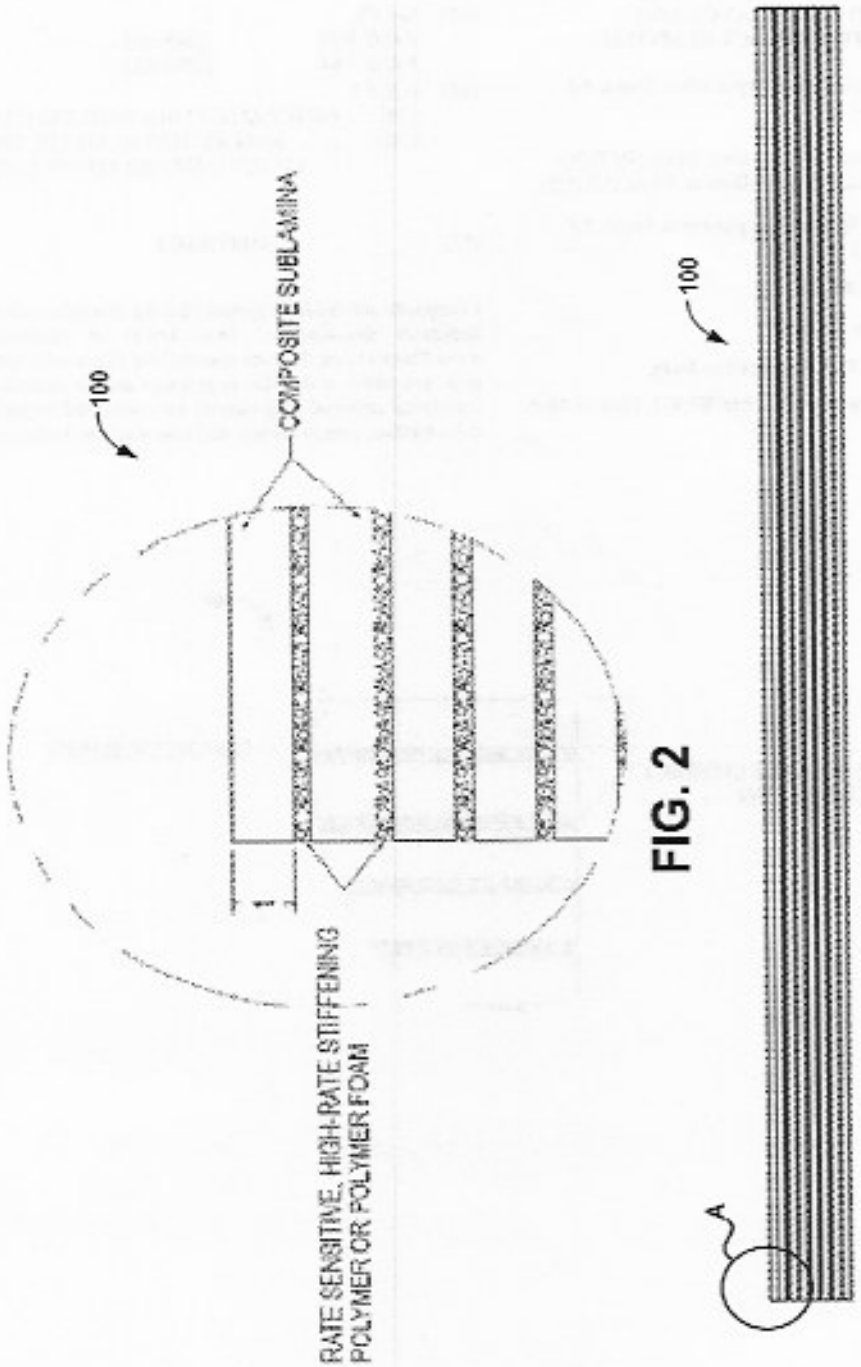

100
A

FIG. 1

100
COMPOSITE SUBLAMINA
t
RATE SENSITIVE, HIGH-RATE STIFFENING
POLYMER OR POLYMER FOAM

FIG. 2

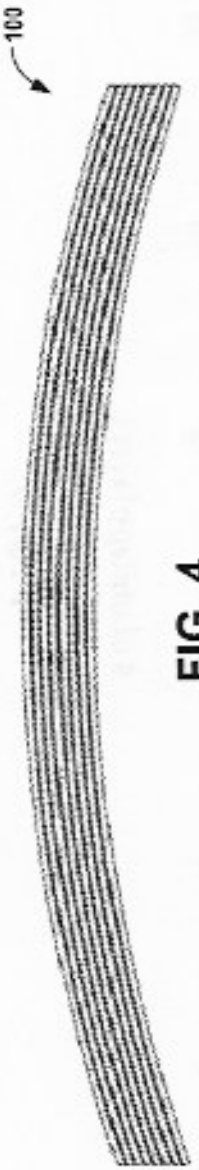


FIG. 4

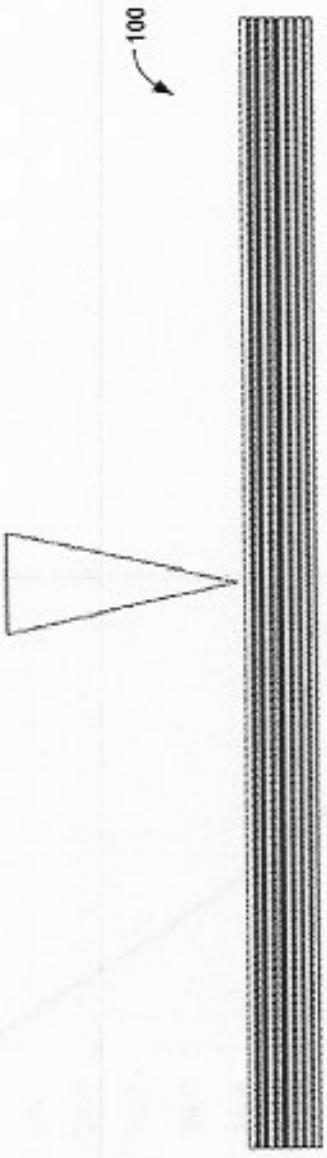


FIG. 5

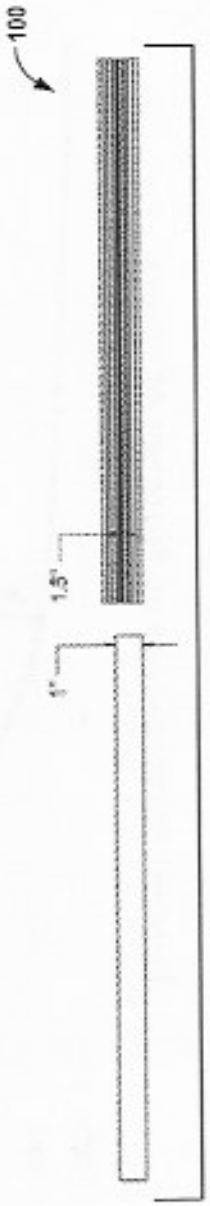


FIG. 6

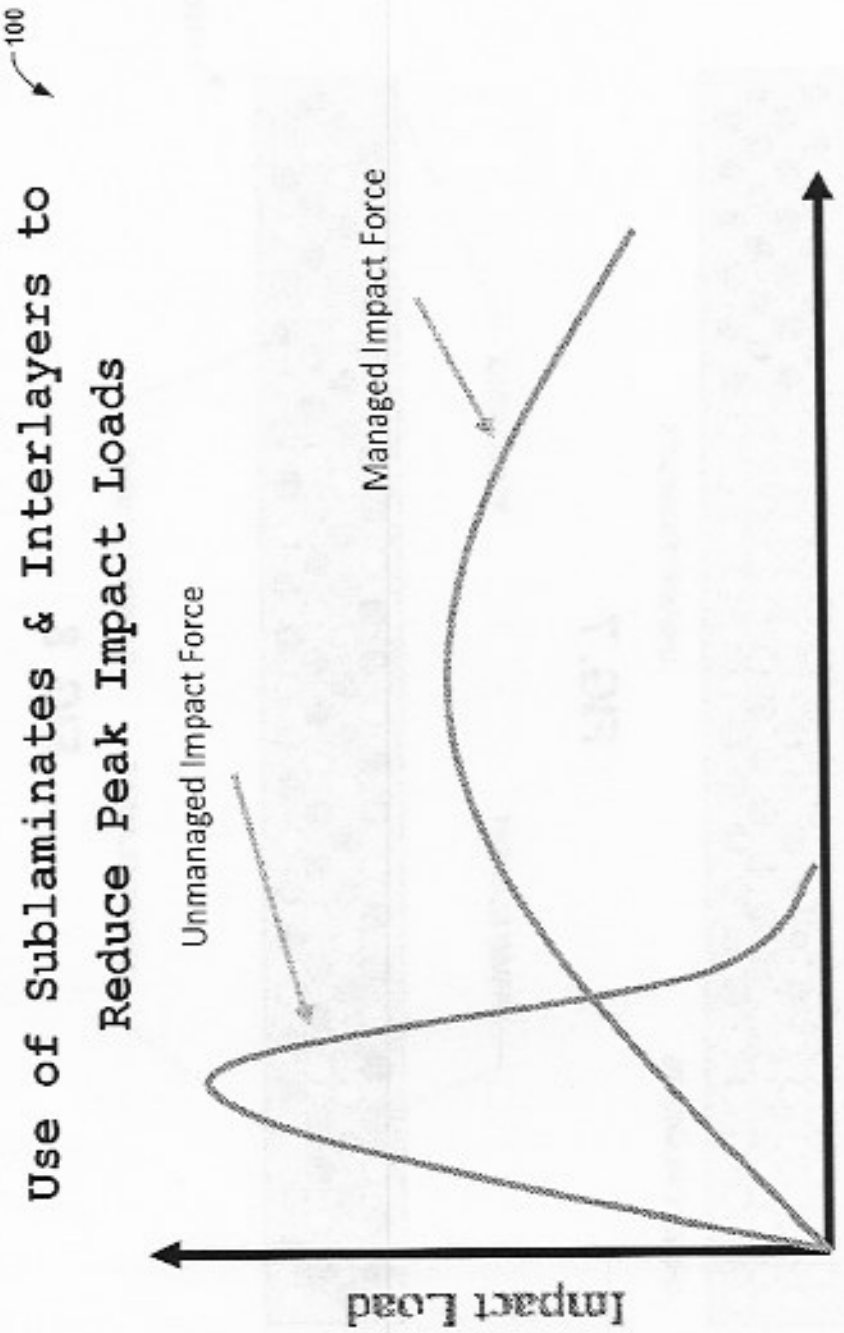

100
Use of Sublaminates & Interlayers to
Reduce Peak Impact Loads
Unmanaged Impact Force
Managed Impact Force
Impact Load
Time

FIG. 9

therein and wherein such larger areas comprise laminar overlays comprising smaller areas without monofilaments.

[0019] In addition, it provides such a laminate wherein such smaller areas comprise user-planned arrangements. And, it provides such a laminate further comprising a set of water-breathable elements comprising laminar overlays of such smaller areas. Further, it provides such a laminate further comprising a set of other laminar overlays. Moreover, it provides such a laminate wherein a first one of such at least two unidirectional tapes includes monofilaments lying in a different predetermined direction than a second one of such at least two unidirectional tapes.

[0020] Additionally, it provides such a laminate wherein a combination of the different predetermined directions of such at least two unidirectional tapes is user-selected to achieve laminate properties having planned directional rigidity/flexibility. Also, it provides such a laminate comprising a three-dimensionally shaped, flexible composite part. In addition, it provides such a product comprising multiple laminate segments attached along peripheral joints. And, it provides such a product comprising at least one laminate segment attached along peripheral joints with at least one non-laminate segment. Further, it provides such a product comprising multiple laminate segments attached along area joints.

[0021] Even further, it provides such a product comprising at least one laminate segment attached along area joints with at least one non-laminate segment. Moreover, it provides such a product comprising at least one laminate segment attached along area joints with at least one unitape segment. Additionally, it provides such a product comprising at least one laminate segment attached along area joints with at least one monofilament segment. Also, it provides such a product further comprising at least one rigid element.

[0022] In accordance with another preferred embodiment hereof, this invention provides a product wherein such at least one unidirectional tape is attached to such product. In accordance with a preferred embodiment hereof, the present system provides each and every novel feature, element, combination, step and/or method disclosed or suggested by this patent application.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] FIG. **1** shows a diagramatic view illustrating at least one composite laminate material according to a preferred embodiment of the present invention.

[0024] FIG. **2** shows an enlarged detail view of detail A of FIG. **1** according to the preferred embodiment of FIG. **1**.

[0025] FIG. **3** shows a data graph, illustrating percent performance vs. number of layers, according to the preferred embodiment of FIG. **1**.

[0026] FIG. **4** shows a diagramatic view, illustrating flexibility of at least one panel of such at least one composite laminate material, according to the preferred embodiment of FIG. **1**.

[0027] FIG. **5** shows a diagramatic view, illustrating impact loading of at least one panel of such at least one composite laminate material, according to the preferred embodiment of FIG. **1**.

[0028] FIG. **6** shows a diagramatic view, illustrating a comparative thickness of at least one panel of such at least one composite laminate material, according to the preferred embodiment of FIG. **1**.

[0029] FIG. **7** shows a diagramatic view, illustrating intralaminar hybridization, according to the preferred embodiment of FIG. **1**.

[0030] FIG. **8** shows a diagramatic view, illustrating comingled filaments, according to the preferred embodiment of FIG. **1**.

[0031] FIG. **9** shows use of sublaminates & interlayers to reduce peak impact loads.

[0032]

BRIEF GLOSSARY OF TERMS AND DEFINITIONS

Adhesive:	A curable resin used to combine composite materials.
Anisotropic:	Not isotropic; having mechanical and or physical properties which vary with direction at a point in the material.
aerial weight:	The weight of fiber per unit area, this is often expressed as grams per square meter (g/m^2).
Autoclave:	A closed vessel for producing an environment of fluid pressure, with or without heat, to an enclosed object which is undergoing a chemical reaction or other operation.
B-stage:	Generally defined herein as an intermediate stage in the reaction of some thermosetting resins. Materials are sometimes pre cure to this stage, called "prepregs", to facilitate handling and processing prior to final cure.
C-stage:	Final stage in the reaction of certain resins in which the material is relatively insoluble and infusible.
Cure:	To change the properties of a polymer resin irreversibly by chemical reaction. Cure may be accomplished by addition of curing (cross-linking) agents, with or without catalyst, and with or without heat.
Decitex (DTEX):	Unit of the linear density of a continuous filament or yarn, equal to 1/10th of a tex or 9/10th of a denier
Dyneema ™	Ultra-high-molecular-weight polyethylene fiber by DSM
Filament:	The smallest unit of a fiber-containing material. Filaments usually are of long length and small diameter.
Polymer:	An organic material composed of molecules of monomers linked together.
Prepreg:	A ready-to-cure sheet or tape material. The resin is partially cured to a B-stage and supplied to a layup step prior to full cure.
Tow:	An untwisted bundle of continuous filaments.
UHMWPE:	Ultra-high-molecular-weight polyethylene. A type of polyolefin made up of extremely long chains of polyethylene. Trade names include Spectra ® and Dyneema ®
Unitape	Uni-Directional tape (UD tape) - flexible reinforced tapes (also referred to as sheets) having uniformly-dense arrangements of reinforcing fibers in parallel alignment and impregnated with an adhesive resin. UD tapes are typically B-staged and form the basic unit of most CT composite fabrics.

DETAILED DESCRIPTION OF THE BEST MODES AND PREFERRED EMBODIMENTS OF THE INVENTION

[0033] Referring to FIGS. **1-9**, light-weight semi-rigid composite anti-ballistic systems **100** described herein is a pure composite anti-ballistic system based on 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. These layers are oriented in multiple directions to distribute the impact loads, control deformation and dissipate impact

injury or incapacitation. Excessive deformation also degrades the ballistic protection for multi-hit impacts closely spaced. For this reason it is desirable to have a number of angles selected. Three provide some improvement but four angles spaced at the 0°/45°/90°/−45° orientations gives the better performance. Some additional improvement can be obtained by adding another set of ply angles such as at 22.5° increments (0°/22.5 °/45 °/67°/90°/−67°/−45°/−22.5°/0° for example), or at +/−30° or +/−60°. The sub-laminates can be made of stacked repeating sets of these ply groups to build up the desired number of unitape layers in order to achieve the required ballistic performance and flexibility.

[0042] The resin content preferably ranges from 1% to 30% of the total areal weight of the unitape with the lower resin contents generally providing better ballistic performance. High and low resin content unitape can be combined in various stacking sequences and layup patterns.

[0043] Thin layers of polymer films, non-wovens, and layers of nano-fibers or films preferably can be located at one or more unitape interfaces to improve or modify ballistic performance.

[0044] Resin materials may preferably be epoxy base, cyanate ester base, or polyester based resins of varying molecular weight or composition combined with various curing agents to provide the desired matrix properties. Matrix materials preferably may also be thermoplastic polyurethane, alternately preferably block copolyesters, alternately preferably two part polyurethane either with the aromatic or aliphatic isocyanate curing mechanism, alternately preferably ceramics, alternately preferably E-beam deposition polymers, alternately preferably silicones, or others. Resins may preferably be in hot melt, alternately preferably aqueous solutions, alternately preferably solutions with organic or inorganic solvent, alternately preferably water or solvent dispersions, alternately preferably powders, alternately preferably spunbonded films, alternately preferably extruded sheets, alternately preferably cast sheets. The cast or extruded sheets preferably may be homopolymer, alternately preferably a multilayer coextrusion, alternately preferably co-cast onto a carrier, film, paper, or cloth or the film may be unsupported.

[0045] Such at least one multilayer, multidirectional sub-laminates preferably comprises unitape of pultruded monofilaments preferably to provide the laminate with a multidirectional-layered network.

[0046] The bending stiffness of a ballistic plate or sheet, neglecting effects of transverse strain, preferably is proportional to the section modulus of the plate or sheet, preferably according to the formula:

$$\text{Section Mod}=Z=BD^{2/6}$$

[0047] Where B is the width and D is the thickness of the plate or sheet.

[0048] For comparison purposes only, we set the width normalized to 1 to determine the effects of the sheet or plate thickness on the flexibility of comparable plates and sheets. One inch is a common thickness for composite sheets because it roughly gives 5 lbs/ft2. For the 1" plate section, the modulus=Z=BD2/6=(1) (1)/6=1/6. Now let examine the effect on flexibility by going thinner, starting at 0.020" and going up in 0.020" increments to 0.10". Z=(1) (1/50)2/6=1/(6) (2500), so the 0.020"=1/2500 of bending stiffness of the 1" since Z is proportional to the thickness of the panel squared. If t=0.030 the Z=1/1111. If t=0.040 the Z=(1/25)2

[0049] For a 1" stack of the 0.020" sheet, total flex=to the sum of section modulus: Zeff=Σ2i (Z×50) 1/2500*(50)=1/50; and I=1 to 33.3; Zeff=Σ2i=1/33.3. As one can see from the pattern, the flexibility of a panel made up of sub-laminate of equalizing total thickness, if all sub-laminate thicknesses are the same proportion using this relationship, then we can break the total desired panel thickness into a number of sub-laminates that provide the necessary increase in flexibility. If a thickness of 0.020" is chosen for the sub-laminate sheet, then the effective stiffness is 1/50 times lower since the bending stiffness of the stack of 50 0.020" sub-laminates is 50 time less than a monolithic 1" ballistic plate.

[0050] If engineered properly, a panel made from the sub-laminate may have performance ranging from minimal reduction in ballistic performance to actually being higher in ballistic protection than solid rigid plates, while still being flexible. The sub-laminate may be used as discrete sheets with maximum flexibility or they may be lightly bonded together with a thin layer of compliant rate-sensitive dilation material embedded in compliant foam.

[0051] Bonding the sub-laminate together in such a way decreases the flexibility of the panel but preferably still allows for a compliant panel, especially if the panel does not need to undergo large deformations as is the case with ballistic plates. It is preferable for a ballistic plate to impart just enough "give" into the panel to provide the necessary level of mobility and comfort.

[0052] This is a subjective parameter that depends upon the total thickness of the ballistic panel system, the properties of the monofilament in the sub-laminate and the degree of compliance engineered at the interfaces between the laminates.

[0053] Although the sub-laminate system has sub-engineered flexural properties, much of the flexibility is due to the low shear & young's modulus of the viscoelastic dilatory foam materials at the interface bonding the sub-laminate panels into a single panel. Dilatory materials are very rate-sensitive and undergo a transition from highly compliant elastomeric material to highly rigid, solid material. Under impact, the rate of sensitive dilatory layers converts from a soft compliant material into a stiff interlayer that locks up the sub-laminates together so that they act as a solid panel, which means that impact stiffness of a panel increases to close to that of a solid ballistic panel.

[0054] The rigidness of the panel under impact spreads the impact loads and maintains the structural integrity of the panel during the impact. Since this is a viscoelastic effect, the rate at which the interlayers transform from soft to rigid can be controlled to manage the impact and spread the force of the impact event over a longer period of time. Spreading the impact load over a longer time period reduces the magnitude of the impact loads, and the load rate preferably can be adjusted to provide optimal load transfer to the individual sub-laminates to provide the highest level of protection from each individual ballistic sub-laminate, as shown in FIG. **1**B.

[0055] Compliant, viscoelastic interlinear layer of rate-sensitive, higher rate stiffening polymer and polymer foam, as shown in FIG. **1**A.

[0056] Panel is flexible under normal use due to sub-laminates, as shown in FIG. **4**.

[0057] Under impact loads the rate-sensitive interface rigidizes or "freezes" the plate into the equivalent of one-piece panel with no sub-laminate, as shown in FIG. **5**.

[0058] At least one area of design flexibility on the sub-laminate panels is the ability to select the thickness of the

erably are laminate formed. Additionally, the curved sections are preferably fabricated in one set of sub-laminates, alternately preferably are fabricated individually and then assembled.

[0073] Upon reading the teachings of this specification, those skilled in the art will now appreciate that, under appropriate circumstances, considering such issues as use environment, future technologies, cost, etc., other uses of the composite system, such as, for example, rigid pates made from same materials systems where flexibility is not desired, blast protection, containment of explosive failure of rotating machinery, containment of jet engine and other gas turbine engine compressor blade failures, sporting good protection, crash protection, reinforcement of masonry, brick and concrete structure and buildings to protect them from blast or seismic damages and secondary collapse or failure, vehicle, aircraft armor, use as a flexible "cloth" replacement for conventional ballistic soft vests, etc., may suffice.

[0074] The flexible sub-laminate preferably makes a very high performance option as a replacement for current vest fabrics for flexible vests and body armor. The composite sub-laminates preferably have superior anti-ballistic properties, and load spreading relative to conventional cloth technologies and preferably have the further advantage that they do not absorb moisture and become liquid saturated, and the fiber monofilaments are fully encapsulated and protected so they are protected from abrasion, chafling, flex fatigue and environmental degradation due to sweat, fluids, chemicals, and UV or visible radiation.

[0075] In vest applications it is generally advantageous to select the sub-laminate thickness that gives the highest degree of anti-ballistic protection with the thinnest overall laminate thickness, and the maximum number of the thinnest unitapes preferably oriented in as many angular directions as is possible consistent with cost and production throughput constraints. Further, the use of shear thickening matrix and interlaminate layers preferably may be used to improve impact properties.

[0076] A thin, compliant, rate-sensitive layer or layers, about 1-10 microns in thickness, preferably can be incorporated into the sub-laminate. This layer or layers can be a viscoelastic material with high loss factor for absorbing, damping, and dissipating impact forces and energy release from the impact while also adding flexibility to the sub-laminate. Strategically locating interlayers preferably can substantially enhance load spread and energy management by tailoring the impact impulse as was previously discussed, and as shown in FIG. **9**.

[0077] This material is especially useful for many aircraft applications since it can be desirable to have a semi-flexible material, for example, in the nacelle armoring the compressor blades of the engine. The flexibility of the armor prevents over-stiffening the nacelle, which could promote premature fatigue of the engine support structure, but has enough rigidity during the impact of the failed compressor blades that it can retain structural integrity while simultaneously containing the blade fragments.

[0078] This material is also an ideal solution for reinforcement of masonry brick, concrete structure and buildings to protect them from blast or seismic damages, and secondary collapse or failure by laminating one or more sub-laminate sheets to the walls or ceilings of the structures using an integrated gel style curing adhesive layer or via a sprayed or brushed on toughened adhesive or a combination of both types of bonding agents.

[0079] The material preferably can be transparent, opaque, translucent, colored, printed or textured for decorative architectural effects or to add camouflage, IR control or other Low Observable finishes and textures. Additionally, the material preferably can incorporate a weatherable outer surface layer that has an environmental control function such as solar reflectivity or UV blocking for insulation or energy efficiency as a secondary feature.

[0080] Although applicant has described applicant's preferred embodiments of this invention, it will be understood that the broadest scope of this invention includes modifications such as diverse shapes, sizes, and materials. Such scope is limited only by the below claims as read in connection with the above specification. Further, many other advantages of applicant's invention will be apparent to those skilled in the art from the above descriptions and the below claims.

1. An 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.

2. The composite of claim **1**, wherein said viscoelastic dilatory material comprises a rate-sensitive high-rate stiffening polymer or a polymer foam.

3. The composite of claim **1**, wherein said viscoelastic dilatory material bonds each of said multiple sub-laminate layers together into a single panel.

4. The composite of claim **1**, wherein said interlayers are about 1-10 microns in thickness.

5. The composite of claim **1** comprising at least ten sub-laminate layers.

6. The composite of claim **1**, wherein each sub-laminate layer comprises at least one unidirectional tape comprising parallel monofilaments embedded in a resin.

7. The composite of claim **6**, wherein said monofilaments have diameters less than about 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 about nine times the monofilament major diameter.

8. The composite of claim **6**, wherein said monofilaments have modulus greater than 1.0×10^6 psi and failure strength greater than greater than 1.0×10^5 psi.

9. The composite of claim **6** comprising two unidirectional tapes oriented as a cross-ply, wherein the parallel monofilaments present in one tape are 90° relative to the parallel monofilaments present in the other tape.

10. The composite of claim **6**, wherein said tapes total four in a ply group, and wherein the parallel monofilaments within each of said four tapes have relative orientation of 0°/45°/90°/−45°.

11. The composite of claim **6**, wherein said tapes total nine in a ply group, and wherein the parallel monofilaments within each of said nine tapes have a relative orientation of 0°/22.5°/45°/67°/90°/−67°/−45°/−22.5°/0°.

12. The composite of claim **6**, wherein said monofilaments are extruded or pultruded.

13. The composite of claim **6**, wherein said resin comprises from 1% to 30% of the total areal weight of said tape.