

LIGHTWEIGHT ARMOR AGAINST MULTIPLE HIGH VELOCITY BULLETS

BACKGROUND OF THE INVENTION

1. Field of the Invention

5 The invention relates to fiber reinforced articles having utility for ballistic resistance to multiple high velocity bullets, impact absorption and penetration resistance in body armor, helmets, breast plates, helicopter seats, spall shields and other applications.

2. Description of the Related Art

10 Modern body armor designed for protection against hand-gun ammunition at velocities of about 1000 ft/sec (305 m/sec) is usually formed from thin layers of woven fabrics or non-woven sheets of fibers that are plied together in a flexible bundle. However, body armor designed to defeat heavy rifle bullets with velocities over 2000 ft/sec (610 m/sec)
15 generally requires a more complex construction in order to satisfy conflicting requirements of weight, thickness, flexibility, multiple hit performance, transient deformation (blunt trauma) and durability. The armor may incorporate rigid front and/or back elements to deform the bullet or to absorb its energy. Inorganic materials such as ceramics have found
20 use in such armor because of their high hardness and low density relative to metals. Plates and tiles, commonly used forms of ceramics, often shatter in the process of deforming a bullet, and thus offer relatively little protection against subsequent bullet hits. This problem is particularly manifested when the bullet contains a steel penetrator designed to
25 penetrate armor.

 There are numerous ballistic-resistant constructions described in the prior art, although most are not directed at protection against rifle bullets or multiple hit performance. USP 4,111,097 describes a laminated multi-layer armor comprising steel and tungsten wire mesh in a foamed
30 plastic. USP 4,868,040 describes a three-element composite comprising a frontal woven fabric composite, a ceramic tile energy absorbing body and a rearward woven fabric composite. USP 5,221,807 describes an armor

comprising a frontal ceramic plate having a regular array of cells, an intermediate layer having a honeycomb structure and a rear plate that may be Kevlar® fiber, ceramic matrix composite or steel. USP 5,545,455 describes a rigid composite comprising polymeric fibrous layers stitched
5 together and continuously encircled by a fibrous girdle. The stitching fibers may be inorganic fibers. USP 5,456,156 describes an armor comprising metal reinforced ceramic and a tough backup plate. USP 5,635,288 describes a rigid composite comprising a monolithic frontal plate consisting of ceramic, steel, glass, aluminum, titanium or graphite and a rearward
10 layer comprising unidirectionally oriented polymeric fibers bonded at their outer surfaces by plastic films.

USP 5,677,029 describes a flexible fiber composite armor with surfaces comprising tessellated triangular or hexagonal shaped hard bodies positioned such that multiple seams are formed and the armor is
15 flexible along the seam directions. The hard bodies may be reinforced with polymeric or inorganic fibers. USP 6,035,438 describes a body armor comprising ceramic disks laid out in an imbricate pattern sandwiched between layers of high strength fibers. USP 6,510,777 describes a vehicle armor of similar construction. USP 6,127,291 describes a flexible
20 penetration-resistant composite comprising woven sub-plyies of polymeric or inorganic ballistic fibers. USP 6,323,145 B1 describes a penetration-resistant interlaced yarn structure of high strength polymeric or inorganic fibers. USP 6,389,594 describes an anti-ballistic article comprising a ceramic plate maintained under isostatic pressure of at least 10
25 atmospheres by a resin enclosure.

USP 6,408,733 B1 describes an armor for multiple bullet protection comprising a monolithic ceramic frontal element and an aramid fiber composite substrate. USP 6,532,857 B1 describes a ceramic array armor comprising elastomer-encapsulated ceramic tiles spaced from one
30 another and an optional metal backing plate. USP 6,601,497 B2 describes an armor component comprising a polygonal ceramic tile confined in a wrapping material wherein the wrapping material may comprise one of a

high-strength fiber, a high-strength fiber in a polymer composite matrix, a high-strength fiber in a metal matrix, a high-strength metallic band, and a high-strength metallic wire.

USP Application 2001/0053645 A1 describes a multi-layered ballistic resistant article comprising at least one hard armor layer and at least one fibrous armor layer, wherein the fibers of one fibrous ply are at an angle of less than 45° to the fibers of the adjacent fibrous ply. The material of the hard armor layer is a metal, a metal/ceramic composite, a ceramic, a hardened polymer or combinations thereof.

Each of the articles in the patents cited above represents improvements in the state of the art. However, none describes the specific constructions of the articles of this invention and none satisfies all of the needs met by this invention. It is a principal objective of this invention to provide lightweight, ballistic-resistant and penetration-resistant composites having multiple hit capability against high velocity bullets.

SUMMARY OF THE INVENTION

The invention is a ballistic-resistant and penetration-resistant article comprising:

a) a frontal laminate comprising one or more plies, the frontal laminate having at least a frontal ply comprising a plurality of laminae of unidirectional inorganic fibers in a polymeric matrix, the laminae in a ply having the same composition and construction, the laminae in adjacent plies of the frontal laminate differing in composition and/or construction from one another, the inorganic fibers being comprised of filaments having a tensile strength of at least 2.0 GPa and a density of less than 4.0 g/cm³, wherein the fiber direction in each lamina is at an angle to the fiber direction in adjacent laminae; and

b) a second laminate united in face-to-face relationship with the frontal laminate, the second laminate comprising one or more plies, each ply comprising a plurality of laminae of polymeric fibers in a network, the polymeric fibers having a tenacity of at least 17 g/d, the network optionally

containing a polymeric matrix material, a ply in the second laminate being defined by laminae having the same composition and construction which differs from the composition and/or construction of the laminae in adjacent plies.

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BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawing figures:

FIGURE 1 is a cross-section of a two-ply embodiment of an article of the invention having one ply of unidirectional inorganic fibers in a frontal laminate, and one ply of polymeric fibers in a second laminate.

FIGURE 2 is a cross-section of a five-ply embodiment of an article of the invention having two plies of unidirectional inorganic fibers in a frontal laminate, each ply having different compositions or constructions, two plies of polymeric fibers in a second laminate, each ply having different compositions or constructions, and one ply of inorganic fibers in a third laminate.

FIGURE 3 is a cross-section of a five-ply embodiment of an article of the invention having:

- a) a frontal laminate consisting of a frontal ply of unidirectional inorganic fibers, a second ply consisting of a titanium metal plate, and a third ply of unidirectional inorganic fibers, the titanium metal plate being embedded on all surfaces by the frontal and third plies;
- b) a second laminate consisting of one ply of polymeric fibers; and
- c) a third laminate consisting of one ply of polymeric fibers of a composition or construction different from those in the second laminate.

FIGURE 4 is a schematic representation of a process for making a lamina.

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DETAILED DESCRIPTION OF THE INVENTION

The invention is fiber reinforced articles having utility for ballistic resistance to multiple high velocity bullets, impact absorption and

penetration-resistance in body armor, helmets, breast plates, helicopter seats, spall shields and other applications. The invention is a ballistic-resistant and penetration-resistant article comprising:

- a) a frontal laminate and b) a second laminate, united face-to-face. The frontal laminate comprises one or more plies, the frontal ply of which comprises a plurality of laminae of unidirectional inorganic fibers in a matrix. A ply is defined by laminae having the same composition and construction and differing in composition and/or construction from the laminae in adjacent plies. The inorganic fibers comprise filaments having a tensile strength of at least 2.0 GPa and a density of less than 4.0 g/cm³. The fiber direction in each lamina is at an angle to the fiber direction in adjacent laminae.

- The second laminate comprises one or more plies, each of which comprises a plurality of laminae of polymeric fibers in a network. The polymeric fibers have a tenacity of at least 17 g/d. The network optionally contains a matrix material. A ply is defined by laminae having the same composition and construction and differing in composition and/or construction from the laminae in adjacent plies.

- As used herein "laminate" denotes a structure wherein superposed sheet-like elements (laminae) are united, either loosely, for example by sewing around their edges or at their corners, or rigidly, for example by full areal bonding, or at any intermediate level, for example by stapling, riveting, sewing, partial bonding, or other suitable means.

- For purposes of the present invention, a fiber is an elongate body the length dimension of which is much greater than the transverse dimensions of width and thickness. Accordingly, "fiber" as used herein includes one or a plurality of filaments, ribbons, strips, and the like having regular or irregular cross-sections in continuous or discontinuous lengths. A yarn is an assemblage of continuous or discontinuous fibers.

- As used herein, "fiber network" or "network" denotes a plurality of fibers arranged into a predetermined configuration, or a plurality of fibers grouped together to form a twisted or untwisted yarn, which yarns are

arranged into a predetermined configuration. The fiber network can have various constructions. For example, the fibers or yarn may be structured as a felt, knit, braid, weave, randomly oriented non-woven (e.g. air-laid), unidirectionally oriented non-woven, or formed into a network by any conventional techniques. According to a particularly preferred network configuration, the fibers are unidirectionally aligned so that they are substantially parallel to each other along the longitudinal direction of the network layer. This is not meant, however, to preclude the use of an insubstantial number of parallel and/or non-parallel fibers for the purpose of stabilizing the other fibers, as is known in the art.

In a further embodiment, an article of the invention comprises:

a) a frontal laminate and b) a second laminate, as described above and united face-to-face, in combination with c) a third laminate, which is stacked face-to-face with the second laminate.

The third laminate also comprises one or more plies, each of which comprises a plurality of laminae of polymeric fibers in a network not containing a matrix. The polymeric fibers have a tenacity of at least 17 g/d, and a ply is defined by laminae having the same composition and construction and differing in composition and/or construction from the laminae in adjacent plies;

In another embodiment, the article of the invention comprises:

a) a frontal laminate and b) a second laminate, as previously described and united face-to-face, in combination with c) a third laminate, united face-to-face to the second laminate. This third laminate also comprises one or more plies, each of which comprises a plurality of laminae of unidirectional inorganic fibers in a polymeric matrix. A ply is here defined by laminae having the same composition and construction and differing in composition and/or construction from the laminae in adjacent plies. The inorganic fibers have a tensile strength of at least 2.0 GPa and a density of less than 4.0 g/cm³. The fiber direction in each lamina is at an angle to the fiber direction in adjacent laminae.

In yet another embodiment, the article of the invention comprises:

a) a frontal laminate united face-to-face to b) a second laminate, and c) a third laminate stacked face-to-face with the second laminate.

5 In this embodiment, the first laminate comprises at least three plies, the frontal ply comprising a plurality of unidirectional inorganic fibers, a second ply comprising a titanium metal plate, and a third ply comprising a plurality of unidirectional inorganic fibers. The titanium metal plate forming the second ply is embedded on all surfaces by the first and third plies. A
10 ply is defined by laminae having the same composition and construction and differing in composition and/or construction from the laminae in adjacent plies. The inorganic fibers are comprised of filaments having a tensile strength of at least 2.0 GPa, and a density of less than 4.0 g/cm³. As in previous embodiments, the fiber direction in each lamina is at an
15 angle to the fiber direction in adjacent laminae.

The second and third laminates of this embodiment independently comprise one or more plies, each of which comprises a plurality of laminae of polymeric fibers in a network. The polymeric fibers have a tenacity at least 17 g/d, and the network optionally contains a
20 polymeric matrix material. As in previous embodiments, a ply is defined by laminae having the same composition and construction and differing in composition and/or construction from the laminae in adjacent plies.

It will be understood that in each embodiment the frontal laminate faces the direction of the incoming threat.

25 Figure 1 is a cross-sectional view of one article **100** of the invention comprising a frontal laminate **50** and a second laminate **60**. In the article illustrated, the frontal laminate **50** is comprised of a single ply which comprises a plurality of laminae of unidirectional inorganic fibers in a polymeric matrix. The fiber direction in each lamina is at an angle to the
30 fiber direction in adjacent laminae, and the composition and construction in each lamina is identical. The second laminate **60** is bonded face-to-face to the frontal laminate **50**. The second laminate **60** is also comprised of a

single ply which comprises a plurality of laminae of unidirectional polymeric fibers in a polymeric matrix. The fiber direction in each lamina is at an angle to the fiber direction in adjacent laminae, and the composition and construction in each lamina is identical.

5 Figure 2 is a cross-sectional view of another article **200** of the invention comprising a frontal laminate **50**, consisting of two plies **10** and **20**; a second laminate **60** consisting of two plies **30** and **40**; and a third laminate **70** consisting of one ply. Plies **10** and **20** of the first laminate **50** are distinguished from one another by consisting of laminae of different
10 inorganic fibers and/or different matrices and/or different constructions. Plies **30** and **40** of the second laminate **60** are distinguished from one another by consisting of laminae of different polymeric fibers and/or different or no matrices and/or different constructions. Laminate **70** consists of a single ply wherein the composition and construction in each
15 lamina is identical.

 Figure 3 is a cross-sectional view of yet another article **300** of the invention comprising a frontal laminate **80**, a second laminate **85**, and a third laminate **90**. The frontal laminate **80** is comprised of three plies. A frontal ply **81** consists of a plurality of laminae of unidirectional inorganic
20 fibers in a polymeric matrix, wherein the fiber direction in each lamina is at an angle to the fiber direction in adjacent laminae and the composition and construction in each lamina is identical. A second ply of the first laminate **82** is a titanium metal plate embedded on all surfaces by the first and third plies (**81** and **83**). The third ply **83** of the first laminate **80** consists of a
25 plurality of laminae of unidirectional inorganic fibers in a polymeric matrix, wherein the fiber direction in each lamina is at an angle to the fiber direction in adjacent laminae and the composition and construction in each lamina is identical. The second laminate **85** is comprised of a single ply that consists of a plurality of laminae of unidirectional polymeric fibers in a
30 polymeric matrix, wherein the fiber direction in each lamina is at an angle to the fiber direction in adjacent laminae and the composition and construction in each lamina is identical. The third laminate **90** is also comprised of a

single ply that consists of a plurality of laminae of unidirectional polymeric fibers in a polymeric matrix, wherein the fiber direction in each lamina is at an angle to the fiber direction in adjacent laminae and the composition and construction in each lamina is identical.

5 Preferably, each of the laminates in an article of the invention has balanced construction. A balanced laminate construction is one in which all laminae are found only in $\pm \theta^\circ$ pairs relative to the centerline of the laminate, or at $0/90^\circ$. Preferably, the angle between the fibers in adjacent laminae is from 45 to 90 degrees.

10 Preferably, the filaments comprising the inorganic fibers have a tensile strength of at least 2.4 GPa and a density of less than 3.4 g/cm^3 , more preferably, a tensile strength of at least 3.4 GPa and a density of less than 3.4 g/cm^3 , and most preferably, a tensile strength of at least 4.0 GPa and a density of less than 3.1 g/cm^3 .

15 Some examples of inorganic fibers useful in a laminate of the invention are listed in Table I. The abbreviation "CVD" in Table I means chemically vapor deposited.

 The plies may be constructed with the fibers listed in Table I, singly or in combination. The filaments of different composition may be
20 combined in a single fiber/yarn, or the unidirectional laminae may be constructed with fibers/yarns of different composition laid down parallel to one another in regular or irregular array. A ply is defined by laminae having the same composition and construction and differing from the composition and/or construction of laminae in adjacent plies. A laminate may be
25 constructed with several plies each having a different fiber and/or a different matrix. A laminate may also be constructed with several plies each having the same inorganic fiber and matrix but having different filament and/or matrix concentrations.

TABLE I

Designation and Supplier	Composition	Strength, GPa	Density, g/cm ³
SCS (a)	CVD SiC on carbon	3.4 – 5.8	2.8 – 3.0
Boron fiber (a)	CVD boron on tungsten	3.4 – 4.5	2.6 – 3.4
Nicalon NL-200 (b)	β -SiC in Si-O-C amorphous phase	3.0	2.55
Hi Nicalon (b)	β -SiC, carbon	2.8	2.74
Hi Nicalon-S (b)	β -SiC, carbon	2.6	3.10
Tyranno® Lox M (c)	54.4% Si, 32.4% C, 10.2% O, 2% Ti	3.3	2.48
Tyranno® ZM (c)	55.3% Si, 33.9% C, 9.8% O, 1.0% Zr	3.3	2.48
SiBN (d)	SiBN ₃ C with 1-3% O	3.0	1.8 – 1.9
E – Glass (e)	Si, Al, Ca oxide glass	2.4	2.54
S – Glass (e)	Si, Al, Ca oxide glass	3.45	2.55
Nextel® 720 (f)	85/15 Al ₂ O ₃ /SiO ₂	2.1	3.4

a) Specialty Materials, Inc., Lowell, MA

b) Nippon-Carbon Co., Ltd., Tokyo, Japan

c) UBE America Inc., New York, NY

d) Bayer AG, Leverkusen, Germany

e) Owens Corning, Toledo, OH

f) 3M Co., Minneapolis, MN

Preferably, the inorganic fibers comprising a laminate are chemically vapor deposited boron on tungsten or chemically vapor deposited silicon carbide on carbon, and combinations thereof. Preferably, the inorganic fibers comprise from 60 to 95 percent by weight of the laminate.

The polymeric fibers comprising the plies of the second laminate or a third laminate are preferably selected from the group consisting of high molecular weight polyethylene, aramid, polybenzazole, rigid rod polymeric fibers (such as M5® brand) and combinations thereof.

As used herein, the term polyethylene means a predominantly linear polyethylene material that may contain minor amounts of chain branching or comonomers not exceeding 5 modifying units per 100 main chain carbon

atoms, and that may also contain admixed therewith not more than about 50 wt % of one or more polymeric additives such as alkene-l-polymers, in particular low density polyethylene, polypropylene or polybutylene, copolymers containing mono-olefins as primary monomers, oxidized
5 polyolefins, graft polyolefin copolymers and polyoxymethylenes, or low molecular weight additives such as antioxidants, lubricants, ultra-violet screening agents, colorants and the like.

High molecular weight polyethylene for the purposes of this invention has an intrinsic viscosity in decalin at 135°C of from about 5
10 deciliter/gram (dl/g) to about 35 dl/g. Such high molecular weight polyethylene fibers may be grown in solution as described in USP 4,137,394 or USP 4,356,138, or a filament spun from a solution to form a gel structure, as described in German Off. No. 3,004, 699 and GB No. 2051667, and especially as described in USP 4,413,110 and sold under the
15 SPECTRA® trademark by Honeywell International Inc. The disclosure of USP 4,413,110 is hereby incorporated by reference to the extent that it is not inconsistent herewith. The polyethylene fibers may also be produced by a rolling and drawing process as described in UPS 5,702,657 and sold under the TENSYLON® trademark by ITS Industries Inc.

20 In the case of aramid fibers, suitable fibers formed from aromatic polyamides are described in USP's 3,671,542 and 5,010,168 which are hereby incorporated by reference. Aramid fibers are produced commercially by E.I. Dupont Co. under the KEVLAR® and NOMEX® trademarks; by Teijin Twaron BV under the TWARON®, TECHNORA®
25 and TEIJINCONEX® trademarks; by JSC Chim Volokno under the name ARMOS; and by Kamensk Volokno JSC under the names RUSAR and SVM. Poly(p-phenylene terephthalamide) and p-phenylene terephthalamide aramid co-polymer fibers having moderately high moduli and tenacity values are particularly useful in the present invention. An
30 example of a p-phenylene terephthalamide copolymer aramid useful in the invention is co-poly-(paraphenylene 3,4'-oxydiphenylene terephthalamide).

Also useful in the practice of this invention are poly(m-phenylene isophthalamide) fibers.

Suitable polybenzazole fibers for the practice of this invention are disclosed for example in USP's 5,286,833, 5,296,185, 5,356,584, 5,534,205 and 6,040,050 hereby incorporated by reference. Preferably, the polybenzazole fibers are ZYLON® poly(p-phenylene-2,6-benzobisoxazole) fibers from Toyobo Co.

Suitable rigid rod polymers having the structure of the M5® brand of fiber are disclosed in USP's 5,674,969, 5,939,553, 5,945,537 and 6,040,478, hereby incorporated by reference. A preferred fiber is M5® brand available from Magellan Systems International, LLC.

The fiber networks in the plies of the second laminate or a third laminate may be constructed with the polymeric fibers listed above singly or in combination. The filaments of different composition may be combined in a single fiber. Unidirectional fiber networks may be constructed with fibers of different composition laid down parallel to one another in regular or irregular array. Felts, braids, knits and woven fabrics may employ different fibers in different directions. A ply is defined by laminae having the same composition and construction differing in composition and/or construction from the laminae in adjacent plies. The second laminate or a third laminate may be constructed with several plies each having a different polymeric fiber, a different or no matrix, or a different fiber network construction. As different polymeric fibers have differing ballistic effectiveness to projectiles of differing velocities, it is preferred to construct the second laminate with plies containing the fiber that is most effective against high velocity projectiles nearest the frontal laminate.

Preferably, the polymeric fibers comprise from 75 to 100 percent by weight of the second laminate, the balance being a matrix material.

The polymeric matrices employed in the inorganic fiber networks preferably have initial tensile moduli of at least 400,000 psi (2.76 GPa) as measured by ASTM D638-94b. More preferably, the polymeric matrix in at least one ply of the frontal laminate has an initial tensile modulus of at least

1 x 10⁶ psi (6.9 GPa), as measured by ASTM D638-94b. High modulus matrix resins useful in a laminate of the invention include thermoset allyls, aminos, cyanates, epoxies, phenolics, unsaturated polyesters, bismaleimides, rigid polyurethanes, silicones, vinyl esters and their
5 copolymers and blends. It is important only that the matrix resin possesses the necessary initial tensile modulus. Thermoset vinyl ester resins are preferred.

Preferably, the vinyl ester is one produced by the esterification of a polyfunctional epoxy resin with an unsaturated monocarboxylic acid,
10 usually methacrylic or acrylic acid. Illustrative vinyl esters include diglycidyl adipate, diglycidyl isophthalate, di-(2,3-epoxybutyl) adipate, di-(2,3-epoxybutyl) oxalate, di-(2,3-epoxyhexyl) succinate, di-(3,4-epoxybutyl) maleate, di-(2,3-epoxyoctyl) pimelate, di-(2,3-epoxybutyl) phthalate, di-(2,3-epoxyoctyl) tetrahydrophthalate, di-(4,5-epoxydodecyl) maleate, di-(2,3-
15 epoxybutyl) terephthalate, di-(2,3-epoxypentyl) thiodipropionate, di-(5,6-epoxytetradecyl) diphenyldicarboxylate, di-(3,4-epoxyheptyl) suphonyldibutyrate, tri-(2,3-epoxybutyl)-1,2,4- butanetricarboxylate, di-(5,6-epoxypentadecyl) maleate, di-(2,3-epoxybutyl) azelate, di-(3,4-epoxypentadecyl) citrate, di-(4,5-epoxyoctyl) cyclohexane-1,3-
20 dicarboxylate, di-(4,5-epoxyoctadecyl) malonate, bisphenol-A-fumaric acid polyester and similar materials.

Most preferred are epoxy-based vinyl ester resins, such as the DERAKANE® resins manufactured by Dow Chemical Company.

The polymeric matrices that are optionally employed in the plies
25 of the second laminate are preferably elastomers having initial tensile moduli of less than 6000 psi (41.3 MPa) as measured by ASTM D638-94b. A wide variety of elastomeric materials and formulations having appropriately low modulus may be utilized in this invention. For example, any of the following materials may be employed: polybutadiene,
30 polyisoprene, natural rubber, ethylene-propylene copolymers, ethylene-propylene-diene terpolymers, polysulfide polymers, polyurethane elastomers, chlorosulfinated polyethylene, polychloroprene, plasticized

polyvinylchloride using dioctyl phthalate or other plasticizers well known in the art, butadiene acrylonitrile elastomers, poly(isobutylene-co-isoprene), polyacrylates, polyesters, polyethers, fluoroelastomers, silicone elastomers, thermoplastic elastomers, copolymers of ethylene. Preferred are block
5 copolymers of conjugated dienes and vinyl aromatic copolymers. Many of these polymers are produced commercially by Kraton Polymers, Inc.

Alternatively, if the article of the invention is to be used in hard armor, or has a structural role, the polymeric matrix optionally employed in the plies of the second laminate preferably has an initial tensile moduli least
10 400,000 psi (2.76 GPa), more preferably 1×10^6 psi (6.9 GPa) as measured by ASTM D638-94b. Thermoset vinyl ester resins are preferred.

As used herein, the term "matrix" does not imply any particular degree of filling of void volume in or between the laminae. As the impact properties of a laminate are determined almost entirely by the fiber content, and it is desirable to minimize the weight of the laminate, the matrix content
15 is preferably kept as low as possible consistent with the requirements of particular manufacturing processes. The level of matrix necessary to stabilize the laminae and to maintain a robust manufacturing operation will be known to the man skilled in the art.

20 The matrix resin may be applied to the fibers in a variety of ways and any method known to those skilled in the art may be used. Preferably, a unidirectional fiber lamina in a matrix is formed in a continuous process illustrated schematically in Figure 4. Fibers are supplied from a creel **102** and passed through a combing station **104** to form a unidirectional network.
25 Different fibers may be arranged on the creel so as to produce a fiber network with a periodic or other arrangement of the fibers in a transverse direction. The fiber network is then placed on a carrier web that can be a paper or a plastic film or plastic sheet substrate **106**. The matrix composition is applied to the fiber network at **108**. The matrix composition
30 may contain a solvent diluent or it may in the form of an aqueous dispersion for ease of application. The coated fiber network is then passed through a pair of rollers **110**. The rollers spread the matrix composition

among the fibers. The rollers may be designed to create a non-uniformly distributed matrix as described in USP 5,093,158 hereby incorporated by reference to the extent not incompatible herewith. The coated fiber network is then passed through a heated oven **112** to evaporate any solvent or water in the matrix composition. A nip roller **116** is used to pull the carrier web and prepreg through the system. The substrate and the prepreg that will become a lamina can then be wound on a roller **118** in preparation for construction of an article of the invention.

A ply of a preferred laminate is preferably produced from continuous rolls of unidirectional prepregs as described above by a continuous cross-plying operation employing the method of USP 5,173,138 or 5,766,725, hereby incorporated by reference to the extent not incompatible herewith, or by hand lay-up, or by any suitable means. With reference to the apparatus and drawings of USP 5,173,138, one prepreg roll is placed on the let off roll **11** of the cross-plying machine and a second prepreg roll is placed on the let off roll **17**. The carrier web may be stripped from the prepreg or it may become part of the final laminate.

The fiber compositions of the prepreg rolls may be the same or different. The prepregs (laminae) are consolidated by the application of heat and pressure in the cross-plying apparatus. Cross-linkable matrix resins are generally not cured at this stage of construction.

To construct plies of the preferred laminates with more than one pair of laminae, the cross-plyed product may itself be cross-plyed, and cross-plyed again a plurality of times to produce a desired laminate construction. In each cross-plying operation, the number of laminae may be doubled. Alternatively, the second and subsequent cross-plying operations may be done with different numbers of lamina in the prepregs to be cross-plyed. When the number of laminae becomes too great for continuous roll formation, the cross-plying may be conducted by hand or by any suitable means.

Finally, the plies are assembled by stacking together face-to-face. The plies may be united by bonding under pressure and at a

temperature sufficient to cure any thermosetting matrix resins.

Temperatures from about 90° to about 160°C and pressures of from about 100 psi to about 2500 psi (69 – 17,000 kPa) are employed, depending upon the types of fibers and matrix present.

5 The articles of the invention possess in heretofore unseen combination light weight and ballistic-resistance to multiple high velocity bullets. One measure of weight efficiency is the specific energy absorption of the laminate at the V50 velocity. The V50 velocity is that velocity at which 50% of bullets will penetrate the laminate as determined by MIL-STD
10 662E. Preferably, a laminate of the invention, when impacted by M80 ball, 7.62 X 51, 147 grain (9.53 g) bullets, has a specific energy absorption at the V50 velocity of at least 100 J-m²/Kg.

Remarkably, the resistance of an article of the invention to penetration by subsequent bullets impacting in a small area remains
15 unaffected even after multiple hits. Even more remarkably, an article of the invention maintains its resistance to penetration by multiple hits from bullets containing steel cores designed to penetrate armor. This is in marked contrast to articles having unreinforced monolithic ceramic elements that are shattered by the first bullet. Preferably, an article of the invention,
20 when serially impacted by M80 ball, 7.62 X 51, 147 grain (9.53 g) bullets at a velocity of at least 2000 ft/sec (610 m/sec) within a lateral area of 15 cm x 15 cm, has a minimum penetration velocity for a third bullet of not less than 90% of the minimum penetration velocity of a first bullet, more preferably not less than 95% of the minimum penetration velocity of a first bullet.

25 Yet more preferably, an article of the invention, when serially impacted by M80 ball, 7.62 X 51, 147 grain (9.53 g) bullets at a velocity of at least 2000 ft/sec (610 m/sec) within a lateral area of 15 cm x 15 cm, has a minimum penetration velocity for a fifth bullet of not less than 90% of the minimum penetration velocity of a first bullet, again more preferably not
30 less than 95% of the minimum penetration velocity of a first bullet.

Still more preferably, an article of the invention, when serially impacted by M80 ball, 7.62 X 51, 147 grain (9.53 g) bullets at a velocity of

at least 2000 ft/sec (610 m/sec) within a lateral area of 15 cm x 15 cm, has a minimum penetration velocity against a seventh bullet of not less than 90% of the minimum penetration velocity of a first bullet, most preferably not less than 95% of the minimum penetration velocity of a first bullet.

5 Preferably also, an article of the invention, when serially impacted by 7.62 X 39 ball type 56, 123gr. (7.97 g) (Russian AK-47) bullets with steel penetrator cores, at a velocity of at least 1900 ft/sec (579 m/sec) within a lateral area of 15 cm x 15 cm, has a minimum penetration velocity for a third, fifth or seventh bullet of not less than 90% of the minimum
10 penetration velocity of a first bullet.

Without being held to a particular theory of why the invention works, it is believed that the high hardness of the inorganic fibers in the frontal laminate act to deform and slow the bullet in the same manner as would a monolithic plate of the same material. However, because the
15 fibers are arranged in unidirectional array, the fracturing of the fibers is confined to a small distance along their lengths. Also in contrast to a woven network where there is direct connection between fibers, the ballistic shock wave is attenuated when transmitted through the matrix to laterally adjacent but unconnected fibers. Thus, many fibers in a given area of the
20 frontal laminate remain intact and are available to perform the same function of deforming and slowing subsequent bullets.

The following examples are presented to provide a more complete understanding of the invention. The specific techniques, conditions, materials, proportions and reported data set forth to illustrate
25 the principles of the invention are exemplary and should not be construed as limiting the scope of the invention.

EXAMPLES

Comparative Example

30 A laminate panel was constructed consisting of a front plate of monolithic silicon carbide (SiC) and a rear laminate bonded to the SiC plate consisting of laminae of unidirectional high molecular weight polyethylene

fibers. The SiC front plate had dimensions of 15.2 cm x 15.2 cm x 0.587 cm and it had an areal density of 3.76 lbs/ft² (18.38 Kg/m²). The SiC plate was manufactured by Saint-Gobain Advanced Ceramics, Niagara Falls, NY. It was a sintered form of α -SiC having a density of 3.10 g/cm³, a modulus of elasticity of 410 GPa and a Knoop Hardness of 2800 kg/mm².

The rear laminate consisted of 56 SPECTRA SHIELD® PCR sheets from Honeywell International Inc. bonded together under heat and pressure, each sheet consisting of two unidirectional laminae of high molecular weight polyethylene fibers in a thermoplastic elastomeric matrix, and cross-plyed 0°/90°. The thickness of the rear laminate was 0.3 inch (0.76 cm), and it had an areal density of 1.51 lbs/ft² (7.38 Kg/m²). The total areal density of the laminate panel was 5.27 lbs/ft² (25.75 Kg/m²).

The 1.35 cm thick laminate panel was fired on in succession by two M80 ball, 7.62 X 51 mm, 147 grain (9.53 g) bullets. The first bullet fired at a velocity of 3081 ft/sec (939 m/sec) did not penetrate the laminate panel but shattered the front SiC plate. The second bullet fired at a velocity of only 1625 ft/sec (495 m/sec) penetrated the laminate panel.

Example 1

Chemically vapor deposited (CVD) boron fiber on tungsten unidirectional prepreg tape was obtained from Specialty Materials, Inc, Lowell, MA. The CVD boron filaments were of 0.004 inch (0.0102 cm) diameter, and had a density of 2.60 g/cm³ and a tensile strength of 3.44 GPa. The CVD boron fibers were 67 percent by weight of the prepreg tape with the balance being epoxy resin. Thirty-four of the CVD boron fiber/epoxy unidirectional tapes were cross-plyed 0°/90° and formed into a frontal laminate in a press at 121°C, and 1.0 MPa. The areal density of this 15.2 cm x 15.2 cm x 0.526 cm laminate was 2.0 lbs/ft² (9.77 Kg/m²).

A second laminate was formed of 74 SPECTRA SHIELD® PCR sheets from Honeywell International Inc. bonded together under heat and pressure, each sheet consisting of two inner unidirectional laminae of high molecular weight polyethylene fibers in a matrix, cross-plyed 0°/90° and having an outer plastic film on each surface. The matrix was a styrene-

isoprene-styrene thermoplastic elastomer having a tensile modulus of 200 psi (1.4 MPa). The high molecular weight polyethylene fibers had a tenacity of 30 g/d and comprised 80 percent by weight of the laminae. This second laminate was united (bonded) face-to-face to the first laminate to
 5 create a panel article of the invention having an areal density of 4.0 lbs/ft² (19.6 Kg/m²).

This 1.54 cm thick panel was serially fired on by 7.62 X 51 mm, 147 grain (9.53 g) steel jacketed bullets in the sequence and with the results shown in Table II below. The bullets impacted the frontal laminate
 10 of the panel.

TABLE II

Bullet No.	Velocity		Penetration
	ft/sec	m/sec	
1	2719	829	Yes
2	2521	768	Yes
3	2379	725	No
4	2422	738	Yes
5	2336	712	No
6	2419	737	Yes
7	2412	735	No
8	2441	744	Yes
9	2391	729	No
10	2495	760	Yes
11	2400	732	No

The first two bullets at velocities of 2719 ft/sec (829 m/sec) and 2521 ft/sec (768 m/sec) penetrated the article of the invention. The third
 15 bullet fired at a velocity of 2379 ft/sec (725 m/sec) did not penetrate the panel. Therefore, the minimum penetration velocity for the first bullet was known to be at least 2379 ft/sec (725 m/sec). Remarkably, the fifth, seventh, ninth and eleventh bullets fired into this same panel at velocities

no less than 98 % of the minimum penetration velocity of the first bullet also did not penetrate the panel.

The article of the invention was also resistant to penetration meeting at least the requirements of NIJ Standard 0115.00 for Type 1 stab
5 protection.

Example 2

Chemically vapor deposited (CVD) boron fiber on tungsten unidirectional prepreg tape was obtained from Specialty Materials, Inc, Lowell, MA. The CVD boron filaments were of 0.004 inch (0.0102 cm)
10 diameter, and had a density of 2.60 g/cm³ and a tensile strength of 3.44 GPa. The CVD boron fibers were 67 percent by weight of the prepreg tape with the balance being epoxy resin. Thirty-four of the CVD boron fiber/epoxy unidirectional tapes were cross-plyed 0°/90° and formed into a frontal laminate in an autoclave at a temperature of 116°C, 344 KPa
15 external pressure and 96 KPa vacuum. The areal density of this 15.2 cm x 14.0 cm x 0.526 cm laminate was 2.0 lbs/ft² (9.77 Kg/m²).

A second laminate was formed of 112 SPECTRA SHIELD® PLUS PCR consolidated sheets, bonded together under heat and pressure, each sheet consisting of two inner unidirectional laminae of high molecular
20 weight polyethylene fibers in a matrix, cross-plyed 0°/90°, and having an outer plastic film on each surface. The matrix was a styrene-isoprene-styrene thermoplastic elastomer having a tensile modulus of 200 psi (1.4 MPa). The high molecular weight polyethylene fibers had a tenacity of 30 g/d. The areal density of this laminate was 3 lbs/ft² (14.66 Kg/m²).

25 The second laminate was bonded face-to-face with the frontal laminate to create a panel article of the invention 1.49 cm thick and having an areal density of 5.0 lbs/ft² (24.4 Kg/m²).

This panel was serially fired on by 7.62 X 39 mm ball type 56; 123 gr. (7.97 g) (Russian AK-47) bullets with steel penetrator cores, in the
30 sequence and with the results shown in Table III. The bullets impacted the frontal laminate of the panel.

Table III

Bullet No.	Velocity		Penetration
	ft/sec	m/sec	
1	2347	715	Yes
2	2231	680	Yes
3	2100	640	Yes
4	1908	582	No
5	1975	602	Yes
6	1922	586	No
7	1982	604	No
8	2042	622	No
9	2084	635	No
10	2078	633	Yes

The panel article of the invention maintained its minimum penetration velocity of at least 1908 ft/sec (582 m/sec) even after nine bullets had been fired into it.

Example 3

A frontal laminate was formed identical to the frontal laminate in Example 2. The areal density of this frontal laminate, having dimensions of 15.2 cm x 14.0 cm x 0.526 cm, was 2.0 lbs/ft² (9.77 Kg/m²).

A second laminate was formed of 172 SPECTRA SHIELD® PLUS PCR consolidated sheets, bonded together under heat and pressure, each sheet consisting of two inner unidirectional laminae of high molecular weight polyethylene fibers in a matrix, cross-plyed 0°/90°, and having an outer plastic film on each surface. The matrix was a styrene-isoprene-styrene thermoplastic elastomer having a tensile modulus of 200 psi (1.4 MPa). The high molecular weight polyethylene fibers had a tenacity of 30 g/d, and the areal density of this laminate was 3.99 lbs/ft² (19.5 Kg/m²).

The second laminate was bonded face-to-face with the frontal laminate creating a panel article of the invention of 2.76 cm thickness and an areal density of 5.99 lbs/ft² (29.3 Kg/m²). This panel was serially fired on by M80 ball, 7.62 X 51 mm, 147 grain (9.53 g) steel jacketed bullets in the sequence and with the results shown in Table IV. The bullets impacted the frontal laminate of the article.

Table IV

Bullet No.	Velocity		Penetration
	ft/sec	m/sec	
1	3239	987	Yes
2	3018	920	No
3	3093	943	No
4	3134	955	No
5	3205	977	Yes

The panel article of the invention maintained its minimum penetration velocity of at least 3018 ft/sec (920 m/sec) even after four
5 bullets had been fired into it.

Example 4

A frontal laminate was formed identical to the frontal laminate in Example 2. The areal density of this frontal laminate, having dimensions of 15.2 cm x 14.0 cm x 0.526 cm, was 2.0 lbs/ft² (9.77 Kg/m²).

10 A second laminate was formed identical to the second laminate in Example 3. The areal density of this laminate was 3.99 lbs/ft² (19.5 Kg/m²).

A third laminate was formed of 24 sheets of GOLDFLEX® material from Honeywell International stacked face-to-face and sewn
15 together around their edges, each sheet consisting of four inner unidirectional laminae of aramid fibers in a matrix, cross-plyed 0°/90°, and having an outer plastic film on each surface. The matrix was a styrene-isoprene-styrene thermoplastic elastomer having a tensile modulus of 200 psi (1.4 MPa). The aramid fibers had a tenacity of 22 g/d. The areal
20 density of this laminate was 1.14 lbs/ft² (5.57 Kg/m²).

The second laminate was bonded face-to-face with the frontal laminate and the third laminate was stacked face-to-face with the second laminate to create an article of the invention 3.48 cm thick and having an areal density of 5.99 lbs/ft² (29.3 Kg/m²).

25 This article was serially fired on by 7.62 X 39 ball type 56, 123 gr. (7.97 g) (Russian AK-47) bullets with steel penetrator cores, in the

sequence and with the results shown in Table V. The bullets impacted the frontal laminate of the article.

Table V

Bullet No.	Velocity		Penetration
	ft/sec	m/sec	
1	2432	741	No
2	2460	750	No
3	2651	808	No
4	2714	827	No
5	2716	828	No
6	3111	948	No
7	3331	1015	Yes

5 The article of the invention maintained its minimum penetration velocity of at least 3111 ft/sec (948 m/sec) even after six bullets had been fired into it.

Example 5

10 A frontal laminate was formed identical to the frontal laminate in Example 1. The areal density of this frontal laminate having dimensions of 15.2 cm x 15.2 cm x 0.526 cm was 2.0 lbs/ft² (9.77 Kg/m²).

15 A second laminate was formed of 27 sheets of an aramid woven fabric containing 15 percent by weight of a vinyl ester matrix resin. The fabric was a plain weave having 21 x 21 ends/ inch (8.27 ends/cm) woven from 1500 denier KEVLAR® 29 yarn and was obtained from Barrday, Inc. The matrix resin was Dow Chemical Co. Derekane 411 containing 1.5% 2,5 dimethyl-2,5di(2-ethylhexanoyl peroxy) hexane curing agent. Impregnated fabric sheets were stacked and bonded together by heating and curing the resin at 120 °C under a pressure of 500 psi (3.45 MPa). The initial tensile modulus of the neat resin in the cured state is 460,000 psi (3.17GPa). The areal density of the second laminate was 1.72 lbs/ft² (9.77 Kg/m²).

20

 A third laminate was formed of 24 sheets of GOLDFLEX® material (Honeywell International Inc.) stacked face-to-face and sewn

together around their edges, each sheet consisting of four inner unidirectional laminae of aramid fibers in a matrix, cross-plyed 0°/90°, and having an outer plastic film on each surface. The matrix was a styrene-isoprene-styrene thermoplastic elastomer having a tensile modulus of 200 psi (1.4 MPa). The aramid fibers had a tenacity of 22 g/d. The areal density of this laminate was 1.14 lbs/ft² (5.57 Kg/m²).

The second laminate was bonded face-to-face with the frontal laminate and the third laminate was stacked face-to-face with the second laminate to create an article of the invention having an areal density of 4.86 lbs/ft² (23.8 Kg/m²).

This article was serially fired on by M80 ball, 7.62 X 51 mm, 147 grain (9.53 g) steel jacketed bullets in the sequence and with the results shown in Table VI. The bullets impacted the frontal laminate of the article.

15

Table VI

Bullet No.	Velocity		Penetration
	ft/sec	m/sec	
1	2484	757	Yes
2	2366	721	Yes
3	2006	611	No
4	2013	614	Yes
5	2100	640	Yes
6	1965	599	Yes
7	1950	594	No
8	1969	600	No
9	2011	613	Yes

The article of the invention maintained its minimum penetration velocity of at least 1950 ft/sec (594 m/sec) even after eight bullets had been fired into it.

20 **Example 6**

Chemically vapor deposited (CVD) boron fiber on tungsten unidirectional prepreg tape was obtained from Specialty Materials, Inc, Lowell, MA. The CVD boron filaments were of 0.004 inch (0.0102 cm) diameter, had a density of 2.60 g/cm³ and a tensile strength of 3.44 GPa.

The CVD boron fibers were 67 percent by weight of the prepreg tape with the balance being epoxy resin. Seventeen of the CVD boron fiber/epoxy unidirectional tapes were stacked together, cross-plyed at 0°/90° to form the frontal ply. An 11 cm x 11 cm titanium plate of 1.8 mm thickness was placed on this stack to form a second ply, and an additional seventeen of the CVD boron fiber/epoxy unidirectional tapes were placed on the stack, cross-plyed at 0°/90° to form a third ply. The entire stack with the titanium plate in the center was then formed into a frontal laminate in an autoclave at a temperature of 116°C, 344 KPa external pressure and 96 KPa vacuum. The areal density of this 15.2 cm x 14.0 cm x 0.526 cm laminate was 2.86 lbs/ft² (14.0 Kg/m²). The titanium plate was embedded on all surfaces by the frontal and third plies of the frontal laminate.

A second laminate was formed of 103 SPECTRA SHIELD® PLUS PCR consolidated sheets, bonded together under heat and pressure, each sheet consisting of two inner unidirectional laminae of high molecular weight polyethylene fibers in a matrix, cross-plyed 0°/90°, and having an outer plastic film on each surface. The matrix was a styrene-isoprene-styrene thermoplastic elastomer having a tensile modulus of 200 psi (1.4 MPa). The high molecular weight polyethylene fibers had a tenacity of 30 g/d. The areal density of this laminate was 2.0 lbs/ft² (9.77 Kg/m²).

A third laminate was formed of 24 sheets of GOLDFLEX® material (Honeywell International Inc.) stacked face-to-face and sewn together around their edges, each sheet consisting of four inner unidirectional laminae of aramid fibers in a matrix, cross-plyed 0°/90°, and having an outer plastic film on each surface. The matrix was a styrene-isoprene-styrene thermoplastic elastomer having a tensile modulus of 200 psi (1.4 MPa). The aramid fibers had a tenacity of 22 g/d. The areal density of this laminate was 1.14 lbs/ft² (5.57 Kg/m²).

The second laminate was bonded face-to-face with the frontal laminate and the third laminate was stacked face-to-face with the second laminate to create an article of the invention having an areal density of 6.0 lbs/ft² (29.3 Kg/m²).

This article was serially fired on by 7.62 x 54R ball type 56, 149 grain (9.66 g), (Russian Dragnov, LPS) bullets with steel penetrator cores, in the sequence and with the results shown in Table VII. The bullets impacted the frontal laminate of the article.

Table VII

Bullet No.	Velocity		Penetration
	ft/sec	m/sec	
1	2170	661	No
2	2281	695	No
3	2403	732	Yes
4	2344	714	No

The article of the invention maintained a minimum penetration velocity of at least 2344 ft/sec (714 m/sec) after four bullets had been fired into it.

Example 7

A frontal laminate is formed identical to the frontal laminate in Example 1. The areal density of this frontal laminate having dimensions of 15.2 cm x 15.2 cm x 0.526 cm was 2.0 lbs/ft² (9.77 Kg/m²).

A second laminate is formed from five sheets of PBO (poly(p-phenylene-2,6-benzobisoxazole) felt having a KEVLAR® scrim. The PBO felt is designated PBO/KR-KR from Bayrische Wollfilz Fabrik and has an areal density of 0.27 lbs/ft² (1.35 Kg/m²) and an initial thickness of 4 mm. The felt sheets are stacked together face-to-face with polyethylene films of 0.35 mm thickness between the sheets and on both sides of the stack, and the stack is molded at 120 °C under a pressure of 100 psi (0.69 MPa). The second laminate has a thickness of 10 mm and an areal density of 1.38 lbs/ft² (6.75 Kg/m²).

A third laminate is formed of 24 sheets of GOLDFLEX® material stacked face-to-face and sewn together around their edges, each sheet consisting of four inner unidirectional laminae of aramid fibers in a matrix,

cross-plyed 0°/90°, and having an outer plastic film on each surface. The matrix is a styrene-isoprene-styrene thermoplastic elastomer having a tensile modulus of 200 psi (1.4 MPa). The aramid fibers have a tenacity of 22 g/d. The areal density of this laminate is 1.14 lbs/ft² (5.57 Kg/m²).

5 The second laminate is bonded face-to-face with the frontal laminate and the third laminate is stacked face-to-face with the second laminate to create an article of the invention having an areal density of 4.52 lbs/ft² (22.1 Kg/m²).

 It is believed that this panel when serially impacted on the frontal
10 laminate by M80 ball, 7.62 X 51, 147 grain (9.53 g) bullets at a velocity of at least 2000 ft/sec (610 m/sec), within a lateral area of 15 cm x 15 cm, would have a minimum penetration velocity for a third bullet of not less than 90% of the minimum penetration velocity of a first bullet.

Example 8

15 SCS-ULTRA® chemically vapor deposited silicon carbide on carbon fibers are obtained from Specialty Materials, Inc. The CVD SiC fibers are of 0.0056 inch (0.0142 cm) diameter and have a tensile strength of 5.86 GPa and a density of 3.0 g/cm³. The fibers are formed into a unidirectional prepreg using the apparatus illustrated in Figure 3. A
20 DERA-KANE® epoxy vinyl ester resin having a tensile modulus of 450,000 psi (3.1 GPa) is applied as the matrix. The CVD SiC fibers constitute 90 percent by weight of the prepreg. The prepreg is cross-plyed 0°/90° using the method and apparatus described in USP 5,173,138. Sixteen of the cross-plyed sheets (32 laminae) are bonded together to form a frontal
25 laminate, having an areal density of 2.70 lbs/ft² (13.2 Kg/m²).

 A second laminate is formed of 37 SPECTRA SHIELD® PCR sheets bonded together under heat and pressure, each sheet consisting of two unidirectional laminae of high molecular weight polyethylene fibers in a thermoplastic elastomeric matrix, and cross-plyed 0°/90°. The high
30 molecular weight polyethylene fibers have a tenacity of 30 g/d. The areal density of the second laminate is 2 lbs/ft² (9.77 Kg/m²).

A third laminate is formed by a method identical to that used to form the frontal laminate except that only eight of the CVD SiC cross-plyed sheets (16 laminae) are bonded together. The areal density of the third laminate is 1.35 lbs/ft² (6.60 Kg/m²).

5 The frontal laminate, the second laminate and the third laminate are bonded together face-to-face to create a laminate panel of the invention having an areal density of 5.64 lbs/ft² (27.6 Kg/m²).

 It is believed that this panel, when serially impacted on the frontal laminate by M80 ball, 7.62 X 51, 147 grain (9.53 g) bullets at a
10 velocity of at least 2000 ft/sec (610 m/sec) within a lateral area of 15 cm x 15 cm, would have a minimum penetration velocity for a third bullet of not less than 90% of the minimum penetration velocity of a first bullet.

 Having thus described the invention in rather full detail, it will be understood that such detail need not be strictly adhered to but that further
15 changes and modifications may suggest themselves to one skilled in the art, all falling within the scope of the invention as defined by the subjoined claims.

What is claimed is:

1. An article comprising:

a) a frontal laminate comprising one or more plies, one of said plies being a frontal ply comprising a plurality of laminae of unidirectional inorganic fibers in a polymeric matrix, the laminae in a ply having the same composition and construction, the laminae in adjacent plies of the frontal laminate differing in composition or construction, said inorganic fibers being comprised of filaments having a tensile strength of at least 2.0 GPa and a density of less than 4.0 g/cm³, wherein the fiber direction in each lamina is at an angle to the fiber direction in adjacent laminae; and

b) a second laminate united face-to-face to the frontal laminate, the second laminate comprising one or more plies, each said ply comprising a plurality of laminae of polymeric fibers in a network, the polymeric fibers having a tenacity of at least 17 g/d, the network optionally containing a matrix material, the laminae in a ply having the same composition and construction, the laminae in adjacent plies of the second laminate differing in composition or construction.

2. The article of claim 1 additionally comprising a third laminate stacked face-to-face to said second laminate, said third laminate comprising one or more plies, each said ply comprising a plurality of laminae of polymeric fibers in a network optionally containing a matrix, the polymeric fibers having a tenacity of at least 17 g/d, the laminae in a ply having the same composition and construction, the laminae in adjacent plies of the third laminate differing in composition or construction.

3. The article of claim 2 wherein the frontal laminate consists of a frontal ply of unidirectional inorganic fibers, a second ply of a titanium metal plate, and a third ply of unidirectional inorganic fibers, the titanium plate being embedded on all surfaces by said first and third plies, said inorganic fibers being comprised of filaments having a tensile strength of at least 2.0 GPa and a density of less than 4.0 g/cm³, wherein the

fiber direction in each lamina is at an angle to the fiber direction in adjacent laminae;

4. The article of claim 1 additionally comprising a third laminate united face-to-face with said second laminate, said third laminate comprising one or more plies, each said ply comprising a plurality of laminae of unidirectional inorganic fibers in a polymeric matrix, the laminae in a ply having the same composition and construction, the laminae in adjacent plies of the third laminate differing in composition or construction, said inorganic fibers being comprised of filaments having a tensile strength of at least 2.0 GPa and a density of less than 4.0 g/cm³, wherein the fiber direction in each lamina is at an angle to the fiber direction in adjacent laminae.
5. The article of claim 1, wherein said frontal laminate and said second laminate have balanced constructions.
6. The article of claim 1, wherein the laminae comprising said second laminate have a fiber network construction selected from the group consisting of woven, knitted, braided, randomly oriented non-woven and unidirectionally oriented non-woven.
7. The article of claim 1, wherein the laminae comprising the second laminate comprise unidirectionally, non-woven fiber networks.
8. The article of claim 7, wherein the angle between the fibers in adjacent laminae comprising said second laminate is from 45 to 90 degrees.
9. The article of claim 1 wherein the filaments comprising said inorganic fibers have a tensile strength of at least 2.4 GPa and a density of less than 3.4 g/cm³.
10. The article of claim 1 wherein the filaments comprising said inorganic fibers have a tensile strength of at least 3.4 GPa and a density of less than 3.4 g/cm³.
11. The article of claim 1 wherein the filaments comprising said inorganic fibers have a tensile strength of at least 4.0 GPa and a density of less than 3.1 g/cm³.

12. The article of claim 1 wherein said inorganic fibers are selected from the group consisting of chemically vapor deposited boron, chemically vapor deposited silicon carbide, β -SiC, β -SiC in a Si-O-C amorphous phase, E-glass, S-glass, a (54.4% Si, 32.4% C, 10.2% O, 2% Ti) composition, a
5 (55.3% Si, 33.9% C, 9.8% O, 1.0% Zr) composition, SiBN₃C with 1-3% O and combinations thereof.
13. The article of claim 1, wherein said inorganic fibers are selected from the group consisting of chemically vapor deposited boron on tungsten, chemically vapor deposited silicon carbide on carbon, and combinations
10 thereof.
14. The article of claim 1 wherein said inorganic fibers comprise from 60 to 95 percent by weight of said frontal laminate.
15. The article of claim 1, wherein said polymeric fibers are selected from the group consisting of high molecular weight polyethylene, aramid,
15 polybenzazole, rigid rod polymer and combinations thereof.
16. The article of claim 1, wherein said polymeric fibers are selected from the group consisting of high molecular weight polyethylene, poly(p-phenylene terephthalamide), poly(2-phenylene-2,6-benzobisoxazole), M5 and combinations thereof.
- 20 17. The article of claim 1, wherein said polymeric fibers comprise from 75 to 95 percent by weight of said second laminate.
18. The article of claim 1, wherein the polymeric matrix in each lamina of each ply of said frontal laminate has an initial tensile modulus at least 400,000 psi (2.76 GPa) as measured by ASTM D638.
- 25 19. The article of claim 1, wherein the polymeric matrix in each lamina of each ply of said second laminate is an elastomer having an initial tensile modulus less than 6,000 psi (41.3 MPa) as measured by ASTM D638.
20. The article of claim 1, when serially impacted by M80 ball, 7.62 X 51, 147 grain (9.53 g) bullets at a velocity of at least 2000 ft/sec (610
30 m/sec) within a lateral area of 15 cm x 15 cm, having a minimum penetration velocity for a third bullet of not less than 90% of the minimum penetration velocity of a first bullet.

21. The article of claim 1, when serially impacted by impacted by M80 ball, 7.62 X 51, 147 grain (9.53 g) bullets at a velocity of at least 2000 ft/sec (610 m/sec) within a lateral area of 15 cm x 15 cm, having a minimum penetration velocity for a third bullet of not less than 95% of the minimum penetration velocity of a first bullet.
22. The article of claim 1, when serially impacted by impacted by M80 ball, 7.62 X 51, 147 grain (9.53 g) bullets at a velocity of at least 2000 ft/sec (610 m/sec) within a lateral area of 15 cm x 15 cm, having a minimum penetration velocity for a fifth bullet of not less than 90% of the minimum penetration velocity of a first bullet.
23. The article of claim 1, when serially impacted by impacted by M80 ball, 7.62 X 51, 147 grain (9.53 g) bullets at a velocity of at least 2000 ft/sec (610 m/sec) within a lateral area of 15 cm x 15 cm, having a minimum penetration velocity against a fifth bullet of not less than 95% of the minimum penetration velocity of a first bullet.
24. The article of claim 1, when serially impacted by impacted by M80 ball, 7.62 X 51, 147 grain (9.53 g) bullets at a velocity of at least 2000 ft/sec (610 m/sec) within a lateral area of 15 cm x 15 cm, having a minimum penetration velocity against a seventh bullet of not less than 90% of the minimum penetration velocity of a first bullet.
25. The article of claim 1, when serially impacted by impacted by M80 ball, 7.62 X 51, 147 grain (9.53 g) bullets at a velocity of at least 2000 ft/sec (610 m/sec) within a lateral area of 15 cm x 15 cm, having a minimum penetration velocity against a seventh bullet of not less than 95% of the minimum penetration velocity of a first bullet.
26. The article of claim 1 having a specific energy absorption against M80 ball, 7.62 X 51, 147 grain (9.53 g) bullets of at least 100 J-m²/Kg at the V50 velocity.
27. The article of claim 1, when serially impacted by 7.62 X 39 ball type 56, 123gr. (7.97 g) (Russian AK-47) bullets with steel penetrator cores, at a velocity of at least 1900 ft/sec (579 m/sec) within a lateral area of 15 cm

x 15 cm, having a minimum penetration velocity for a third bullet of not less than 90% of the minimum penetration velocity of a first bullet.

28. The article of claim 1, when serially impacted by 7.62 X 39 ball type 56, 123gr. (7.97 g) (Russian AK-47) bullets with steel penetrator cores, at a
5 velocity of at least 1900 ft/sec (579 m/sec) within a lateral area of 15 cm x 15 cm, having a minimum penetration velocity for a fifth bullet of not less than 90% of the minimum penetration velocity of a first bullet.

29. The article of claim 1, when serially impacted by 7.62 X 39 ball type 56, 123gr. (7.97 g) (Russian AK-47) bullets with steel penetrator cores,
10 at a velocity of at least 1900 ft/sec (579 m/sec) within a lateral area of 15 cm x 15 cm, having a minimum penetration velocity for a seventh bullet of not less than 90% of the minimum penetration velocity of a first bullet.

30. The article of claim 3, when serially impacted by 7.62 x 54R ball type
15 56, 149 gr. (9.66 g), (Russian Dragov, LPS) bullets with steel penetrator cores, having a minimum penetration velocity for a third bullet of not less than 90% of the minimum penetration velocity of a first bullet.