US 20150082976A1

(19) **United States**

(12) **Patent Application Publication**

Meldner et al.

(10) **Pub. No.: US 2015/0082976 A1**

(43) **Pub. Date: Mar. 26, 2015**

(54) **LIGHT-WEIGHT SEMI-RIGID COMPOSITE ANTI-BALLISTIC SYSTEMS WITH ENGINEERED COMPLIANCE AND RATE-SENSITIVE IMPACT RESPONSE**

(71) Applicant: **Cubic Tech Corporation**, Mesa, AZ (US)

(72) Inventors: **Heiner W. Meldner**, Reno, NV (US); **Roland Joseph Downs**, Mesa, AZ (US)

(73) Assignee: **Cubic Tech Corporation**, Mesa, AZ (US)

(21) Appl. No.: **14/208,017**

(22) Filed: **Mar. 13, 2014**

Related U.S. Application Data

(60) Provisional application No. 61/780,803, filed on Mar. 13, 2013.

Publication Classification

(51) **Int. Cl.**

F41H 1/02 (2006.01)

F41H 5/04 (2006.01)

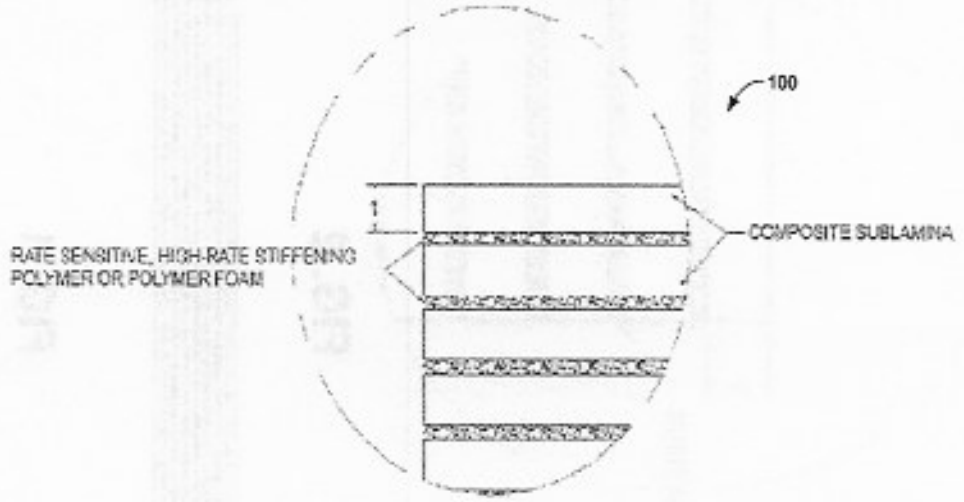
(52) **U.S. Cl.**

CPC ... *F41H 1/02* (2013.01); *F41H 5/04* (2013.01)

USPC **89/36.02**; 428/114; 428/110; 428/413; 428/423.1; 428/480; 428/319.3; 428/216

(57) **ABSTRACT**

Composite anti-ballistic systems having multiple nested sub-laminates manufactured from layers of unidirectional monofilaments made from engineering fibers with anti-ballistic properties embedded in polymer matrix materials and interfacial materials engineered for controlled compliance, deformation, energy release and rate sensitive behavior.



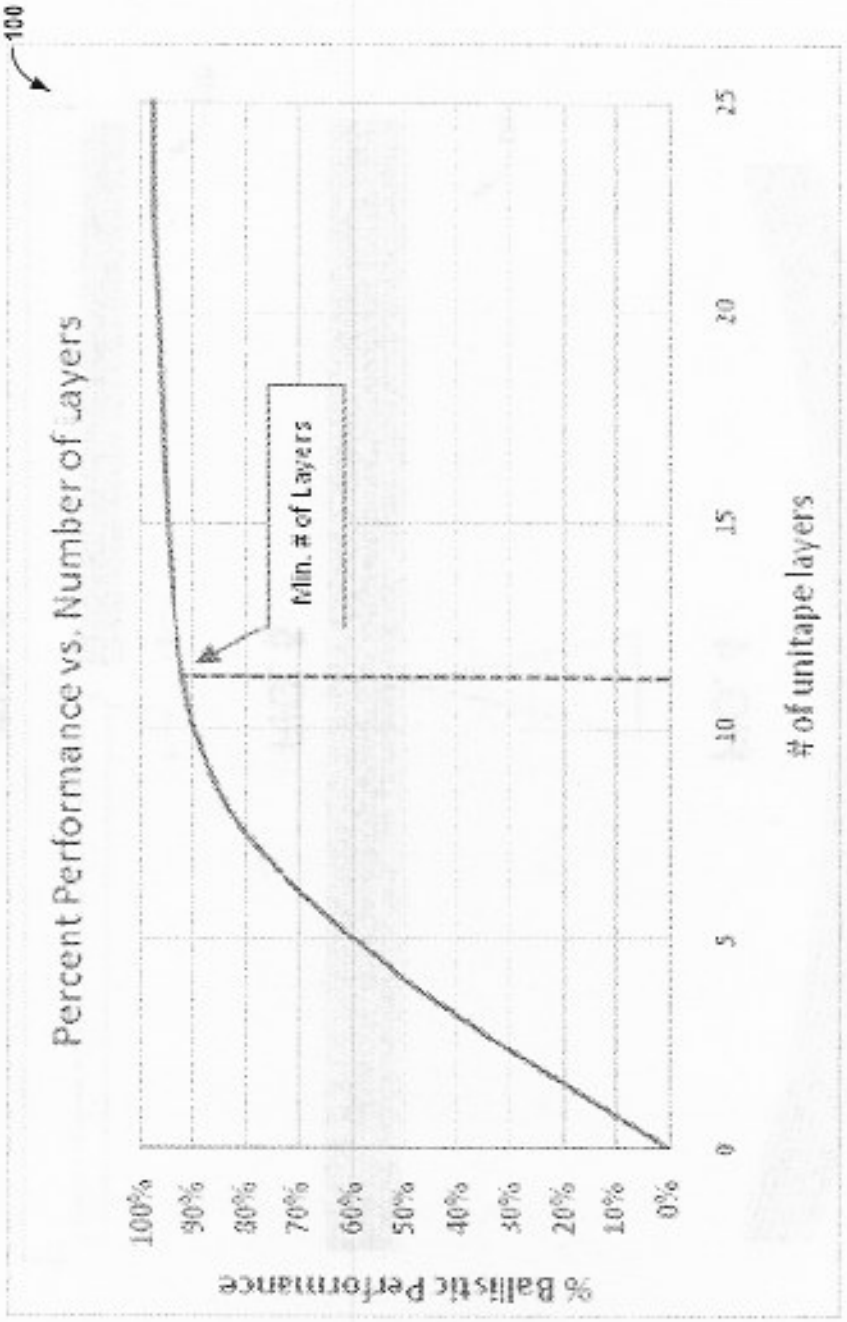

100
Percent Performance vs. Number of Layers
Min. # of Layers
% Ballistic Performance
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
5
10
15
20
25
# of unitape layers

FIG. 3

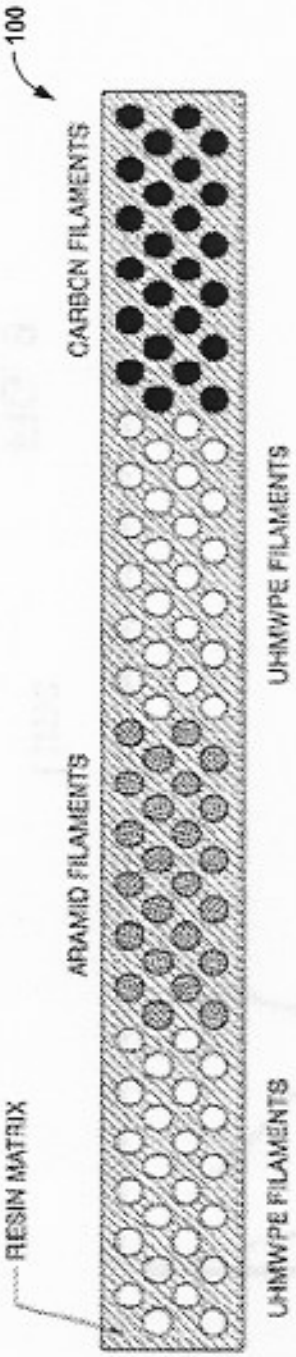

100
CARBON FILAMENTS
ARAMID FILAMENTS
UHMWPE FILAMENTS
RESIN MATRIX
UHMWPE FILAMENTS

FIG. 7

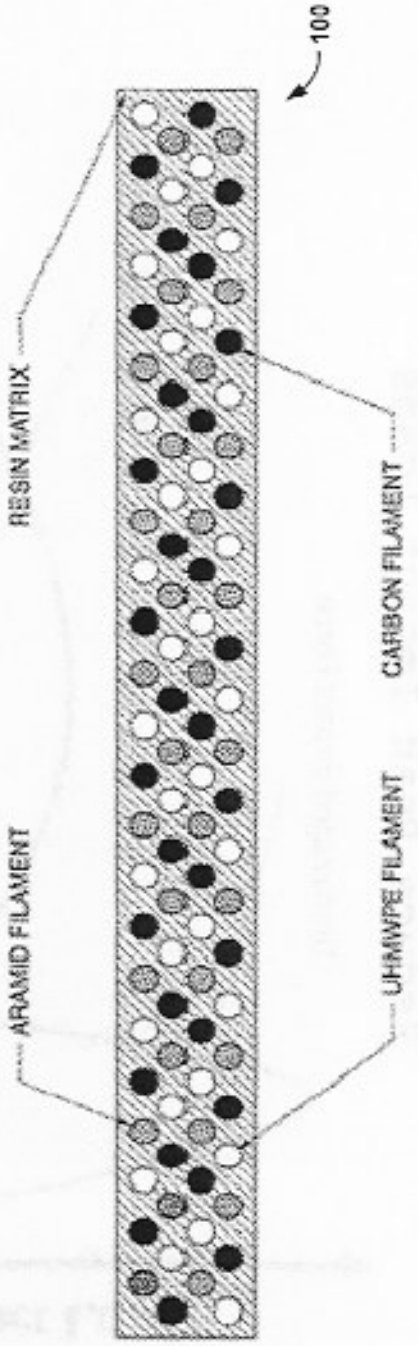

100
RESIN MATRIX
ARAMID FILAMENT
CARBON FILAMENT
UHMWPE FILAMENT

FIG. 8

LIGHT-WEIGHT SEMI-RIGID COMPOSITE ANTI-BALLISTIC SYSTEMS WITH ENGINEERED COMPLIANCE AND RATE-SENSITIVE IMPACT RESPONSE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application Ser. No. 61/780,803, filed Mar. 13, 2013, which is incorporated herein in its entirety.

BACKGROUND

[0002] Related disclosures are found in U.S. Pat. No. 5,470,062, entitled "COMPOSITE MATERIAL FOR FABRICATION OF SAILS AND OTHER ARTICLES," which was issued on Nov. 28, 1995; and U.S. Pat. No. 5,333,568, entitled "MATERIAL FOR THE FABRICATION OF SAILS" which was issued on Aug. 2, 1994; and U.S. patent application Ser. No. 13/168,912, filed Jun. 24, 2011 entitled "WATERPROOF BREATHABLE COMPOSITE MATERIALS FOR FABRICATION OF FLEXIBLE MEMBRANES AND OTHER ARTICLES,"; and U.S. patent application Ser. No. 13/197,741, filed Aug. 3, 2011 entitled "SYSTEM AND METHOD FOR THE TRANSFER OF COLOR AND OTHER PHYSICAL PROPERTIES TO LAMINATE COMPOSITE MATERIALS AND OTHER ARTICLES", the contents of all of which are hereby incorporated by reference for any purpose in their entirety.

[0003] This invention relates to providing improved monofilament-related products, methods, and equipment. More particularly, this invention relates to providing systems for design and manufacture of products using the technologies and useful arts herein taught and embodied. Even more particularly, this invention provides improvements in efficiently controlling properties of fabric-related products, including but not limited to: weight, rigidity, penetrability, waterproof-ability, breathability, color, mold-ability, cost, customizability, flexibility, package-ability, etc., including desired combinations of such properties.

[0004] In the past, there has been difficulty in achieving desired combinations of such properties, especially with regard to fabric-related products like clothing and shoes, camping and hiking goods, comfortable armor, protective inflatables, etc.

[0005] This invention more particularly relates to providing a system for improved composite anti-ballistic systems. More particularly this invention relates to providing a system for composite anti-ballistic systems utilizing composite materials of varying properties.

[0006] Current soldier personal protection for anti-ballistic protection is generally either by the common SAPI armor plates or by conventional soft vests. Rigid ceramic SAPI plates provide effective protection, but they limit mobility and are uncomfortable, which distracts soldiers in the field and induces unnecessary rapid fatigue. Additionally, SAPI plates are very susceptible to serious damage due to impacts endemic to soldier's operations in the field; and the damage is difficult to detect, impossible to repair and can result in serious or total degradation in ballistic protection. SAPI plates also have poor protection of closely-spaced multiple hits.

OBJECTS AND FEATURES OF THE INVENTION

[0007] A primary object and feature of the present invention is to provide a system overcoming the above-mentioned problem.

[0008] Another primary object and feature of the present invention is to provide a system to fine-tune, at desired places on a product, directional control of rigidity/flexibility/elasticity properties.

[0009] Yet another primary object and feature of the present invention is to provide products combining extreme light weight with extreme strength.

[0010] It is a further object and feature of the present invention to provide such a system providing continuous bulk manufacture of such products and their constituent parts.

[0011] Another object and feature of the present invention is to provide adaptability to the various stations of such continuous bulk manufacturing system.

[0012] It is a further object and feature of the present invention to provide such a system providing composite anti-ballistic devices.

[0013] Another object and feature of the present invention is to provide such a system having multiple nested sub-laminates manufactured from layers of unidirectional monofilaments.

[0014] A further object and feature of the present invention is to provide such a system made from engineering fibers with anti-ballistic properties.

[0015] It is another object and feature of the present invention to provide such a system comprising polymer matrix materials and interfacial materials engineered for controlled compliance, deformation, energy release and rate sensitive behavior.

[0016] A further primary object and feature of the present invention is to provide such a system that is efficient, inexpensive, and handy. Other objects and features of this invention will become apparent with reference to the following descriptions.

SUMMARY OF THE INVENTION

[0017] In accordance with a preferred embodiment hereof, this invention provides a laminate including reinforcing elements therein, such reinforcing elements including at least one unidirectional tape having monofilaments therein, all of such monofilaments lying in a predetermined direction within the tape, wherein such monofilaments have diameters less than 20 microns and wherein spacing between individual monofilaments within an adjoining strengthening group of monofilaments is within a gap distance in the range between non-abutting monofilaments up to nine times the monofilament major diameter.

[0018] Moreover, it provides such a laminate wherein such monofilaments are extruded. Additionally, it provides such a laminate wherein such reinforcing elements include at least two unidirectional tapes, each having extruded monofilaments therein, all of such monofilaments lying in a predetermined direction within the tape, wherein such monofilaments have diameters less than 20 microns and wherein spacing between individual monofilaments within an adjoining strengthening group of monofilaments is within a gap distance in the range between non-abutting monofilaments up to nine times the monofilament major diameter. Also, it provides such a laminate wherein each of such at least two unidirectional tapes includes larger areas without monofilaments

energy to provide ballistic protection in a form that has sufficient, controlled rigidity under ballistic impact to provide the necessary functions of anti penetration, load spreading, impact energy management and shock management. Such orientation of layers further provide sufficient flexibility and compliance when worn that loss of mobility and range of motion is minimized, and wearer comfort is improved. These improvements enhance combat effectiveness and minimize operator fatigue due to reduced mobility and restriction of range of motion encountered with rigid SAPI plates.

[0034] Although the system may be integrated into a system also utilizing a ceramic or metallic component, the pure composite implementation of the system is not susceptible to impact damage like observed in a ceramic SAPI plate and is insensitive to most normal in-service incidental impacts. The system also exhibits superior protection against multiple close spaced hits. Since the system does not absorb significant percentages moisture, the resulting anti-ballistic system does not gain weight or become water-logged due to hydrolysis. The system also is protected from degradation due to flex fatigue, UV radiation and exposure to most agents or chemicals normally encountered.

[0035] The system preferably comprises at least one composite anti-ballistic device. Such at least one composite anti-ballistic device preferably comprises improved compliance stretchability and flexibility for higher mobility and less range-of-motion-restriction by preferably using at least one multi-layer, multi-directional sublayer approach.

[0036] Such at least one flexible ballistic panel is preferably made from layers of sub-laminates. The sub-laminates of the panel system are preferably manufactured from layers of unidirectional monofilaments of engineering fibers having antiballistic properties, a modulus greater than 1.0×106 psi and a failure strength in excess of 100,000 psi.

[0037] Such at least one multi-layer, multi-directional sub-laminate approach preferably uses thin (less than 6 monofilament diameters for conventional monofilaments, less than 0.005" for ultra thin or nano monofilaments, ropes, yarns fibers) unitape tape layers, alternately preferably intra or interlaminar hybridization of filaments. Such filaments preferably comprise various engineering fibers with a Young's Modulus of over 1 msi and an ultimate tensile strength of more than 100 KSI). Such Engineering fibers preferably include: UBMWPE (available under the trade names Dyneema and Spectra), Aramid (available under the trade names Kevlar and Twaron), PBO fiber under the Zylon name, liquid crystal polymer Vectran, glass fibers such as E and S glass, M5 fibers, carbon and para-aramid under the Technora name. Such Engineered fibers preferably further include nano-filaments, nano-ropes, nano-yarns, nano-tows, nano-powder, and/or nano-film that preferably may be incorporated into the unitape layer, with the unitape and/or applied to the outer surface of the unitape. Such at least one nano-material may be applied to the outer surface of individual monofilaments by nano spray, electron beam deposition, sputtering, vapor deposition, atmospheric plasma deposition, infusion, or as part of polymer coating. Such coating shall preferably comprises a cross linking system with a thermal activation, alternately preferably two part self curing, alternately preferably radiation cured such as E-beam, RF cured, UV cured, or heat cured. The surface of the fibers, the surface of the nano-component and/or the polymer resin may all he provided with chemically reactive functional groups that create a strong chemical bond between the monofilament surface, the nano-component, the short fiber component or the resin, to improve adhesion and enhance energy dissipation.

[0038] Individual unitape plies may vary from 1.5-80 g/m^2 of areal density. The unitape preferably contain one single class of fiber such as Aramid, UHMWPE, glass, etc., alternately preferably contain a combination of classes or styles (same class of fiber but different spec for example), alternately preferably any combination of the above preferably in a predetermined pattern or configuration. The different fiber types may be discrete alternating sets of each material across the width or thickness of the unitape or they can be distributed in a uniform intermixed or comingled configuration. These unitapes may be layered in any combination of materials within each layer of the sub-laminate. Examples are having a sub-laminate made from only one grade of Aramid such as Kevlar or UHMWPE Dyneema monofilament in each unitape in the sub-laminate, or by using one or more different unitapes in the sub-laminate wherein each unitape is made from one type of monofilament. Another example is having a unitape made up of hybrid unitape with multiple fiber types incorporated in each layer but having all the unitape in the sub-laminate made from the same specification of hybrid. Yet another example is the most general where the sub-laminate is made from unitapes with multiple mixes of fiber in the unitape and multiple types of unitape used to make up the sub-laminate.

[0039] Individual unitapes within the sub-laminate may alternately preferably also be made from differing fiber areal densities. Hybrid sub-laminates of this kind can provide improved ballistic performance when one of the types of fiber may provide superior protection under some conditions but may not provide adequate protection under another set of conditions. A good example would be the use of UHMWPE monofilaments, which provide excellent anti-ballistic protection under most conditions but are limited in their ability to protect from some impacts by incendiary projectiles that exceed temperature limits of the base polymer. Kevlar or PBO hybrids can improve the ability of the UHMWPE base laminate to protect against the incendiary projectile due to the higher temperature capabilities of the aramid or PBO monofilaments. Using monofilaments of dissimilar properties can also improve the ballistic impact performance because the interactions of the dissimilar monofilaments can generate significant impact energy absorption, shock dissipation and controlled deformations due to the incompatibility of strains between the dissimilar monofilaments.

[0040] The minimum number of plies of the sub-laminate can be determined by semi-empirical methods to find the approximate number of plies needed to bring the specific ballistic performance of the sheet up to the level most comparable to the monolithic plate case by obtaining the optimum "lamination effect." At a certain number of unitape layers the improvement in ballistic performance levels off and the number of plies is determined by the use of a sub-laminate thickness that provides the degree of flex desired, as shown in FIG. 1.

[0041] Each unidirectional ply can be oriented in any given in-plane angle. The simplest is a two-direction, cross-ply [0°/90°] configuration which is easy to fabricate but often does not provide the best ballistic protection nor the best resistance to global panel deformation nor to "back wall deformation." Back wall deformation is the area directly under the impact area where the laminate is extroded & pushed back into the body of the wearer, which can cause

viscoelastic, dilation interlayers. The most effective of the commercial systems are in the form of lightweight foams that allow for the incorporation of relative thick layers with minimal weight increase. The flexibility of the panel is enhanced by the case of thicker compliant layers, which is derivable from a mobility and comfort perspective. Use of thicker compliant layers also increases the thickness of the global panel system. This thickness increase by itself does not generally limit mobility or restrict motion since flexibility is actually enhanced. This increased thickness does significantly increase the effective section modulus of the global panel system during the transient rigid state under impact which can significantly increase the "effective stiffness" of the rigid panel, as shown in FIG. **6**.

[0059] For example, the one 1" monolithic panel is broken up into 4 sub-laminates with viscoelastic layers that bring the total thickness of the panel up to 1.5", in this case the section modulus of the monolithic plate is preferably determined by the formulas:

Section Modulus=$(1)^2/6$ for monolithic

Section Modulus=$(1.5)^2/6$ for sub-laminate

$SM|_{monolithic}=1/6$

$SM|_{sub}=2.25/6$

[0060] Note: so the effective stiffness of the rigid panel under impact has 2.25 times the stiffness and resistance to deformation.

[0061] The "rigidized" compliance layer can act as a core material under impact to improve the structural properties of panel system globally. The viscoelastic layers preferably can also be engineered to provide some progression of load transfer into the individual sub-laminates as the impact event progresses through the panel system which can improve load spread, energy management and contribute to enhanced anti-penetration.

[0062] Additionally, applicant's engineered viscoelastic dilation layers preferably provide improved anti-ballistic properties, and improved flexibility for better mobility and increased range of motion without adding excessive weight and/or bulk. This rigidizing, or "freezing," behavior under impact load preferably provides multiple benefits including: 1. distributing the impact loads, to spread them within the assembly reducing maximum peak loads and associated injury; 2. restricting deformation of the panel in the out-of-plane direction, thus reducing "back wall deformation" that is a measure of how much the panel is deflected inward towards the body of the wearer; 3. increasing the area of the panel used to resist the impact for better energy absorption and shock dissipation; and, 4. allowing improved resistance to projectile penetration by optimizing the progressive response of the panel system to the projectile as it strikes and enters the panel.

[0063] The system preferably further comprises hybridization of fiber types by combinations of interlaminar hybridization (different ballistic fiber type layer by layer), alternately preferably intralaminar hybridization (one or more different fiber types within a layer to a predetermined pattern or design), as shown in FIG. **7**, alternately preferably comingled (two or more fiber types generally uniformly mixed at the monofilament level), as shown in FIG. **8**.

[0064] The system alternately preferably comprises hybridization via different fiber types (i.e. Dyneema and Kevlar). Alternately preferably, the system comprises hybridization via different styles, alternately preferably different product forms, alternately preferably different mechanical properties of the same or similar fiber or monofilament (i.e. Dyneema SK 76 hybridized with Dyneema SK90, or Zylon HM hybridized with lower modulus Zylon). This approach is especially useful when significant improvements in one fiber type are offset by reduction in another critical property.

[0065] For example, some Dyneema fibers have been drawn to a very fine filament which improves in-plane response but introduces some other limitations which prevent full realization of the fibers anti-ballistic potential. Larger diameter UHMWPE fibers may have lower properties but their thicker filaments combined with a slightly different microstructure can combine to provide higher overall anti-ballistic performance and protection than either one is capable of independently. The system preferably comprises improvement or optimization of the ballistic performance of the monofilaments, preferably by use of fiber surface treatments, surface functionalization, surface coatings, surface grafting and/or deposition with one or more types or layers to optimize the response and integration of the monofilaments to the matrix.

[0066] The system preferably further comprises engineered fiber, preferably matrix interfacial properties by use of fiber surface treatments, surface functionalization, surface coatings, surface grafting and/or deposition with one or more types or layers to optimize the response and integration of the monofilaments to the matrix.

[0067] The system preferably further comprises incorporation of various rate sensitive polymers and/or non-woven composites of various fibers and polymers, preferably to produce a rate sensitive system, preferably in strategic interlaminar and intralaminar locations for matrix and intralaminar interfaces.

[0068] The system preferably further comprises, engineered micro flaws in monofilaments, preferably to promote optimized localized massive simultaneous micro-fracture of filaments, preferably to take advantage of the inherent high strain energy release rate thresholds related to the high Work-Energy-To-Initiate-Fracture properties preferably combined with the high internal hysteresis associated energy dissipation with post failure relaxation with some anti-ballistic monofilaments such as UHMWPE and M5 fibers.

[0069] The sub-laminates may be made from a single anti-ballistic monofilament, or multiple fibers may be combined to create a hybrid of many types of monofilaments.

[0070] Hybridization may be at the global panel level where sub-laminates are individually manufactured from one type of monofilament but several sub-laminates consisting of different types of monofilament may be used in a desired configuration. At least one non-hybrid sub-laminate (i.e. UHMWPE, Aramid, PBO, glass) along with sub-laminates featuring various forms and/or combinations of fiber classes or hybridization schemes may alternately preferably be used in a configuration.

[0071] All of the sub-laminates in a panel may be made from one single class of fiber such as UHMWPE, Aramid, PBO, Glass, etc. if desired. Panels made this way can be either flat or curved to better fit the wearer. If the panels are curved, the sub-laminates may be formed such that they nest together properly when stacked to form the total laminate plate system.

[0072] The curved sections preferably are press formed, alternately preferably are autoclave formed, alternately pref-

14. An antiballistic device comprising at least one antiballistic composite, said antiballistic composite comprising:
(a) multiple sub-laminate layers; and
(b) viscoelastic dilatory material distributed as interlayers between said sub-laminate layers;
wherein said viscoelastic dilatory material converts from soft compliant material to stiff interlayers when said composite is subjected to impact.

15. The device of claim 14, wherein each sub-laminate layer comprises at least one unidirectional tape comprising parallel monofilaments embedded in a resin.

16. The device of claim 14 comprising multiple antiballistic composites nested into a plate system.

17. The device of claim 14 further comprising a ceramic or metallic component.

18. The device of claim 14, wherein said viscoelastic dilatory material comprises a rate-sensitive high-rate stiffening polymer or a polymer foam.

19. The device of claim 14, wherein said device is worn to provide anti-penetration, load spreading, impact management and shock management to the wearer.

20. The device of claim 19, wherein said device is a vest.

* * * * *