle solid fractures, the amount of energy absorbed depends on the grain size of the fractured material. The fracture energy is inversely proportional to the square root of the fractured grain size. Thus, how the layer fractures may be important to its ability to absorb impact energy. Armor plates manufactured according to methods known in the art tend to have a fracture zone that look like a cone propagating from the location of the impact, where the material closest to the impact site may have a fine grain fracture size, but much of the fractured material has a large grain fracture size and low energy dissipation. In contrast, the armor plate **100** of the present invention disperses the impact laterally, which causes fine grain fractures to occur over a much wider surface area. This energy absorption allows the armor plate **100** of the present invention to protect against higher velocity projectiles compared to known armor plates with a similar thickness.

[0045] With reference now to FIG. **6**, deformable layer **110**, ceramic layer **112**, fracture layer **114**, and spall liner **116** can be joined together to form plate **100** using any technique known in the art. In one embodiment, the layers of armor plate **100** are joined together using curable resins, heat, adhesives, and/or pressure. Preferably, the layers are secured to each other such that armor plate **100** is at least translucent and preferably transparent. In one embodiment transmission values of light in the visible spectrum is at least about 70%, more preferably at least about 80%, and even more preferably at least about 90%.

[0046] FIG. **6** illustrates an example embodiment where deformable layer **110**, ceramic layer **112**, fracture layer **114**, and spall liner **116** are joined together by a plurality of intermediate layers such as adhesive layers **142***a*, **142***b*, and **142***c*. Adhesive layers **142***a*, **142***b*, and **142***c* can be made from any material compatible with deformable layer **110**, ceramic layer **112**, fracture layer **114**, and/or spall liner **116**. Examples of suitable materials include polymers or resins such as, but not limited to, polyvinyl butyral, cyanoacrylates, epoxies, polyurethanes, acrylics, and combinations of these. The adhesives may be transparent or nontransparent. In one embodiment intermediate layers such as, but not limited to adhesive layers **142**, may have a thickness less than 10 mm, more specifically less than about 2 mm, more specifically less than about 1 mm, or even less than 100μ. if present, the intermediate layers have a thickness that does not prevent a compression wave from traveling between deformable layer **110**, ceramic layer **112**, and/or fracture layer **114**. For many materials, a thickness less than 2 mm more preferably less than 1 mm can be used.

[0047] The layers of armor plate **100** can also be held together in parallel using means other than an adhesive. For example, armor plate **100** can have deformable layer **110**, ceramic layer **112**, and/or fracture layer **114** in free contact with one another, but clamped together using a frame or other clamping mechanism. A frame or other substrate, such as those illustrated in the devices shown in FIGS. **7-10**, can apply a positive force on armor plate **110** to clamp or otherwise secured the layers together.

[0048] The overall thickness of armor plate **100** will typically depend on the amount of protection desired. Armor plates for preventing the penetration of high momentum projectiles may be of greater thickness than those for preventing the penetration of lower momentum projectiles, but with increased weight. In one embodiment the combined thickness of the deformable layer, ceramic layer, fracture layer, and spall liner have a thickness of less than 50 mm, more preferably less than 25 mm, even more preferably less than 20 mm, and most preferably less than 15 mm. In an alternative embodiment, the deformable layer, the ceramic layer, the fracture layer, and the spall liner have a combined thickness in a range from about 4 mm to about 25 mm, more preferably from about 5 mm to about 20 mm, and most preferably about 6 mm to about 15 mm.

[0049] In some embodiments it may be desirable to make armor plate **100** as thin and as light as possible while achieving a desired level of protection from projectile impact. To achieve a desired thinness, it can be advantageous to make armor plate **100** with only four layers (i.e., deformable layer, ceramic layer, fracture layer, and spall liner) and optionally an adhesive between one or more of the layers and/or a surface coating for modifying optical transmissions (e.g., a tint).

[0050] In one embodiment, armor plate **100** may include additional layers on front surface **117** and/or back surface **119**. For example, armor plate **100** may include coatings that modify the color and/or light transmission through armor plate **100**. In one embodiment a tint coating may be applied to armor plate **100**. For example, a tint coating may be desirable for an armor plate used as a window to reduce the amount of light entering through the window and/or to inhibit people on an outside of the window to see inside.

[0051] To form armor plate **100**, the layers of armor plate **100** can be temporarily fastened together, for example, with tape, and then placed in an autoclave, optionally under vacuum. The armor plate **100** may be pressurized and/or heated. Pressures that may be used include atmospheric, greater than atmospheric, greater than 2 bar, greater than 4 bar or greater than 8 bar. In some embodiments, pressure may be applied in a pressure chamber or by mechanical means, for instance, rollers or a press. Pressure and heat may be applied until the adhesive layers **142** (e.g., PVB) reach a softening point, allowing air bubbles to be expelled and allowing the adhesive to clarify and flow.

[0052] The softening temperature of adhesives layers **142** may be, for example, greater than 70° C., greater than 100° C., greater than 150° C., greater than 200° C., or greater than 250° C. In some embodiments the optimum temperature will depend on the pressure applied and the specific adhesive material used to bind the layers. In an alternative embodiment adhesive layers **142** can be polymerized to join the layers of armor plate **100**.

[0053] After hardening, cooling, and/or polymerizing, the layers of armor plate **100** are securely immobilized in relation to each other and may be mounted in a substrate. FIGS. **7-9** illustrate example supporting structures that armor plate **100** can be incorporated into. FIG. **7** shows an armored vehicle **150** having a first armor plate **100***a*, a second armor plate **100***b*, and a third armor plate **103** which function in Windows on vehicle **150**. Armor plates **100***a* and **100***b* are mounted in doors **152** and **154**, respectively of a body **156**. Armor plate **100***c* functions as a front window Body **156** provides a protective enclosure within its interior. Armor plates **100***a* and **100***b* may be transparent so as to allow personnel in the interior of body **156** the ability to view the surroundings exterior to body **156**. Body **156** may be made from an armored material, which is typically opaque. Armored vehicle **150** can include wheels **158** an engine cabin **160** and other features typical of vehicles for providing locomotion (e.g., engine and drivetrain). Armored vehicle **150** can be of any type known in the art, including but not limited to, cars, trucks, boats, airplanes, trains, and the like.

[0054] FIG. **8** illustrates a helmet **200** that incorporates an armor plate **100***d* according to the present invention. Armor plate **100***d* is incorporated into a visor **202** having a curved surface secured to a helmet structure **204** through a pair of fasteners **206** on opposing sides of helmet structure **204**. Visor **202** functions as a transparent face shield. Helmet **200** may include one or more brackets **208** and **210** to support visor **202**. Visor **202** is preferably transparent so as to allow a person wearing helmet **200** to view their surroundings. Armor plate **100** is particularly advantageous when used in articles that are worn on the head of a person. The use of fracture layer **114** and armor plate **100** allows substantial percentages of the momentum of a bullet or other object to be absorbed into fracture layer **114** without transferring momentum to be supporting structures such as helmet structure **204**. This protects the wearer from injuries that can be caused by rapid acceleration of helmet **200**.

[0055] FIG. **9** illustrates yet another embodiment of a device that can incorporate armor plate **100**. FIG. **9** shows goggles **220** having armor plate **100***e*, which function as a lens. Armor plate **100***e* is mounted in frame structure **222**. Armor plate **100***e* can be shaped to provide a lens for correcting myopia and/or hyperopia. A strap to 24 allows goggles **220** to be worn on a person's head.

[0056] While FIGS. **6-8** illustrate specific examples of devices in which armor plate **100** may be incorporated, those skilled in the art will recognize that armor plate **100** may be incorporated into any structure where a thin, armored, transparent and/or translucent plate is desirable. For example, armor plate **100** may be used in windows of buildings, paneling or walls in or on buildings, including buildings where target shooting is carried out. While the present invention is advantageous for use with devices that need to be armored against artillery threats, the present invention is not limited to these. Armor plate **100** can be used in any application where a projectile could pose a threat (e.g., motorcycle helmets designed to protect against flying debris on a road).

[0057] In one embodiment armor plate **100** can be segmented into a panel of armor plates. FIG. **10** illustrates a panel **250** having four segmented armor plates **100***f*. Segmented armor plates **100***f* are mounted in a frame structure **252**. Segmenting the armor plates reduces crack propagation between portions of the armor plate. In one embodiment, the individual segments are sized to minimize crack propagation between segments while providing a suitable viewing area. Minimizing crack propagation prevents one segment from being compromised by a bullet striking an adjacent segment. In one embodiment this segment can have a surface area in a range from about 0.5 in^2 to about 10 in, 1-4 inches.

EXAMPLES

[0058] The following examples provide formulas for making transparent armor plates according to one embodiment of the invention.

[0059] Example 1 describes a first type of armored plate (Type I). Type I had a deformable layer of 0.05" thick Lexan, followed by 0.065" of sapphire (ceramic layer), then 0.125" soda lime glass (fracture layer) and 0.0935" of Lexan (spall liner). The sandwich was glued with a thin layer (25μ) of transparent poly(vinylbutiral) resin.

[0060] Example 2 describes a second type of armor plate (Type II). Type II sandwich was made of 0.05" Lexan (deformable layer), 0.065" sapphire (ceramic layer), 0.0625" soda lime glass (fracture layer) and 0.125" Lexan (spall liner). The sandwich was glued with a thin layer (25μ) of transparent poly(vinylbutiral)].

[0061] Example 3 describes a third type of armored plate (Type III). Type III was made of 0.05" Lexan (deformable layer), followed by 0.1425" of sapphire (ceramic layer), then 0.075" glass (fracture layer) and 0.1" of Lexan (spall liner).

[0062] Example 4 describes a fourth type of armored plate (Type IV). Type IV was made of 0.05" Lexan (deformable layer), followed by 0.0625" of sapphire (ceramic layer), then 0.125" glass (fracture layer) and 0.1" of Lexan (spall liner).

[0063] Example 5 describes a fifth type of armored plate (Type V). Type V was made of 0.1" Lexan (deformable layer), followed by 0.12" of spinel (ceramic layer), then 0.12" glass (fracture layer) and 0.1" of Lexan (spall liner).

[0064] Type III-V were bonded using an extra thick (1-1.2 mm) adhesive layer instead of the desired 25μlayer. As expected, this increase in the adhesives they are attenuated the shock wave on the interface between the ceramic she and the fracture layer, thereby adversely affecting armor plate performance. Nevertheless, Examples III-V outperform traditional transparent armor plates.

[0065] Ballistic tests were conducted at the Indian Head Naval Surface Warfare Center range. Tests were with 22-caliber 17-grain fragment simulating projectile (FSP). This FSP is a standard projectile for transparent armor testing. Changing propellant mass in a cartridge varied projectile velocity. Four Ohler model 57 beam interrupter velocity screens were used to measure the velocity. The target system had a motor controlled positioning. The velocity data was collected using a high-speed data acquisition system. A high speed Phantom camera provided video recordings of the shots. Example Test parameters are shown in Table 1 below, where PP indicates partial sample penetration. The tests shown in Table 1 are for Type I materials. Similar tests were performed for samples Types II-IV.

TABLE 1

Shot #	Powder	Projectile	Charge Wt (g)	Velocity (rUs)	Penetration
1.	Black Powder	0.22 FSP	0.25	1281	PP
2.	Black Powder	0.22 FSP	0.275	1279	PP
3.	Black Powder	0.22 FSP	0.32	1369	PP
4.	Black Powder	0.22 FSP	0.35	1445	PP
5.	Black Powder	0.22 FSP	0.375	1519	PP
6.	Black Powder	0.22 FSP	0.4	1545	PP
7.	Black Powder	0.22 FSP	0.425	1628	PP
8.	Black Powder	0.22 FSP	0.425	1577	PP
9.	Black Powder	0.22 FSP	0.45	1529	PP
10.	Black Powder	0.22 FSP	0.475	1681	PP
11.	Black Powder	0.22 FSP	0.5	1492	PP

[0066] Test results for Types I-V are shown FIG. **11** in the form of V_{50} velocities versus plate weight normalized to the area unit. FIG. **11** also shows V_{50} for Lexan (dotted line) and sapphire (solid line). As shown in the data plotted in FIG. **11**, all the samples from Example 1-5 outperformed sapphire and Lexan. Moreover, extrapolated velocities indicate better performance by the transparent armor plates of the present invention than for any most, if not all, existing transparent armor, even without layer optimization.

[0067] As shown in FIG. **11**, Type I samples significantly outperformed Type II samples, providing more than 1700 Ft/s V_{50}. This result indicates that increasing the glass thickness at the expense of Lexan improves armor plate performance. This is a surprising and unexpected result since glass alone is very inferior to Lexan. This result also confirms that a significant portion of the projectile's momentum was absorbed in the fracturing of the glass.

[0068] The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

What is claimed is:

1. An armor plate comprising:

a deformable layer comprised of a material having an elongation before failure of at least about 20%;

a ceramic layer adjacent the deformable layer;

a fracture layer adjacent the ceramic layer; and

a spall liner backing the fracture layer.

2. The armor plate as recited in claim **1**, wherein the deformable layer is comprised of polycarbonate.

3. The armor plate as recited in claim **1**, wherein the deformable layer has an elongation before failure of at least about 50%.

4. The armor plate as recited in claim **1**, wherein the deformable layer has an elongation before failure of at least about 100%.

5. The armor plate as recited in claim **1**, wherein the deformable layer has an average thickness in a range from about 1 mm to about 4 mm.

6. The armor plate as recited in claim **1**, wherein the ceramic layer is comprised of sapphire, aluminum oxynitride, spinel, AlN, alumina, silicon carbide, boronitride, boron carbide, diamond, and combination thereof.

7. The armor plate as recited in claim **1**, wherein the ceramic layer has an average thickness in a range from about 1 mm to about 2 mm.

8. The armor plate as recited in claim **1**, wherein the fracture layer is selected from the group consisting of glass, soda glass, a silicate material, or a combination thereof.

9. The armor plate as recited in claim **1**, wherein the fracture layer has an average thickness in a range from about 0.5 mm to about 5 mm.

10. The armor plate as recited in claim **1**, wherein the spall liner is comprised of a polycarbonate.

11. The armor plate as recited in claim **1**, wherein the deformable layer provides the initial impact layer for a projectile striking the armor plate.

12. The armor plate as recited in claim **1**, the deformable layer, the ceramic layer, the fracture layer, and the spall liner have a combined thickness in a range from about 4 mm to about 15 mm.

13. The armor plate as recited in claim **1**, further comprising an adhesive joining the deformable layer and the ceramic layer, joining the ceramic layer and the fracture layer, and/or joining the fracture layer and the spall liner.

14. The armor plate as recited in claim **1**, wherein the deformable layer has a thickness in a range from about 1 mm to about 4 mm, the ceramic layer has a thickness in a range from about 1 mm to about 2 mm, and the fracture layer has a thickness in a range from about 0.5 mm to about 5 mm, and the spall liner has a thickness in a range from about 1 mm to about 4 mm.

15. The armor plate as recited in claim **1**, wherein the deformable layer, the ceramic layer, the fracture layer, and the spall liner are transparent.

16. A vehicle comprising a body having one or more windows comprised of the armor plate as defined in claim **15**.

17. An armored helmet including a visor comprising the armor plate as defined in claim **15**.

18. A goggle having one or more lenses comprised of the armor plate as defined in claim **15**.

19. A transparent armor plate, comprising:

a transparent deformable layer configured to receive an initial impact force of a projectile and generate a compression wave;

a fracture layer;

a transparent ceramic layer disposed between the deformable layer and the fracture layer, the transparent ceramic layer configured to receive the compression wave from the deformable layer and transfer the energy thereof to the fracture layer,

wherein the fracture layer is configured to dissipate the compression wave by fracturing; and

a spall liner backing the fracture layer and configured to contain the fractured layer after being fractured.

20. A transparent armor plate as in claim **19**, wherein the transparent deformable layer has an elongation before failure of at least about 50%.

21. A transparent armor plate as in claim **19**, wherein the deformable layer, the ceramic layer, the fracture layer, and the spall liner have a combined thickness in a range from about 4 mm to about 15 mm.

22. A transparent body armor material as in claim **19**, wherein the transparent deformable layer comprises polycarbonate, the transparent ceramic layer is selected from the group consisting of sapphire, aluminum oxynitride, spinel, or a combination thereof, and the transparent fracture layer includes glass, soda glass, a silicate material, or a combination thereof.

23. A transparent armor plate consisting essentially of:

a transparent deformable layer comprised of a material having an elongation before failure of at least 20%;

a transparent ceramic layer adjacent the deformable layer;

a transparent fracture layer adjacent ceramic layer;

a transparent spall liner backing the fracture layer;

optionally an adhesive bonding two or more of the layers of the armor plate together; and

optionally a tint coating.

24. A transparent armor plate as in claim **23**, wherein the deformable layer comprises polycarbonate.

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