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Joynt et al.(10) **Pub. No.: US 2009/0293709 A1**(43) **Pub. Date: Dec. 3, 2009**(54) **APPARATUS FOR DEFEATING HIGH ENERGY PROJECTILES****Publication Classification**(51) **Int. Cl.**
F41H 5/04 (2006.01)(52) **U.S. Cl.** **89/36.02**(57) **ABSTRACT**

The disclosed armor system for protecting a vehicle from high energy projectiles includes a leading layer, relative to the projectile trajectory, positioned exterior to the hull; a first plurality of sheet-like layers of a low density material positioned between the leading layer and the hull; and a second plurality of sheet-like high strength metal layers positioned between the leading layer and the hull. The individual ones of the first plurality of high strength metal layers are positioned alternating with, and to the rear of, individual ones of the second plurality of low density material layers. The leading layer can be one of a sheet-like metal layer, a metallicized grid layer, and the outer-most layer of the first plurality of low density materials layers. The materials of the high strength metal layers may be selected from high strength steel and high strength aluminum, and the materials of the low density material may be selected from low density polypropylene composites and R-Glass composites.

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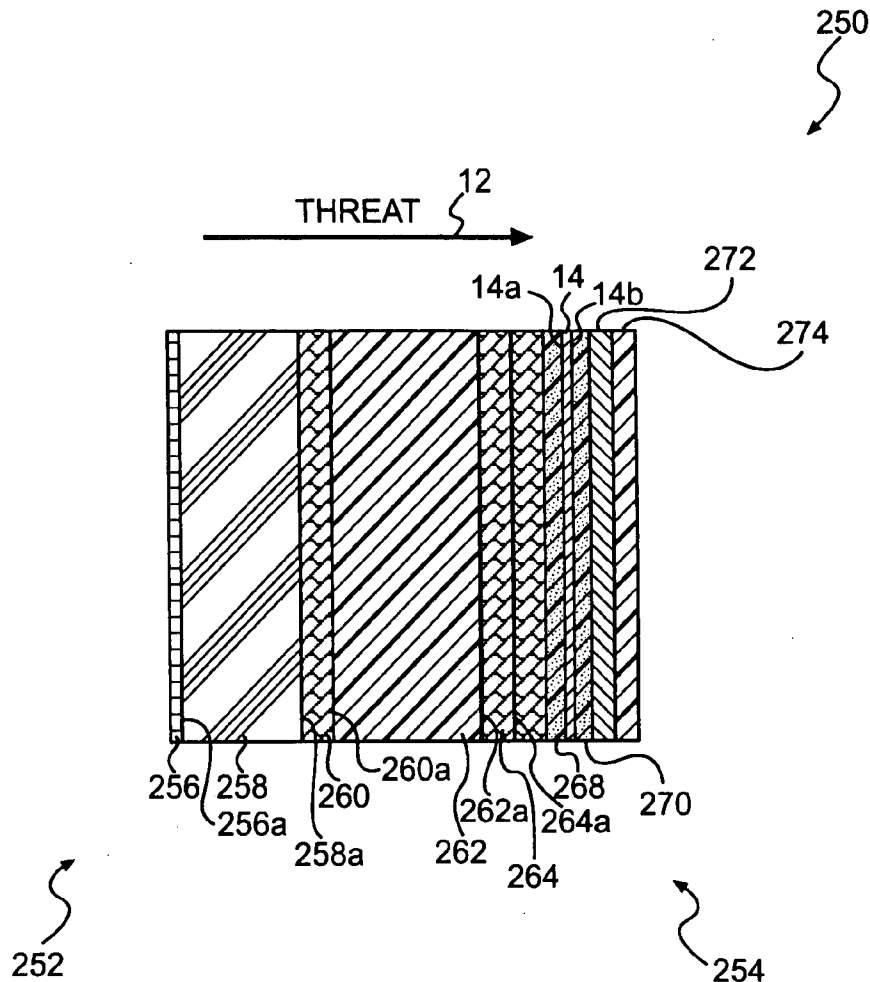
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WASHINGTON, DC 20001-4413 (US)(21) Appl. No.: **12/155,977**(22) Filed: **Jun. 12, 2008****Related U.S. Application Data**(60) Provisional application No. 61/071,917, filed on May
27, 2008.

FIG. 1

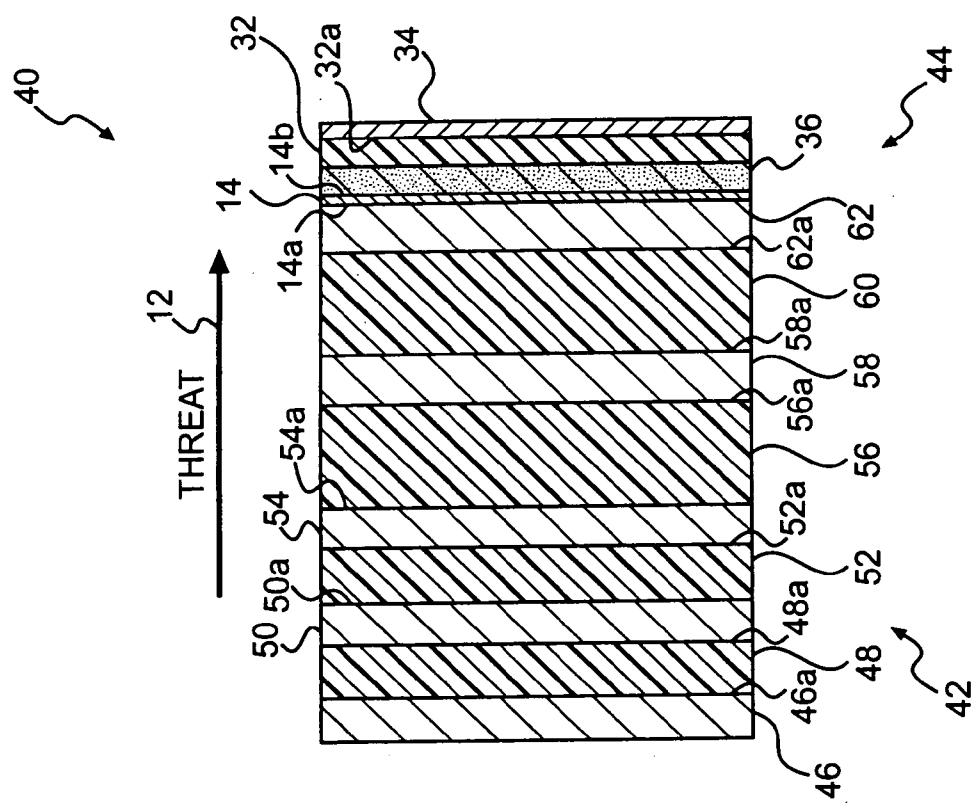


FIG. 2

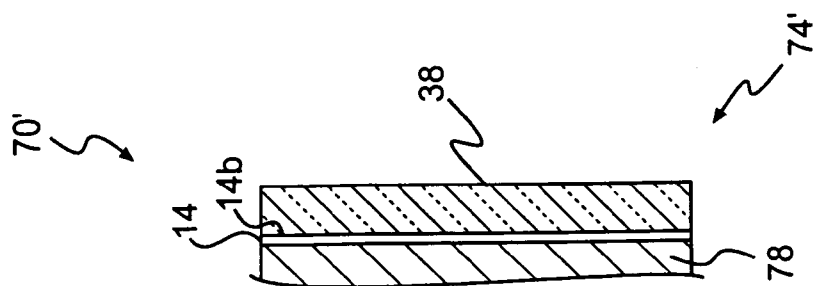


FIG. 3A

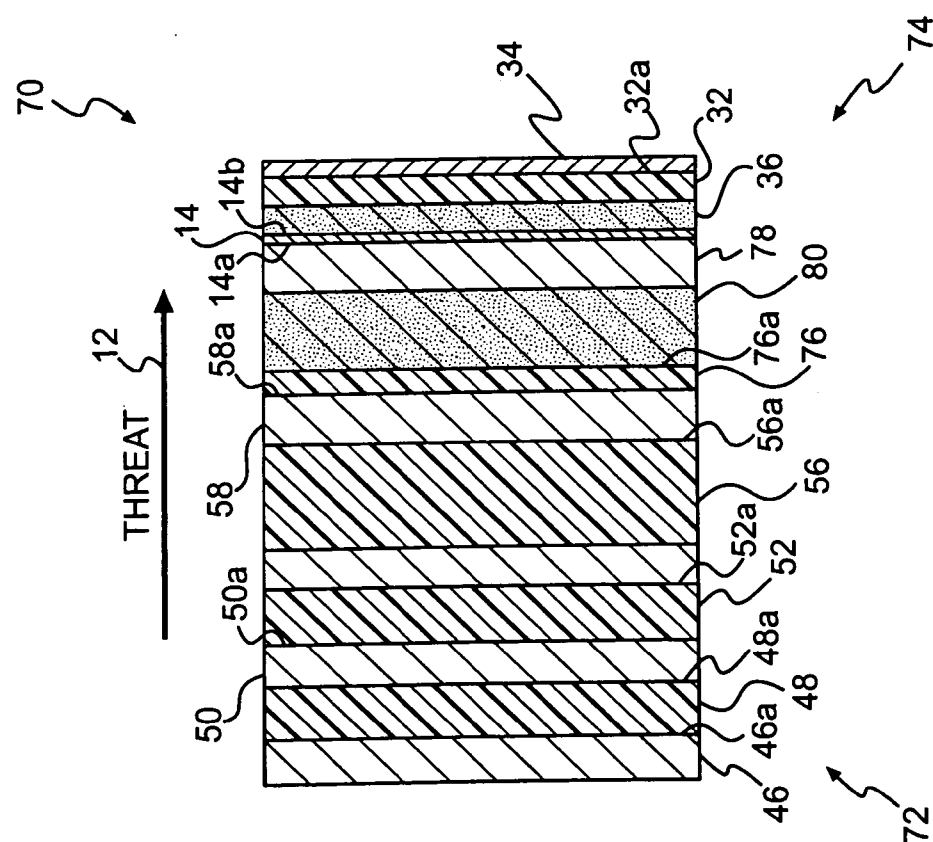


FIG. 3

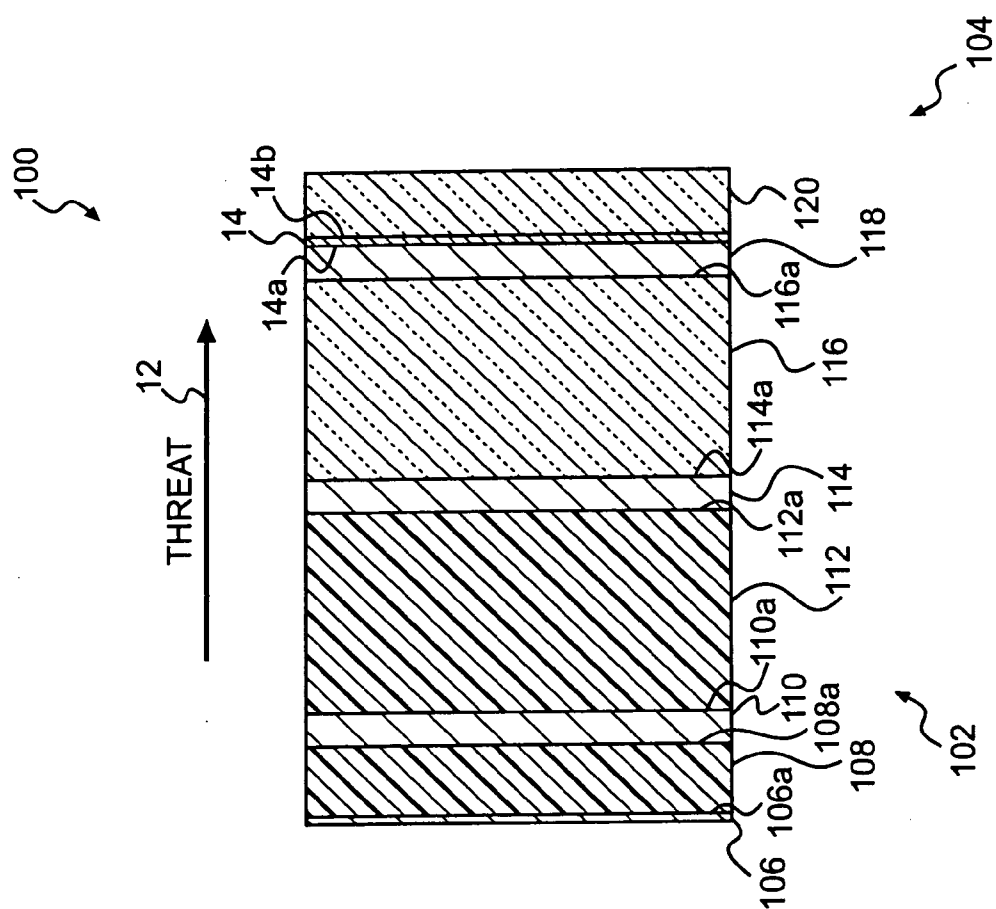


FIG. 4

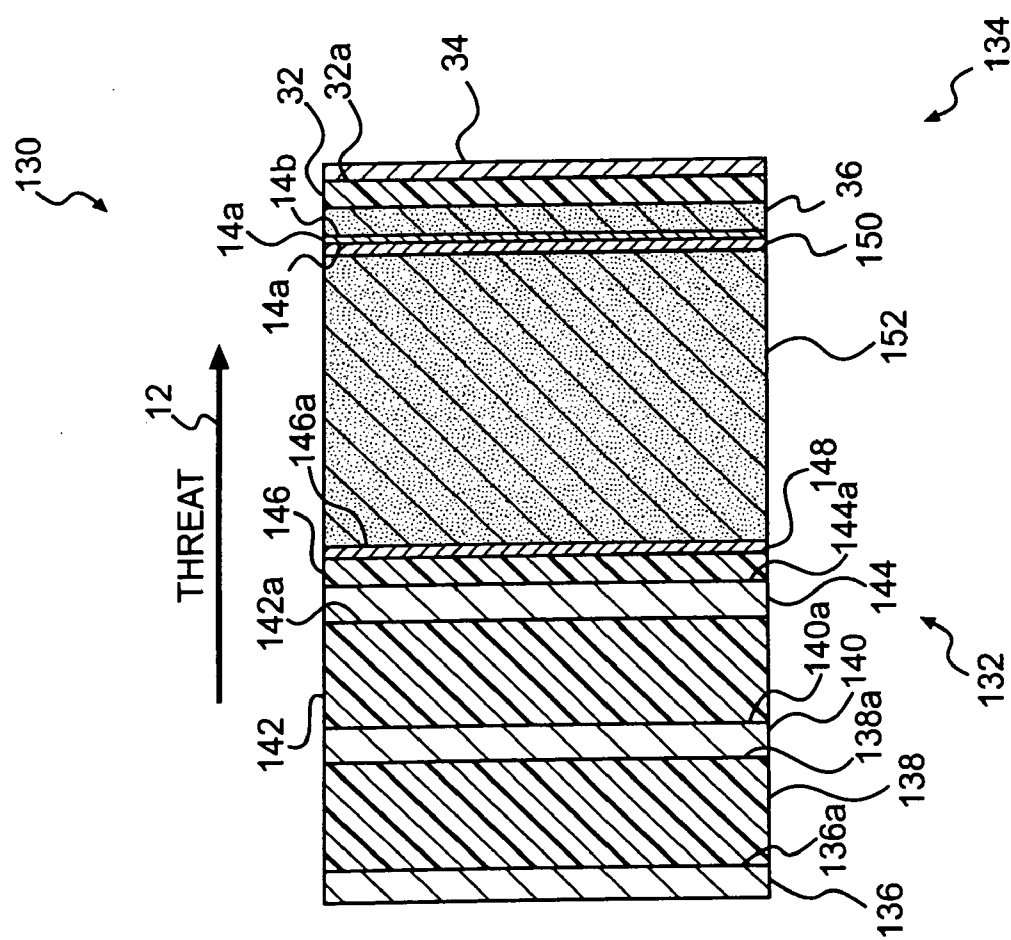


FIG. 5

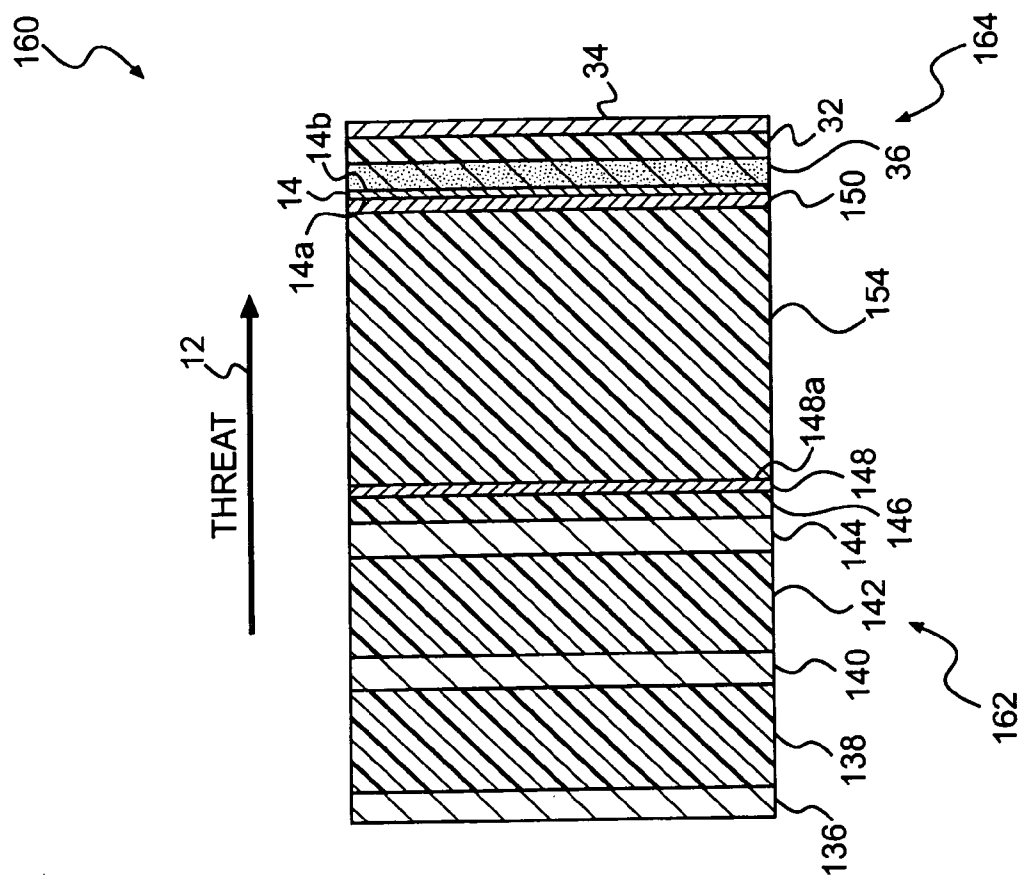


FIG. 6

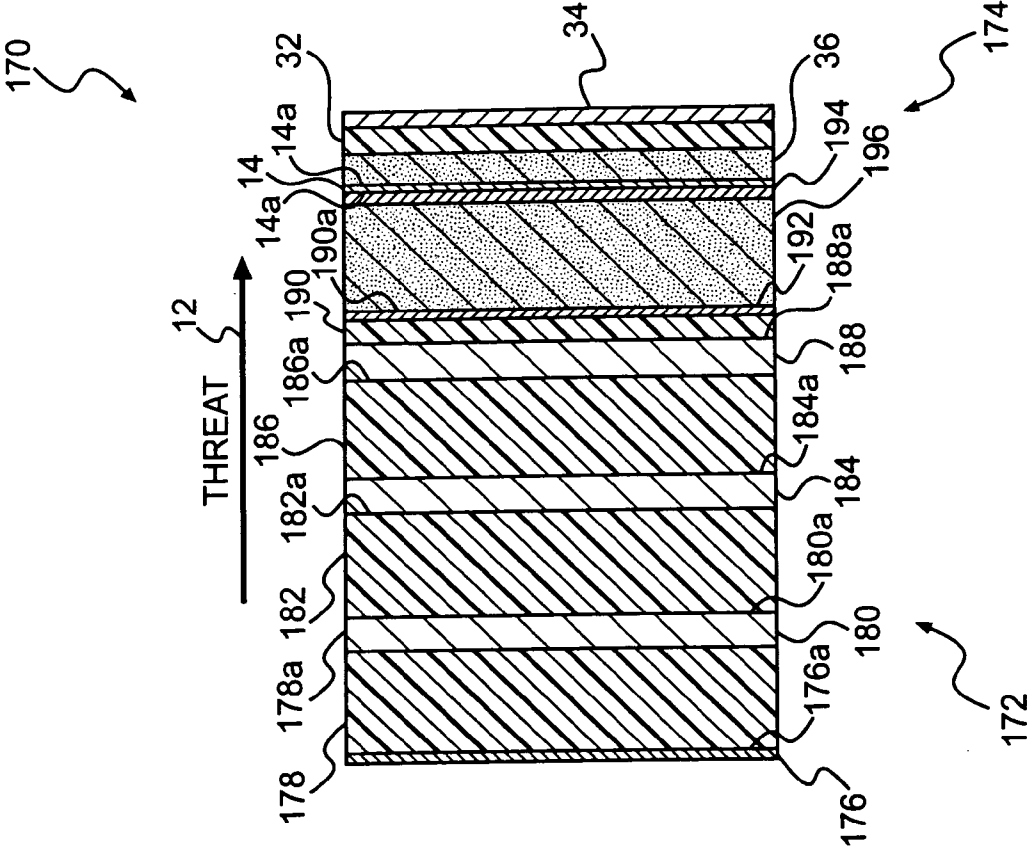


FIG. 7

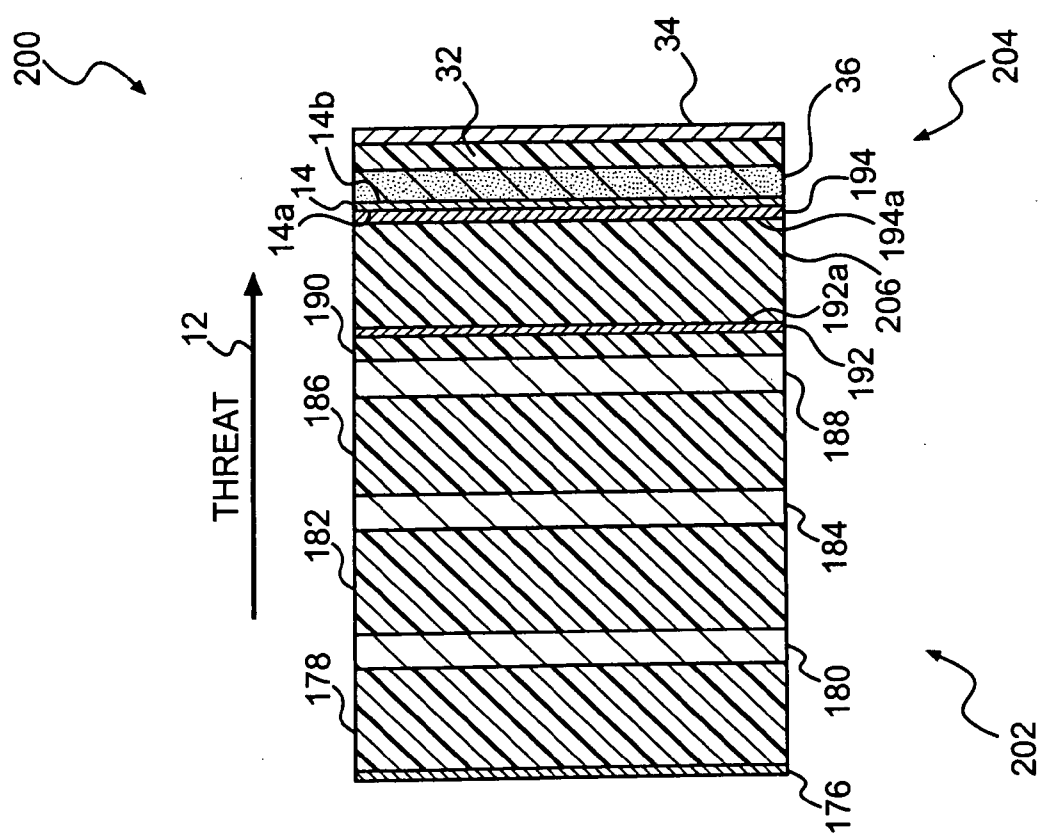


FIG. 8

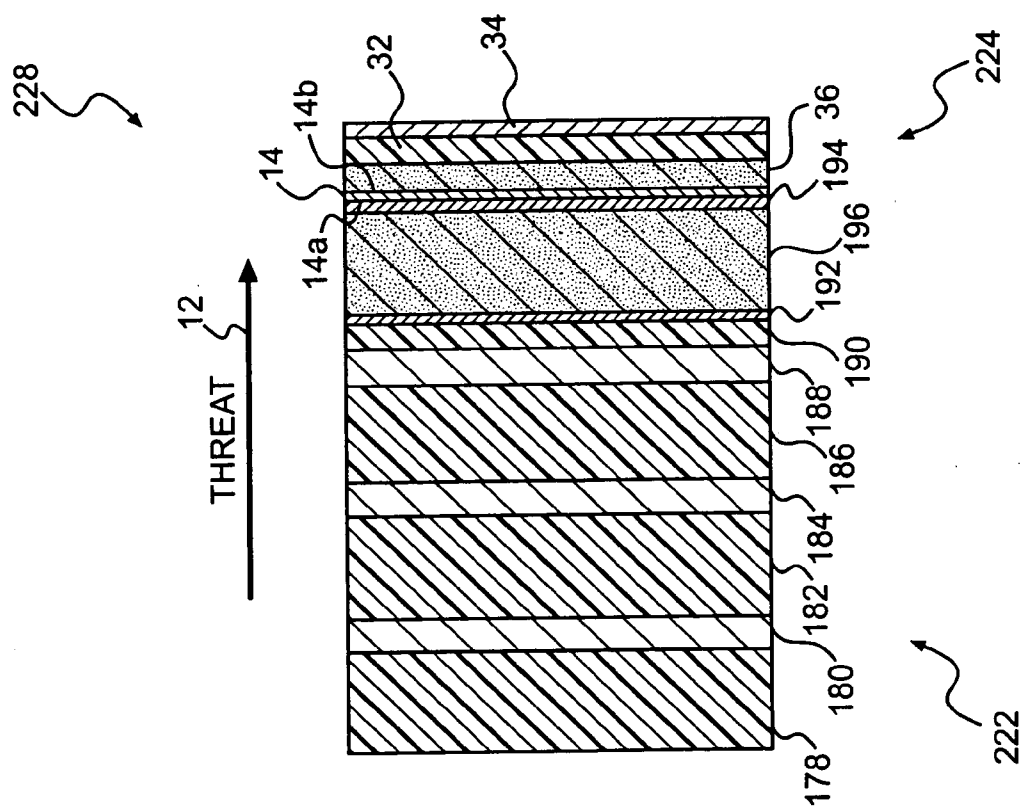


FIG. 9

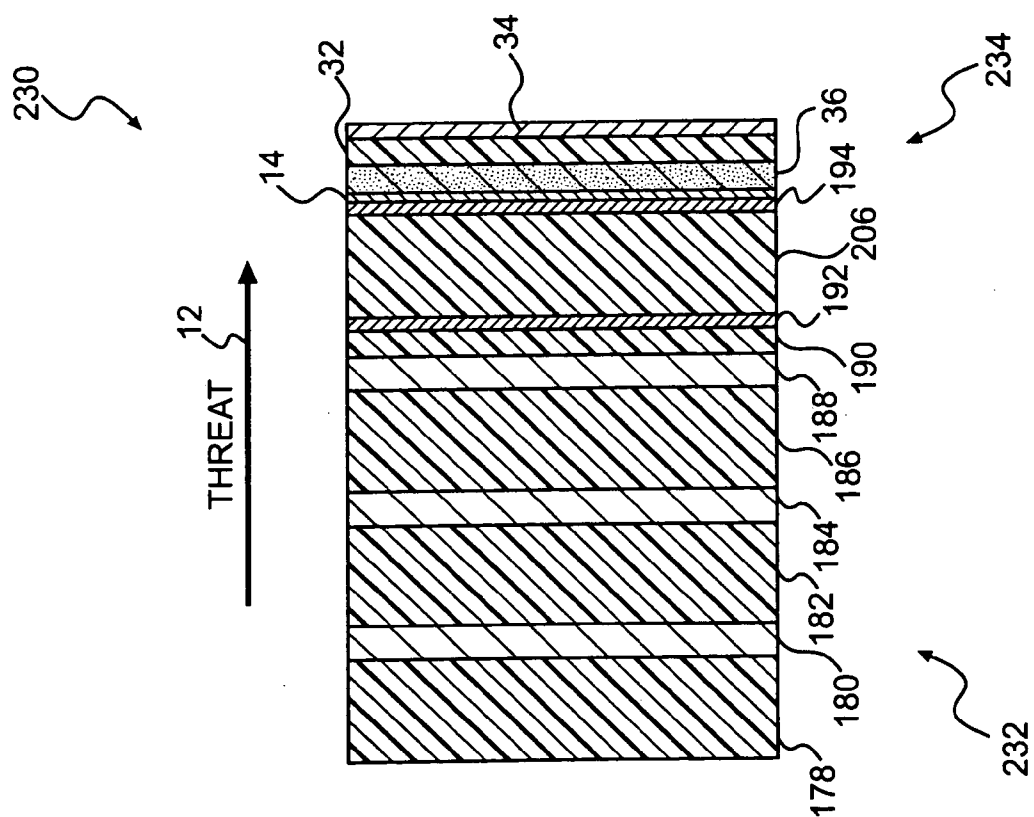


FIG. 10

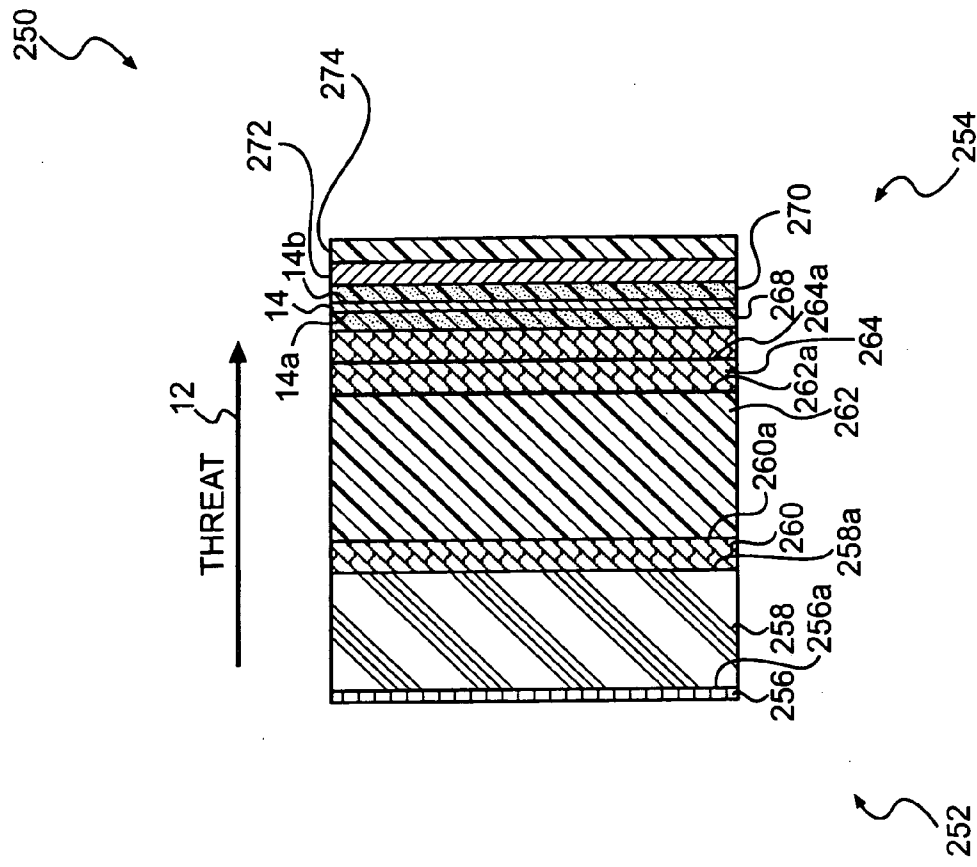


FIG. 11

APPARATUS FOR DEFEATING HIGH ENERGY PROJECTILES

PRIORITY

[0001] This non-provisional application claims priority to U.S. Provisional Patent Application No. 61/071,917 filed May 27, 2008.

FIELD OF THE INVENTION

[0002] The present invention relates to an armor system that resists penetration by high energy solid projectiles and high velocity jets e.g. from hollow charge weapons such as rocket propelled grenades.

BACKGROUND OF THE INVENTION

[0003] Conventional armor is subjected to a variety of projectiles designed to defeat the armor by either penetrating the armor with a solid or jet-like object or by inducing shock waves in the armor that are reflected in a manner to cause spalling of the armor such that an opening is formed and the penetrator (usually stuck to a portion of the armor) passes through the armor, or an inner layer of the armor spalls and is projected at high velocity without physical penetration of the armor.

[0004] Some anti-armor weapons are propelled to the outer surface of the armor where a shaped charge is exploded to form a generally linear "jet" of metal that will penetrate solid armor. Such weapons are often called Hollow Charge (HC) weapons. A rocket propelled grenade ("RPG") is such a weapon. An RPG 7 is a Russian origin weapon that produces a penetrating metal jet, the tip of which hits the target at about 8000 m/s. when encountering jets at such velocities solid metal armors behave more like liquids than solids. Irrespective of their strength, they are displaced radially and the jet penetrates the armor.

[0005] Various protection systems are effective at defeating HC jets. Amongst different systems the best known are reactive armors that use explosives in the protection layers that detonate on being hit to break up most of the HC jet before it penetrates the target. Such systems are often augmented by what is termed "slat armor," a plurality of metal slats disposed outside the body of the vehicle to prevent the firing circuit for an RPG from functioning.

[0006] A second type of anti-armor weapon uses a linear, heavy metal penetrator projected at high velocity to penetrate the armor. This type of weapon is referred to as EFP (explosive formed projectile) or SFF (self forming fragment) or a "pie charge" or sometimes a "plate charge."

[0007] In some of these weapons the warhead behaves as a hybrid of the HC and the EFP and produces a series of metal penetrators projected in line towards the target. Such a weapon will be referred to herein as a Hybrid warhead. Hybrid warheads behave according to how much "jetting" or HC effect it has and up to how much of a single, big penetrator-like an EFP it produces.

[0008] Another type of anti-armor weapon propels a relatively large, heavy, generally ball-shaped solid projectile (or a series of multiple projectiles) at high velocity. When the ball-shaped metal projectile(s) hits the armor the impact induces shock waves that reflect in a manner such that a plug-like portion of the armor is sheared from the surrounding material and is projected along the path of the metal projectile(s), with the metal projectile(s) attached thereto. Such an

occurrence can, obviously, have very significant detrimental effects on the systems and personnel within a vehicle having its armor defeated in such a manner.

[0009] While the HC type weapons involve design features and materials that dictate they be manufactured by an entity having technical expertise, the latter type of weapons (EFP and Hybrid) can be constructed from materials readily available in a combat area. For that reason, and the fact such weapons are effective, has proved troublesome to vehicles using conventional armor.

[0010] The penetration performance for the three mentioned types of warheads is normally described as the ability to penetrate a solid amount of RHA (Rolled Homogeneous Armor) steel armor. Performances typical for the weapon types are: HC warheads may penetrate 1 to 3 ft thickness of RHA; EFP warheads may penetrate 1 to 6 inches of RHA; and Hybrids warheads may penetrate 2 to 12 inches thick RHA. These estimates are based on the warheads weighing less than 15 lbs and fired at their best respective optimum stand off distances. The diameter of the holes made through the first inch of RHA would be: HC up to an inch diameter hole; EFP up to a 9 inch diameter hole; a Hybrids somewhere in between. The best respective optimum stand off distances for the different charges are: an HC charge is good under 3 feet but at 10 ft or more it is very poor; for an EFP charge a stand off distance up to 30 feet produces almost the same (good) penetration and will only fall off significantly at very large distances like 50 yards; and for Hybrid charges penetration is good at standoff distances up to 10 ft but after 20 feet penetration falls off significantly. The way these charges are used is determined by these standoff distances and the manner in which their effectiveness is optimized (e.g., the angles of the trajectory of the penetrator to the armor). These factors effect the design of the protection armor.

[0011] While any anti-armor projectile can be defeated by armor of sufficient strength and thickness, extra armor thickness is heavy and expensive, adds weight to any armored vehicle using it, which, in turn, places greater strain on the vehicle engine, and drive train, and thus has a low "mass efficiency."

[0012] Armor solutions that offer a weight advantage against these types of weapons can be measured in how much weight of RHA it saves when compared with the RHA needed to stop a particular weapon penetrating. This advantage can be calculated as a protection ratio, the ratio being equal to the weight of RHA required to stop the weapon penetrating, divided by the weight of the proposed armor system that will stop the same weapon. Such weights are calculated per unit frontal area presented in the direction of the anticipated trajectory of the weapon.

[0013] Thus, there exists a need for an armor that can defeat the high energy projectiles (i.e., projectiles having velocities of greater than about 2500 m/s) from anti-armor devices without requiring excess thicknesses of armor, and thus have a high mass efficiency. Preferably, such armor would be made of materials that can be readily fabricated and incorporated into a vehicle design at a reasonable cost, and even more preferably, can be added to existing vehicles.

SUMMARY OF THE INVENTION

[0014] The present invention seeks to utilize the heretofore unappreciated ability of some low density, non-metal composite materials to degrade the effectiveness of such high energy projectiles such that known metal-type armor can

further slow and eventually defeat the projectiles using ballistics engineering considerations, e.g., for projectile velocities of about 1600 m/s or less.

[0015] In accordance with an aspect of the present invention an armor system for protecting a vehicle from high energy projectiles, the projectile having an expected trajectory and the vehicle having a hull, includes an armor subsystem configured to be mounted exterior to the vehicle hull along the expected trajectory, the exterior armor subsystem further including sheet-like layers of low density non-ceramic, non-metal composite materials alternating with sheet-like layers of high strength metal materials.

[0016] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

[0017] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate several embodiments of the invention and together with the description, serve to explain the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] FIG. 1 is a schematic, cross-sectional view of a first embodiment of the invention;

[0019] FIG. 2 is a schematic, cross-sectional view of a second embodiment of the invention;

[0020] FIG. 3 is a schematic, cross-sectional view of a third embodiment of the invention, and FIG. 3A is a variation thereof;

[0021] FIG. 4 is a schematic, cross-sectional view of a fourth embodiment of the invention;

[0022] FIG. 5 is a schematic, cross-sectional view of a fifth embodiment of the invention;

[0023] FIG. 6 is a schematic, cross-sectional view of a sixth embodiment of the invention;

[0024] FIG. 7 is a schematic, cross-sectional view of a seventh embodiment of the invention;

[0025] FIG. 8 is a schematic, cross-sectional view of a eighth embodiment of the invention;

[0026] FIG. 9 is a schematic, cross-sectional view of a ninth embodiment of the invention;

[0027] FIG. 10 is a schematic, cross-sectional view of a tenth embodiment of the invention; and

[0028] FIG. 11 is a schematic, cross-sectional view of an eleventh embodiment of the invention.

DESCRIPTION OF THE EMBODIMENTS

[0029] Reference will now be made in detail to the disclosed embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

[0030] FIG. 1 presents a first embodiment of the invention, namely an armor system generally designated by the numeral 10 for protecting a vehicle from high energy projectiles. In the following discussion, the projectile has an expected trajectory relative to the vehicle, which trajectory is designated by the numeral 12 in the figures. Trajectory 12 establishes a direction for understanding certain terms used in the following discussion, such as “leading,” “rear” or “behind,” “front,” etc., namely the direction that the components of armor system 10 would successively confront the projectile as it approached the vehicle hull, designated generally by the

numeral 14. Moreover, the terms are “exterior” and “interior” as used in conjunction with the vehicle hull 14 are given their usual meanings.

[0031] Specifically, armor system 10 in the FIG. 1 embodiment includes exterior armor subsystem 16 and interior armor subsystem 17. Exterior armor subsystem 16 more particularly includes a leading sheet-like layer 18 of high strength aluminum an intermediate sheet-like layer of a low density relative to metal materials polypropylene composite 20 abutting rear surface 18a of leading aluminum layer 18, and a sheet-like layer of 22 of high strength aluminum abutting rear surface 20a of the low density polypropylene composite layer 20. Further, exterior armor subsystem 16 includes another sheet-like layer 24 of a low density polypropylene composite abutting rear surface 22a of aluminum layer 22, and yet another sheet-like layer of aluminum 26 abutting rear surface 24a low density polypropylene composite layer 24. Still further, exterior armor subsystem 16 includes a further sheet-like layer of a 28 of a low density polypropylene composite abutting rear surface 26a of the aluminum layer 26, and a further sheet-like layer 30 of a high strength aluminum abutting rear surface 28a of the low density polypropylene composite layer 28.

[0032] While it may be preferred that the third intermediate aluminum layer 30 of exterior armor subsystem 16b also abuts to the exterior surface 14a of hull 14, as depicted in FIG. 1, aluminum layer 30 may be spaced from hull 14 such as by mechanical spacers or a low density foam-like material in order to provide a dispersion space, as taught in pending application Ser. No. 12/010,268 the disclosure of which is hereby specifically incorporated by reference.

[0033] Also, a low density polypropylene composite material is currently preferred for layers 20, 24 and 28, particularly a material called Tegriss® available from Milliken & Company, 920 Milliken Road, P.O. Box 1926, Spartansburg, S.C. 29303 USA. Such a material is described in U.S. Pat. No. 7,300,691 to Callaway et al., the content of which is incorporated by reference herein. However, one or more of these layers may be substituted by other low density materials such as R-Glass composites, S-Glass composites, E-Glass composites, Kevlar® reinforced polymer, Kevlar® reinforced polyethylene composites, and hybrid materials formed from one of these alternative low density materials. Kevlar® is a high strength aramid available from Dupont. E-Glass is a glass material that has a lower alkali content than ordinary “window” glass and has good tensile and compressive strength and stiffness. E-Glass is available in fiber form from AGY. R-Glass and S-Glass are similar to E-Glass but have higher tensile strength and modulus. R-Glass is available from OCV Reinforcements, and S-Glass is available from AGY. Kevlar® reinforced polyethylene composites are available from LTC. R-Glass composites are available from OCV Reinforcements. S-Glass composites are available from AGY. E-Glass composites are available from AGY.

[0034] One skilled in the art given the present disclosure may be able to search out and select other low density materials that could be used to replace one or more of the low density polypropylene composite layers 20, 24, and 28. As discussed more fully in pending application Ser. No. 61/064, 234, the entire disclosure of which is hereby incorporated by reference, these layers, while not traditionally thought of as “armor” components, have been found to help attenuate the high velocity jets of metals that may accompany high energy projectiles, and thus increase the chance of defeating such threats. Also, the high strength aluminum for layers 18, 22,

26, and 30 may be selected from known high strength aluminum materials such as 7039 and 5083 or any of the other aluminum alloys disclosed in pending application Ser. No. 12/010,268. One skilled in the art would immediately be aware of other high strength aluminum materials that could be substituted for one or more of the aluminum layers 18, 22, 26, and 30.

[0035] As also shown in the embodiment of FIG. 1, interior armor subsystem 17 includes a sheet-like layer of layer 32 of a low density polypropylene composite spaced a predetermined distance behind interior surface of hull 14, and a further sheet-like layer 34 of a hybrid aramid and glass composite abutting rear surface 32a of low density polypropylene composite layer 32. The spacing between low density polypropylene composite layer 32 and hull 14 can be achieved by mechanical spacers/fasteners or by the use of a layer 36 of an appropriate thickness of a low density foam material such as EL Foam P300 or any foam that meets FMVSS 302 Burn Rate Test, which foam layer may have only a minimal effect on defeating the high energy projectile or its accompanying jet or residual fragments but may nonetheless provide a dispersion space that may allow low density polypropylene composite layer 32 and hybrid aramid and glass composite layer 34 to contain any projectile residuals that manage to breach hull 14, including any spalling fragments from hull 14. Currently preferred materials for the low density polypropylene composite layer 32 include Tegriss® and for layer 34 a Kevlar® and E-Glass® hybrid composite available from LTC, although other materials can be used given the present disclosure, as one skilled in the art would understand.

[0036] An example of a particular armor system constructed in accordance with embodiment 10 depicted in FIG. 1 may have each of leading aluminum layer 18 and the first “intermediate” (i.e., positioned between the leading layer and the hull) aluminum layer 22 to be about 1¼ inch thick sheets, while each of the second and third intermediate aluminum layers 26 and 30 be about 1½ inch sheets. The first intermediate low density polypropylene composite layer 20 may be about 4½ inches thick, and the second and third intermediate low density polypropylene layers 24 and 28 be about 1½ inches thick. Also, foam layer/space 36 of interior armor subsystem 17 may be about ¾ inch thick; low density polypropylene composite layer 32 about ¾ inch thick; and Kevlar®/E-Glass hybrid layer 34 about ½ inch thick.

[0037] It is contemplated that the exterior armor subsystem 16 as depicted in the embodiment of FIG. 1 can be used without the particular interior armor subsystem 17 shown, or any interior armor materials at all, but it is currently preferred that the exterior armor subsystem 16 be used in conjunction with interior subsystem 17 to afford a greater degree of protection to the contents and individuals in the vehicle. Also, as used in the above discussion of the components of exterior armor subsystem 16 as well as the components of interior subsystem 17, the term “abutting” is taken to mean closely adjacent with the possibility of a relatively thin, intervening adhesive layer and/or an adhesive sheet interposed between the “abutting” components.

[0038] It is also presently contemplated that exterior subsystem 16 and interior subsystem 18 can be manufactured in modules to be easily installed and/or replaced. One skilled in the art would understand that the individual modules of exterior subsystem 16, being configured to mount to the exterior of the vehicle, may have a different configuration and planar

dimensions than modules for interior armor subsystem 17. Also, while the armor system 10 including exterior armor system 16 and which may further include interior armor subsystem 17, are intended for use in protecting a vehicle, one skilled in the art given the present disclosure may configure armor system 10 to help safeguard non-vehicle structures with or without human occupants.

[0039] FIG. 2 depicts a second embodiment of the armor system of the present invention, namely armor subsystem 40, which includes exterior subsystem 42 and which also may include an interior armor system 44. Interior armor system 44 in the FIG. 2 embodiment is substantially the same as interior armor subsystem 17 depicted in FIG. 1 embodiment and will therefore not be discussed further.

[0040] As in the exterior armor subsystem 16 in the FIG. 1 embodiment, the exterior subsystem 42 in the embodiment shown in FIG. 2 includes a leading layer 46 of high strength aluminum followed by alternating layers of a low density polypropylene composite and a high strength aluminum. In particular, exterior subsystem 42 includes leading high strength aluminum layer 46; a first intermediate layer 48 of low density polypropylene composite abutting rear surface 46a of leading aluminum layer 46; a first intermediate layer 50 of a high strength aluminum abutting rear surface 48a of low density polypropylene composite layer 48; second intermediate layer 52 of a low density polypropylene composite abutting rear surface 50a of aluminum layer 50; second intermediate high strength aluminum layer 54 abutting rear surface 52a of low density polypropylene composite layer 52; third intermediate low density polypropylene composite layer 56 abutting rear surface 54a of aluminum layer 54; and third intermediate high strength aluminum layer 58 abutting the rear surface 56a of density polypropylene composite layer 56. In contrast to exterior armor subsystem 16 in FIG. 1, exterior armor subsystem 42 of the FIG. 2 embodiment includes a fourth intermediate layer 60 of a low density polypropylene composite abutting rear surface 58a of the third intermediate aluminum layer 58, and a fourth intermediate high strength aluminum layer 62 abutting rear surface 60a of fourth intermediate low density polypropylene composite layer 60. As depicted in FIG. 2, fourth intermediate high strength aluminum layer 62 abuts the exterior surface 14a of hull 14; or, it may alternatively spaced to provide a dispersion space, as discussed in relation to FIG. 1.

[0041] Also, the depictions of the thicknesses of the high strength aluminum layers and the low density polypropylene composite layers in the FIG. 2 embodiment, relative to FIG. 1, reflects the possibility of adjusting not only the absolute thicknesses of the various layers but also the relative thicknesses of the layers within a particular armor system configuration based on the expected threats in a particular combat theater. For example, a particular armor system configured in accordance with armor system 40 as depicted in FIG. 2 may utilize about 1¼ inch thick aluminum sheets for each of leading layer 46 and intermediate layers 50 and 54, together with about 1½ inch thick aluminum sheets for each of the other intermediate aluminum layers. The low density polypropylene composite layers 48 and 52 may each be about 1½ inch thick and about 3 inches thick for each of the low density polypropylene layers 56 and 60. As in the FIG. 1 embodiment, high strength aluminum may include 7039 or 5083 sheet materials, and the low density polypropylene composite may be Tegriss®, although other high strength aluminum materials and low density (both polypropylene and

non-polypropylene) materials may be substituted for one or more of the respective layers. The dimensions of the layers of interior armor subsystem 44 may be as in FIG. 1.

[0042] In the third embodiment as shown in FIG. 3, armor system 70 includes exterior armor subsystem 72 and interior armor subsystem 74. Interior armor subsystem 74 is substantially the same as that used in the FIG. 1 and FIG. 2 embodiments, and thus will not be discussed further. However, it is specifically contemplated that conventional spall liners 38, such as S2, available from AGY can be used in place of interior armor subsystem 74. This variation 74' in interior system 74 of armor system 70 is depicted in system 70' in FIG. 3A. Moreover, conventional spall liners such as S2 may be substituted for the interior armor subsystems in the other embodiments disclosed herein. With reference again to FIG. 3, exterior armor subsystem 72 differs from the construction in FIG. 2, in that the fourth intermediate low density polypropylene composite layer 76 has a smaller thickness relative to the FIG. 2 embodiment and the fourth intermediate high strength aluminum layer 78 is not abutted to rear surface 76a of low density polypropylene layer 76, but is spaced a predetermined distance from rear surface 76a. Again, the spacing can be accomplished using mechanical spacers/connectors but it may be preferred to use a low density foam-like layer 80 as depicted in FIG. 3. The space provided by foam-like layer 80 is intended to allow dispersion of fragments, high velocity metal jets, etc., to assist the downstream portion of armor system 70 in protecting equipment and personnel in the vehicle. In the FIG. 3 embodiment, the fourth low density polypropylene composite layer 76 may be about 3/4 of an inch thick, and the space/foam layer 80 may be about 2 1/4 inches in thickness.

[0043] The aluminum and low density polypropylene materials discussed in relation to the embodiments in FIGS. 1 and 2 may be used in the FIG. 3 embodiment, as well as in the other embodiments to be disclosed hereinafter.

[0044] FIG. 4 discloses yet another embodiment of the armor system according to the present invention. In the FIG. 4 embodiment, armor system 100 includes an exterior armor subsystem 102 and interior armor subsystem of 104. As in the embodiments in FIGS. 1-3, exterior armor system 102 includes alternating sheet-like layers of high strength aluminum and sheet-like layers of a low density polypropylene composite material. However, the FIG. 4 embodiment uses a significantly thinner leading aluminum layer, relative to the embodiments in FIGS. 1-3, and also utilizes low density R-Glass® materials in addition to the low density polypropylene composite materials, as well as different thicknesses of the low density material layers.

[0045] Specifically, exterior armor subsystem 102 includes leading layer 106 of high strength aluminum; a first intermediate layer 108 of a low density polypropylene composite abutted to rear surface 106a of the aluminum leading surface 106; a first intermediate layer of high strength aluminum 110 abutting rear surface 108a of low density polypropylene composite layer 108; a second intermediate layer 112 of low density polypropylene composite abutting rear surface 110a of aluminum layer 110; and a second intermediate layer of high strength aluminum 114 abutting rear surface 112a of low density polypropylene layer 112. In contrast to the embodiments in FIGS. 1-3, however, the FIG. 4 embodiment utilizes a third low density layer 116 of an R-Glass composite abutting rear surface 114a of aluminum layer 114. Third intermediate layer of high strength aluminum 118 abuts the rear

surface 116a of the R-Glass composite layer 116. As discussed in relation to the previous embodiments, the final exterior aluminum layer, such as layer 118 in the present embodiment may be configured to directly abut exterior surface 114a of hull 14, as depicted. However, layer 118 can be spaced from the hull 14, such as by mechanical spacers/fasteners or foam-like layers for a armor system configuration having a dispersion space immediately adjacent exterior surface 114a of the hull.

[0046] Finally, the FIG. 4 embodiment includes a single layer comprising interior armor subsystem 104, namely a sheet-like layer 120 of an R-Glass composite abutting rear interior surface 14b of hull 14. It is contemplated that further layers of low density materials may be used in conjunction with the single R-Glass layer 120 shown in FIG. 4, and it is also contemplated that a single layer of R-Glass composite material in accordance with interior armor subsystem 104 may be used in place of or together with the interior armor subsystems as disclosed in FIGS. 1-3, as well as in subsequent embodiments to be disclosed hereinafter.

[0047] Contemplated dimensions of a particular armor system configured as armor system 100 shown in FIG. 4 may include, for the aluminum layers, leading layer 106, about 1/4 inch thick, and intermediate aluminum layers 110, 114, and 118, about 1 1/2 thick. For the low density layers, the first intermediate low density polypropylene composite layer 108 may be about 2 inches thick and the second intermediate low density polypropylene composite layer 112 may be 6 inches thick. R-Glass layer 116 may be about 6 inches thick. The single R-Glass composite layer 120 of interior armor subsystem 104 may be about 2 inches thick and may abut hull 14 as depicted or be spaced by fasteners or a foam layer.

[0048] In FIG. 5, yet another embodiment of the armor systems in accordance with the present invention is disclosed, namely armor system 130 having exterior armor subsystem 132 and interior armor subsystem 134. Interior armor system 134 is substantially the same as that discussed previously in relation to the embodiment of FIG. 1 and will not be discussed further.

[0049] Regarding exterior armor subsystem 132, leading layer 136 is high strength aluminum; the first intermediate low density layer 138 is a low density polypropylene composite which abuts rear surface 136a of aluminum layer 136; and the first intermediate aluminum layer 140 of high strength aluminum abuts rear surface 138a of low density polypropylene layer 138. Exterior armor subsystem 132 further includes second intermediate low density polypropylene composite layer 142 abutting the rear surface of 140a of aluminum layer 140; a second intermediate high strength aluminum layer 144 abutting a rear surface 142a of low density polypropylene composite layer 142; and a third intermediate layer of low density polypropylene composite 146 abutting rear surface 144a of the second interior aluminum layer 144.

[0050] The FIG. 5 embodiment further includes two layers of high strength steel, including a first steel intermediate layer 148 abutting the rear surface 146 of low density polypropylene composite layer 146 and a second steel intermediate layer 150 abutting exterior surface 14a of hull 14. Steel layers 148 and 150 are spaced apart a predetermined distance, such as by mechanical attachments and/or, as depicted in FIG. 5, by foam-like material layer 152 to provide an air gap for lateral dispersion of fragments. High strength steels that may be suitable for use in embodiments such as FIG. 5 include 224-T, 351, A514, A517, Weldox®, and Mil A-12560 Rolled

Homogenous Armor ("RHA"), and other steel disclosed in pending application (10036-10-02). Suitable thickness dimensions for one example constructed in accordance with the embodiment shown in FIG. 5 include: for each of the three high strength aluminum layers **136**, **140** and **144**, about 1 inch; for the two low density polypropylene composite layers **138** and **142**, about 3 inches; for the third intermediate low density polypropylene layer **146**, about $\frac{3}{4}$ of an inch; for each of the two high strength steel layers **148** and **150**, about 9.5 mm. Additionally, the steel layers **148** and **150** are spaced apart by about 208 mm by foam layer **152**, in order to provide a dispersion gap, as discussed previously.

[0051] FIG. 6 depicts yet another embodiment of the armor system of the present invention. The FIG. 6 embodiment is similar to the embodiment in FIG. 5, as discussed above, such that many of the sheet-like metal layers and alternating low density material layers in the exterior armor subsystem **162** are similar to those in exterior armor subsystem **132** of the FIG. 5 embodiment, with the differences to be discussed below. Also, the interior armor subsystem **164** has substantially the same components as the interior armor subsystem **17** in the FIG. 1 embodiment.

[0052] The FIG. 6 embodiment differs from the embodiment in FIG. 5 in that the "air gap" between steel metal layers **148** and **150** provided by the foam layer **152** in FIG. 5 has been replaced with a sheet-like layer of low density polypropylene composite **154** in the FIG. 6 embodiment. Layer **154** abuts rear surface **148a** of high strength steel layer **148** and also abuts the front surface **150a** of high strength steel layer **150**. Hence, it is expected that the exterior armor subsystem **162** in FIG. 6 may provide more protection against the high speed metal jet component of the projectile threat by physically eroding the jet as it traverses the width of layer **154** while possibly being less effective to disburse the particles traversing the width in the lateral direction as was the purpose of the air gap provided by foam layer **152** in the FIG. 5 embodiment. Again, one skilled in the art of designing armor systems would be mindful of the type of threats that would be expected in a particular war theatre and can adjust both the materials and the configurations of the alternating low density material layers and metal layers accordingly, given the present disclosure.

[0053] FIGS. 7 and 8 show further embodiments of the present invention using combinations of low density material layers, such as low density polypropylene composite layers, and layers of sheet-like metal such as high strength aluminum and/or high strength steel layers, in the respective exterior armor subassemblies. In the respective interior subassemblies, such as interior subassembly **174** in the FIG. 7 embodiment, the components are essentially the same as those discussed earlier in relation to the embodiment in FIG. 1 and several other of the embodiments where the intent is to capture residuals, if any, of the projectile threat that managed to breach vehicle hull **14** and/or spall from the rear surface **14b** of the hull **14**.

[0054] With respect first to the embodiment in FIG. 7, exterior subsystem **172** includes a leading layer **176** of a metal grid which can be a screen-like material formed from metal wires or a metalized non-metal fabric. The purpose of leading metal grid layer **176** is to break up the high velocity molten metal jets accompanying the projectile and to initiate a dispersion of the materials in the direction transverse to the threat direction **12**. Behind the leading metal grid layer **176**

are successive layers of low density polypropylene composite and alternating sheet-like layers of high strength aluminum.

[0055] Specifically, low density polypropylene layer **178** is positioned to abut rear surface **176a** of leading metal grid layer **176** layer **180** of high strength aluminum is positioned to abut rear surface **178a** of the low density polypropylene composite layer **178** low density polypropylene layer **182** is positioned to abut rear surface **180a** of high strength aluminum layer **180**, and high strength aluminum layer **184** abuts the rear surface **182a** of low density polypropylene layer **182**. Still further, high density polypropylene composite layer **186** is positioned to abut rear surface **184a** of high strength aluminum layer **184** and a further layer of high strength aluminum **188** abuts rear surface **186** of low density polypropylene composite layer **186** and another layer **190** of low density polypropylene composite abuts the rear surface **188a** of high strength aluminum layer **188**.

[0056] Still further, exterior armor subsystem **172** includes two sheet-like layers of high strength steel namely high strength steel layer **192** abutting rear surface **190a** of low density polypropylene composite layer **190** and high strength steel layer **194** abutting the front surface **14a** of the vehicle hull of **14**. High strength steel layers **192** and **194** are spaced apart a predetermined distance to create an air gap, such as by the use of a low density foam-like material **196**. The intended dispersing function of the air gap/foam layer **196** is essentially the same as the intended function for the air gaps in embodiments FIGS. 3 and 5 discussed above.

[0057] Turning now to the embodiment shown in FIG. 8, armor system **200** including exterior subsystem **202** and interior subsystem **204** is similar to the armor system **170** disclosed in FIG. 7 except that the air gap/foam layer **196** is replaced with a low density polypropylene composite layer **206**. Specifically, low density polypropylene composite layer **206** is positioned between high strength steel layers **192** and **194** and abuts the rear surface of **192a** of high strength layer **192** and the front surface **194a** of high strength steel layer **194**.

[0058] The thickness dimensions of the components of the embodiments depicted in FIGS. 7 and 8 are essentially the same, namely a leading metal grid layer **176** of about $\frac{1}{4}$ inch, low density polypropylene layers **178**, **182**, and **186** each about three inches, high strength aluminum layers **180**, **184**, and **188** each about one inch, and low density polypropylene layer **190** of about $\frac{3}{4}$ inch. Also, each of high strength steel layers **192** and **194** are approximately 9.5 mm thick, and the air gap width in the FIG. 7 embodiment and the low density polypropylene composite layer **206** thickness in the FIG. 8 embodiment are each about 208 mm. Again, one skilled in the art would understand that the particular thickness dimensions, as well as the relative thicknesses of the components may be varied depending upon the level of threat anticipated in a particular theatre.

[0059] Still further, FIGS. 9 and 10 depict further embodiments of the armor system of the present invention, which embodiments are similar to those shown in FIGS. 7 and 8 but wherein the metal grid layer **176** is omitted entirely. That is, in each of the armor systems **220** and **230**, respectively, the first low density polypropylene composite layer **178** of the respective exterior armor subsystems **222** and **232** serves also as the "leading" layer of the armor system, being the first layer to engage the projectile threat. That is, the high speed metal jet sharing capabilities of the low density polypropylene composite may be sufficient to provide initial disruption of the

incoming high speed metal jet without the need for a metal or metal-like initial leading layer. Aside from the elimination of the leading metal grid layer 176, the embodiments in FIGS. 9 and 10 correspond essentially to the embodiments in FIGS. 7 and 8, respectively, with each having a pair of high strength steel plates 192 and 194 spaced apart in FIG. 9 by an air gap formed by e.g., foam layer 196 or, in the case of FIG. 10, by a further low density polypropylene layer 206. The dimensions of the components other than the metal grid layer are substantially the same as the dimensions of the armor systems of FIGS. 7 and 8.

[0060] In the further embodiment depicted in FIG. 11, armor system 250 includes exterior subsystem 252 and interior subsystem 254, respectively positioned on opposing sides of vehicle hull 14. In particular, and is depicted in FIG. 11, exterior armor subsystem 252 includes a leading layer 256 which may be a high strength aluminum layer followed by a layer 258 which may be a low density polypropylene composite layer abutting the rear surface 256a of leading layer 256. Exterior armor subsystem 252 further includes a first intermediate metal armor layer 260, which may be high strength aluminum abutting rear surface 258a of layer 258, which intermediate metal armor layer is followed by a layer 262 which may be an R-Glass composite in phenolic resin abutting rear surface 260a of metal armor layer 260.

[0061] Still further, a pair of additional intermediate metal armor layers 264 and 266 are provided in exterior armor subsystem 252, with metal armor layer 264 abutting rear surface 262a of composite layer 262 and metal armor layer 266 abutting rear surface 264a of metal armor layer 264. Metal armor layers 264 and 266 may also be formed of a high strength aluminum. Metal layer 266 is spaced from upstream surface 14a of hull 14 by an air gap such as may be provided by a low density foam material as discussed in the previous embodiments.

[0062] In a representative application of the FIG. 11 embodiment, leading layer 256 may be about ¼ inches thick while each of metal armor layers 260, 264 and 266 may be about 1 inch thick. Low density polypropylene composite layer 258, which may be Tegril[®], is about 4 inches thick, while R-Glass composite/phenolic resin layer 262 also may be about 4 inches thick. In addition, spacing/foam layer 268 may be about ½ inch thick. The R-Glass composite/phenolic resin layer 262 may be obtained from OCV Reinforcements.

[0063] With respect to interior subsystem 254, it is currently preferred to be a multilayer construction of foam layer 270, aluminum oxide ceramic layer 272, and a Kevlar/E-Glass hybrid composite layer 274, all available from LTC. In an application of the embodiment depicted in FIG. 11, foam layer 270 is about 19 mm thick, aluminum oxide ceramic layer 272 is about 16 mm thick, and the Kevlar/E-Glass hybrid composite layer 274 is about ½ inch thick. It is further contemplated that another interior armor subsystem configuration, e.g. such as interior armor subsystem 234 shown in FIG. 10 could be used in place of interior armor subsystem 254.

[0064] It will be apparent to those skilled in the art that various modifications and variations can be made to the present invention. The present invention includes modifications and variations of this invention which fall within the scope of the following claims and their equivalents.

What is claimed is:

1. An armor system for protecting a vehicle from high energy projectiles, the projectile having an expected trajectory and the vehicle having a hull, the system comprising:

an exterior armor subsystem configured to be mounted exterior to the vehicle hull, the exterior armor subsystem including

- (a) a leading layer, relative to the expected projectile trajectory;
- (b) a first intermediate sheet-like layer of a low density material abutting a rear surface of the leading layer;
- (c) a first intermediate sheet-like layer of metal abutting a rear surface of the first intermediate low density material layer;
- (d) a second intermediate sheet-like layer of a low density material abutting a rear surface of the first intermediate metal layer;
- (e) a second intermediate sheet-like layer of metal abutting a rear surface of the second intermediate low density material layer;
- (f) a third intermediate sheet-like layer of a low density material abutting a rear surface of the second intermediate metal layer; and
- (g) a third intermediate sheet-like layer of metal positioned between the third intermediate low density material layer and an exterior surface of the vehicle hull, and abutting a rear surface of the third intermediate low density material layer.

2. The armor system as in claim 1, further comprising an interior armor subsystem interior to the vehicle hull, the interior armor subsystem including one or more sheet-like layers of a low density material positioned to the rear of an interior surface of the hull.

3. The armor system as in claim 2, wherein the low density material in the one or more interior low density material layers is selected from members of the group consisting of R-Glass composites, S-Glass composites, E-Glass composites, Kevlar[®] reinforced polymer, Kevlar[®] reinforced polyethylene composites, and hybrids of one or more of the group members.

4. The armor system as in claim 2, having a first low density material interior layer of a low density polypropylene composite spaced a predetermined distance from an interior surface of the hull, and a second low density material interior layer of a composite of an aramid and a glass material abutting a rear surface of the first interior low density polypropylene composite layer.

5. The armor system as in claim 1, wherein the leading layer is a sheet-like layer of a high strength aluminum or a metal grid.

6. The armor system as in claim 1, wherein the leading layer is a sheet-like layer of a low density material, and wherein the leading layer also comprises the first intermediate low density material layer.

7. The armor system as in and claim 1, wherein one or more of the leading layer, and the first, second, and third intermediate metal layers is a high strength aluminum, and wherein the low density material of one or more of the first, second, and third intermediate layers of a low density material is a low density polypropylene composite.

8. The armor system of claim 7, wherein the high strength aluminum selected from the group consisting of 7039, 5083, and 2024-T351.

9. The armor system as in claim 1, wherein the third intermediate metal layer also abuts an exterior surface of the vehicle hull.

10. The armor system as in claim 1, wherein the third intermediate metal layer abuts a rear surface of the third intermediate low density material layer and also abuts an exterior surface of the hull; wherein the leading layer and the first, second, and third intermediate layer are a high strength aluminum; wherein the first and second intermediate low density material layer are a low density polypropylene composite; and wherein the third intermediate low density material layer is an R-Glass composite in a phenolic resin.

11. The armor system of claim 1, wherein a fourth intermediate sheet-like layer of a low density material abuts a rear surface of the third metal layer, and wherein a fourth sheet-like metal armor layer abuts an exterior surface of the hull.

12. The armor system as in claim 11, wherein the fourth intermediate low density material layer is spaced a predetermined distance from the fourth intermediate metal layer.

13. The armor system as in claim 11, wherein the fourth intermediate low density material layer also abuts a front surface of the fourth intermediate metal layer.

14. The armor system as in claim 11, wherein the material of the fourth intermediate low density material layer is a low density polypropylene composite, and wherein the metal of the fourth intermediate metal armor layer is a high strength aluminum.

15. The armor system as in claim 1, wherein the third intermediate metal layer is a high strength steel, and wherein the armor system further includes a fourth intermediate sheet-like layer of a high strength steel abutting an exterior surface of the hull.

16. The armor system as in claim 15, wherein the third and fourth intermediate steel layers are spaced apart a predetermined distance.

17. The armor system as in claim 15, further including a fourth intermediate sheet-like layer of a low density material abutting a rear surface of the third intermediate steel layer and abutting a front surface of the fourth intermediate steel layer.

18. The armor system as in claim 15 wherein the high strength steels of the third and fourth intermediate steel layers are selected from the group consisting of A514, A517, Weldom®, and Mil A-12560 Rolled Homogeneous Armor.

19. The armor system as in claim 1, wherein the low density materials of the first, second, and third intermediate low density material layers are selected from members of the group consisting of R-Glass composites, S-Glass composites, E-Glass composites, Kevlar® reinforced polymer, Kevlar® reinforced polyethylene composites, and hybrids of one or more of the group members.

20. An armor system for protecting a vehicle from high energy projectiles, the projectile having an expected trajectory and the vehicle having a hull, the system comprising:

an exterior armor subsystem configured for being mounted sheet like exterior to the vehicle hull, the exterior armor subsystem including

- (a) a leading sheet-like layer of a high strength aluminum, relative to the expected projectile trajectory;
- (b) a first intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the leading aluminum layer;
- (c) a first intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the first intermediate low density polypropylene composite layer;

(d) a second intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the first intermediate aluminum layer;

(e) a second intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the second intermediate low density polypropylene composite layer;

(f) a third intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the second intermediate aluminum layer;

(g) a third intermediate sheet-like layer of a high strength aluminum layer abutting a rear surface of the third intermediate low density polypropylene composite layer;

(h) a fourth intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the third intermediate aluminum layer; and

(i) a fourth sheet-like high strength aluminum layer abutting an exterior surface of the hull,

wherein the fourth intermediate low density polypropylene composite layer is spaced a predetermined distance from the fourth intermediate aluminum layer.

21. The armor system as in claim 20, wherein one or more of the first, second, third and fourth intermediate low density polypropylene composite layers is Tegriss®.

22. An armor system for protecting a vehicle from high energy projectiles, the projectile having an expected trajectory and the vehicle having a hull, the system comprising:

an exterior armor subsystem configured for being mounted exterior to the vehicle hull, the exterior armor subsystem including

(a) a leading layer of a high strength aluminum, relative to the expected projectile trajectory;

(b) a first intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the leading aluminum layer;

(c) a first intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the first intermediate low density polypropylene composite layer;

(d) a second intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the first intermediate aluminum layer;

(e) a second intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the second intermediate low density polypropylene composite layer;

(f) a third intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the second intermediate aluminum layer;

(g) a fourth intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the third intermediate aluminum layer; and

(h) a fourth intermediate sheet-like high strength aluminum layer abutting a rear surface of the fourth intermediate low density polypropylene composite layer and also abutting an exterior surface of the hull.

23. The armor system as in claim 22, wherein one or more of the first, second, third and fourth intermediate low density polypropylene composite layers is Tegriss®.

24. An armor system for protecting a vehicle from high energy projectiles, the projectile having an expected trajectory and the vehicle having a hull, the system comprising:

an exterior armor subsystem configured to be mounted exterior to the vehicle hull, the exterior armor subsystem including

- (a) a leading layer of a high strength aluminum, relative to the expected projectile trajectory;
- (b) a first intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the leading aluminum layer;
- (c) a first intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the first intermediate low density polypropylene composite layer;
- (d) a second intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the first intermediate aluminum layer;
- (e) a second intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the second intermediate low density polypropylene composite layer;
- (f) a third intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the second intermediate aluminum layer;
- (g) a third intermediate sheet-like layer of a high strength steel abutting a rear surface of the third intermediate low density polypropylene composite layer; and
- (h) a fourth intermediate sheet-like layer of a high strength steel abutting an exterior surface of the hull,
- (i) wherein the third and fourth intermediate steel layers are spaced apart a predetermined distance.

25. The armor system as in claim **24**, wherein one or more of the first, second, third and fourth intermediate low density polypropylene composite layers is Tegr^{is}®.

26. An armor system for protecting a vehicle from high energy projectiles, the projectile having an expected trajectory and the vehicle having a hull, the system comprising:

an armor subsystem exterior to the vehicle hull, the exterior armor subsystem including

- (a) a leading layer of a high strength aluminum, relative to the expected projectile trajectory;
- (b) a first intermediate sheet-like layer of a low density polypropylene abutting a rear surface of the leading aluminum layer;
- (c) a first intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the first intermediate low density polypropylene composite layer; and
- (d) a second intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the first intermediate aluminum layer;
- (e) a second intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the second intermediate low density polypropylene composite layer;
- (f) a third intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the second intermediate aluminum layer;
- (g) a third intermediate sheet-like layer of a high strength steel abutting a rear surface of the third intermediate low density polypropylene composite layer;
- (h) a fourth intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the third intermediate steel layer; and
- (i) a fourth intermediate sheet-like layer of a high strength steel abutting a rear surface of the fourth intermediate low density polypropylene composite layer and also abutting an exterior surface of the hull.

27. The armor system as in claim **26**, wherein one or more of the first, second, third and fourth intermediate low density polypropylene composite layers is Tegr^{is}®.

28. An armor system for protecting a vehicle from high energy projectiles, the projectile having an expected trajectory and the vehicle having a hull, the system comprising:

an exterior armor subsystem configured to be mounted exterior to the vehicle hull, the exterior armor subsystem including

- (a) a leading sheet-like layer of high strength aluminum, relative to the expected projectile trajectory;
- (b) a first intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the leading aluminum layer;
- (c) a first intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the first intermediate low density polypropylene composite layer;
- (d) a second intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the first intermediate aluminum layer;
- (e) a second intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the second intermediate low density polypropylene composite layer;
- (f) a third intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the second intermediate aluminum layer; and
- (g) a third intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the third intermediate low density polypropylene composite layer and also abutting an exterior surface of the hull.

29. The armor system as in claim **28**, wherein one or more of the first, second, third and fourth intermediate low density polypropylene composite layers is Tegr^{is}®.

30. An armor system for protecting a vehicle from high energy projectiles, the projectile having an expected trajectory and the vehicle having a hull, the system comprising:

an exterior armor subsystem configured to be mounted exterior to the vehicle hull, the exterior armor subsystem including

- (a) a leading sheet-like layer of a low density polypropylene composite, relative to the expected projectile trajectory;
- (b) a first intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the leading low density polypropylene composite layer;
- (c) a first intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the first intermediate aluminum layer;
- (d) a second intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the first intermediate low density polypropylene composite layer;
- (e) a second intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the second intermediate aluminum layer;
- (f) a third intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the second intermediate low density polypropylene composite layer;
- (g) a third intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the third intermediate aluminum layer;
- (h) a fourth intermediate sheet-like layer of a high strength steel abutting a rear surface of the third intermediate low density polypropylene composite layer; and

(i) a fifth intermediate sheet-like layer of a high strength steel abutting an exterior surface of the hull, wherein the fourth and fifth intermediate steel layers are spaced apart a predetermined distance.

31. The armor system as in claim **30**, wherein one or more of the first, second, third and fourth intermediate low density polypropylene composite layers is Tegr^{is}®.

32. An armor system for protecting a vehicle from high energy projectiles, the projectile having an expected trajectory and the vehicle having a hull, the system comprising:

an exterior armor subsystem configured to be mounted exterior to the vehicle hull, the exterior armor subsystem including

- (a) a leading sheet-like layer of a low density polypropylene composite, relative to the expected projectile trajectory;
- (b) a first intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the leading low density polypropylene composite layer;
- (c) a first intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the first intermediate aluminum layer;
- (d) a second intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the first intermediate low density polypropylene composite layer;
- (e) a second intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the second intermediate aluminum layer;
- (f) a third intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the second intermediate low density polypropylene composite layer;
- (g) a third intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the third intermediate aluminum layer;
- (h) a fourth intermediate sheet-like layer of a high strength steel abutting a rear surface of the third intermediate low density polypropylene composite layer;
- (i) a fourth intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the fourth intermediate aluminum layer; and
- (j) a fifth sheet-like layer of a high strength steel abutting a rear surface of the fourth intermediate low density polypropylene composite layer and also abutting an exterior surface of the hull.

33. The armor system as in claim **32**, wherein one or more of the first, second, third and fourth intermediate low density polypropylene composite layers is Tegr^{is}®.

34. An armor system for protecting a vehicle from high energy projectiles, the projectile having an expected trajectory and the vehicle having a hull, the system comprising:

an exterior armor subsystem configured to be mounted exterior to the vehicle hull, the exterior armor subsystem including

- (a) a leading metal grid layer, relative to the expected projectile trajectory;
- (b) a first intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the leading metal grid layer;
- (c) a first intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the first intermediate low density polypropylene composite layer;

(d) a second intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the first intermediate aluminum layer;

(e) a second intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the second intermediate low density polypropylene composite layer;

(f) a third intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the second intermediate aluminum layer;

(g) a third intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the third intermediate low density polypropylene composite layer;

(h) a fourth intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the third intermediate aluminum layer;

(i) a fourth intermediate sheet-like layer of a high strength steel abutting a rear surface of the fourth intermediate low density polypropylene composite layer; and

(j) a fifth intermediate sheet-like layer of a high strength steel abutting an exterior surface of the hull,

wherein the fourth and fifth intermediate steel layers are spaced apart a predetermined distance.

35. The armor system as in claim **34** wherein one or more of the first, second, third and fourth intermediate low density polypropylene composite layers is Tegr^{is}®.

36. An armor system for protecting a vehicle from high energy projectiles, the projectile having an expected trajectory and the vehicle having a hull, the system comprising:

an armor subsystem configured to be mounted exterior to the vehicle hull, the exterior armor subsystem including

- (a) a leading metal grid layer, relative to the expected projectile trajectory;
- (b) a first intermediate sheet-like layer of a low density material abutting a rear surface of the leading metalized grid;
- (c) a first intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the first intermediate low density polypropylene composite layer;
- (d) a second intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the first intermediate aluminum layer;
- (e) a second intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the second intermediate low density polypropylene composite layer;
- (f) a third intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the second intermediate aluminum layer;
- (g) a third intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the third intermediate low density polypropylene composite layer;
- (h) a fourth intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the third intermediate aluminum layer;
- (i) a fourth intermediate sheet-like layer of a high strength steel abutting a rear surface of the fourth intermediate low density polypropylene composite layer;
- (j) a fifth intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the fourth intermediate steel layer; and
- (k) a fifth intermediate sheet-like layer of a high strength steel abutting a rear surface of the fifth intermediate low

density polypropylene composite layer and also abutting an exterior surface of the hull.

37. The armor system as in claim **36**, wherein one or more of the first, second, third, fourth and fifth intermediate low density polypropylene composite layers is Tegr^{is}®.

38. The armor system as in any one of claims **20**, **22**, **24**, **26**, **28**, **30**, **32**, **34**, and **36**, further comprising an interior armor subsystem configured for being mounted interior to the vehicle hull, the interior armor subsystem including

- (i) an interior sheet-like layer of low density polypropylene composite spaced a predetermined distance behind an interior surface of the vehicle hull; and
- (ii) an interior sheet-like layer of an aramid and glass composite abutting a rear surface of the interior low density polypropylene composite layer.

39. The armor system as in claim **38**, wherein the interior layer of a low density polypropylene composite is Tegr^{is}®, and the interior layer of an aramid and glass composite is a hybrid composite of Kevlar® and E-Glass®.

40. An armor system for protecting a vehicle from high energy projectiles, the projectile having an expected trajectory and the vehicle having a hull, the system comprising:

an exterior armor subsystem configured for being mounted exterior to the vehicle hull, the exterior armor subsystem including

- (a) a leading sheet-like layer of a high strength aluminum, relative to the expected projectile trajectory;
- (b) a first intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the leading aluminum layer;
- (c) a first intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the first intermediate low density polypropylene composite layer;
- (d) a second intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the first intermediate aluminum layer;
- (e) a second intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the second intermediate low density polypropylene composite layer;
- (f) a third intermediate sheet-like layer of R-Glass composite in a phenolic resin abutting a rear surface of the second intermediate aluminum layer;
- (g) a third intermediate sheet-like layer of a high strength aluminum layer abutting a rear surface of the third intermediate R-Glass composite in phenolic resin layer and also abutting an exterior surface of the hull.

41. The armor system as in claim **40**, wherein one or both of the first and second intermediate low density polypropylene layer is Tegr^{is}®.

42. The armor system as in claim **40**, further including a sheet-like layer of an R-Glass composite in phenolic resin abutting an interior surface of the hull.

43. An armor system for protecting a vehicle from high energy projectiles, the projectile having an expected trajectory and the vehicle having a hull, the system comprising:

an exterior armor subsystem configured for being mounted exterior to the vehicle hull, the exterior armor subsystem including

- (a) a leading sheet-like layer of a high strength aluminum, relative to the expected projectile trajectory;
- (b) a intermediate sheet-like layer of a low density polypropylene composite abutting a rear surface of the leading aluminum layer;
- (c) a first intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the intermediate low density polypropylene composite layer;
- (d) a intermediate sheet-like layer resin of a R-Glass composite in a phenolic resin abutting a rear surface of the first intermediate high strength aluminum layer;
- (e) a second intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the R-Glass composite/phenolic resin layer;
- (f) a third intermediate sheet-like layer of a high strength aluminum abutting a rear surface of the second intermediate aluminum layer; and

wherein the third intermediate high strength aluminum layer is spaced from an exterior surface of the hull by a foam layer hull.

44. The armor system as in claim **40**, wherein the first intermediate low density polypropylene layer is Tegr^{is}®.

45. The armor system as in claim **40**, further including an interior armor subsystem comprising in sequence, sheet-like layers of a foam, an aluminum oxide ceramic, and a Kevlar® and E-Glass® hybrid composite, the foam layer abutting an interior surface of the hull.

46. An armor system for protecting a vehicle from high energy projectiles, the projectile having an expected trajectory and the vehicle having a hull, the system comprising:

- a leading layer, relative to the trajectory, the leading layer positioned exterior to the hull;
 - a first plurality of sheet-like layers of a low density material positioned between the leading layer and the hull; and
 - a second plurality of sheet-like high strength metal layers positioned between the leading layer and the hull,
- wherein individual ones of the first plurality of high strength metal layers being positioned alternating with, and to the rear of, individual ones of the second plurality of low density material layers.

47. The armor system as in claim **46**, wherein the leading layer comprises one of a sheet-like metal layer, a metalized grid layer, and the outer-most layer of said first plurality of low density materials layers.

48. The armor system as in claim **46**, wherein the materials of the high strength metal layers are selected from high strength steel and high strength aluminum, and wherein the materials of the low density material are selected from low density polypropylene composites and R-Glass composites.

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