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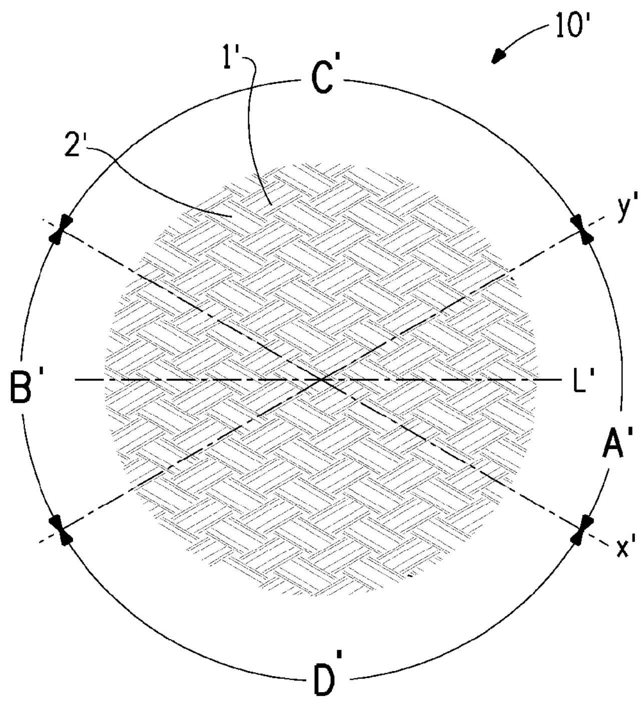

FIG. 2

(57) Abstract: A woven fabric from yarn for use in the manufacture of ballistic projectile or puncture resistant articles where the fabric has a first plurality of parallel oriented yarns within the plane of the fabric interwoven with a second plurality of parallel oriented yarns within the plane of the fabric having a direction/orientation within the plane of the fabric different from that of the first plurality and where the crossing of any fiber yarn from the first plurality with a fiber yarn from the second plurality forms a pair of acute vertical angles having an angular measurement less than 90 degrees.

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TITLE OF THE INVENTION

FABRIC ARCHITECTURES FOR IMPROVED BALLISTIC IMPACT PERFORMANCE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to fabric architectures and soft body armors constructed therefrom.

2. Description of the Related Art

Protective body armors such as those providing protection against ballistic and stab type threats have long been an area of significant interest. One challenge for body armor manufacturers is to provide adequate protection from a particular threat or threats that the wearer may be subjected to in the field, while minimizing the weight, or areal density of the protective garment so as not to impede the dexterity of the wearer.

Characterization of the protective capabilities of any armor material against ballistic projectile threats, such as deformable bullets and non-deformable shrapnel, requires some determination of the ballistic velocity limit with respect to the material's areal density and size, as well as the properties of the projectile (mass, hardness, shape, etc.). One common ballistic limit performance criteria is the ballistic V50, or the velocity at which 50% of the projectiles can be defeated by the armor. Specific testing and calculation protocols for determining V50 of body armors are outlined by the National Institute of Justice (NIJ) Standard-0101.04 Ballistic Resistance of Personal Body Armor, dated September 2000. Beyond the ability of armor to stop the penetration of a projectile, the need to minimize blunt trauma associated with the ballistic impact for concealable body armors worn by police, security, and correctional officers, becomes an additional safety requirement set forth by NIJ Standard-0101.04. This standard outlines the testing protocol and performance requirements for an acceptable level of blunt trauma through measurement of the backface signature associated with ballistic impact of armors placed upon a clay witness simulation material. In NIJ Standard-

0101.04, the acceptable amount of backface deformation is defined as being no greater than 44 mm in a clay witness (Roma Plastilina clay, 5.5 in (140 mm) clay witness depth).

The NIJ Standard-0101.04 provides ballistic requirements specific to different types of projectiles and impact energy levels. Three common NIJ threat levels for soft body armor include Threat Level II, IIA, and IIIA. Threat level II relates to higher velocity 357 magnum, 10.2 g (158 gr) and 9 mm, 8.0g (124 gr) bullets (impact velocities of less than about 1400 ft/s (427 m/s) and 1175 ft/s (358 m/s), respectively). Level IIA relates to lower velocity 40 S&W caliber full metal jacket bullets, with a nominal mass of 11.7 g (180 gr) and 9 mm 8.0 g (124 gr) bullets, (impact velocities of less than about 1025 ft/s (312 m/s) and 1090 ft/s (332 m/s), respectively). Threat level IIIA relates to 44 magnum, 15.6 g (240 gr) and sub machine gun 9 mm (124 gr) bullets having impact velocities of less than about 1400 ft/s).

While the ballistic performance requirements set forth above can be achieved using any of several commercially available anti-ballistic materials, or combinations of said materials, the challenge for soft body armor manufactures is the selection and arrangement of ballistic layers required to prevent penetration with an acceptable safety margin and minimize backface deformation while also minimizing the weight, bulk and stiffness of the armor to improve comfort.

Commercially available anti-ballistic materials include a variety of woven ballistic fiber yarn fabrics, ballistic fabric reinforced composites, ballistic fiber unidirectional laminates and nonwovens. Of these various constructions, woven fabrics fabricated from high tenacity fiber yarns have the longest history of use in soft body armor fabrication. Weaving has long been a relatively inexpensive means of uniformly generating fabric ballistic resistant plies from high tenacity fiber yarns, relying on mechanical interlocking or "interlacing" of the yarns to hold the yarns in place instead of chemical locking by adhesive resins which can contribute additional weight and stiffness to a garment. Soft body armors fabricated from ballistic resistant fabrics are very often more conformable and flexible during use, providing greater comfort than hybrid armors containing stiff backface control layers such as unidirectional fiber laminates or resin impregnated fabrics. Additionally, it has been shown that ballistic resistant garments generated entirely of woven high tenacity fiber yarns maintain ballistic resistant properties after years of service and wear. Alternatives to an all woven ballistic resistant vest are in commerce. Such articles are prepared from combinations of high tenacity fibers, matrix resins and films, often making them more costly to produce. Additionally, by virtue of the component materials having temperature and strain dependent physical properties (eg. coefficient of thermal expansion, modulus, etc.) dissimilar to that of the ballistic fiber, these composite layers often have a useable life cycle dictated by the weakest of the materials selected.

Typical biaxial woven ballistic resistant fabrics (fabrics consisting of interwoven interlaced yarns having two yarn orientations within the plane of the fabric) are generated on automated looms. These looming operations generate woven fabrics having interwoven fill fiber yarns oriented 90 degrees to those yarns in the warp, or machine direction. The fabric properties are largely governed by four basic variables: yarn denier, thread count, weave pattern and fabric finish. Several styles of woven fabrics exist, including plain, satin, twill, basket, and leno weaves. Meeting the minimum ballistic performance requirements using only the above woven fabrics presents a challenge for ballistic armor manufacturers. While many low cover factor (loosely woven) ballistic resistant fiber yarn fabrics provide satisfactory V50 performance at the desired areal density (vests fabricated therefrom can be shown to repeatedly impede projectiles from penetrating the vest material at velocities safely above the threshold values outlined in NIJ Standard-0101.04), they do not provide adequate backface deformation resistance. Conversely, the use of higher cover factor (more tightly woven) ballistic resistant fiber yarn fabrics at the same vest areal density while improving backface deformation performance, often results in significant reduction in V50 performance, sometimes falling below the NIJ Standard-0101.04 velocities required for backface signature measurement. Currently no all p-aramid fiber yarn (such as that sold under the trade name Kevlar® or Twaron®) woven fabric vests are available commercially at an areal density of less than 1 lb/ft^2, that can meet the NIJ Standard-0101.04 level IIIA backface requirement for a 44 magnum ballistic threat.

One common method for reducing the backface signature in soft body armors is through incorporating rigid plies of high tenacity fiber or fabric reinforced resin composite plies to impede deformation during impact. This includes bonding polymeric films or applying polymeric coatings to woven ballistic fabrics, or bonding two woven ballistic fabric layers using a low melting temperature polymer film, or pressure sensitive adhesive to provide an anti-ballistic ply that can be added to ballistic body armor constructions to improve backface signature, as described in WO 00/08411, US Pat. No. 5,677,029, and US 2003/0109188. Resin or elastomer impregnated ballistic fiber fabric is another type of composite ply added to ballistic vest constructions to improve ballistic backface signature. While the addition of these layers has been shown to improve the backface signature performance of an armor material, they can often have a deleterious effect on V50 performance. In addition, the resin adds to the weight and stiffness of the ballistic vest assembly.

Unidirectional fiber laminates, comprised of a first plurality of oriented parallel high tenacity fibers in a polymeric matrix adhesively bound to a second plurality of oriented parallel high tenacity fibers in a polymeric matrix, where the fiber orientation of the second plurality is often 90 degrees rotated relative to the orientation of the first plurality, have become popular anti-ballistic materials that can provide good backface trauma control while maintaining safe V50 performance. Methods of making these unidirectional fiber laminates are generally described in U.S. Pat. Nos. 4,916,000; 4,748,064; 4,737,401; 4,681,792; 4,650,710; 4,623,574; 4,563,392; 4,543,286; 4,501,854; 4,457,985, and 4,403,012. These unidirectional laminates are commercially available under the trade names Spectra Shield® Plus Flex, and Gold Flex™, from Honeywell International, Inc. and Dyneema®UD from DSM. While these unidirectional fiber laminates can be used alone to provide ballistic protection, it has been shown that further reductions in areal density without performance loss can be achieved when these materials are used in conjunction with woven ballistic fiber yarn fabrics, as illustrated in U.S. Patent 6,119,575

Performance improvements associated with using unidirectional fiber or fabric and resin composite layers in vests can be very dependent on their location within the multi-ply construction, as discussed in U.S. Patent 6,119,575. In many documented instances, the placement of these stiffer composite layers behind traditional ballistic fabrics provides the optimum in backface signature and V50 performance. Due to this "sidedness" these hybrid ballistic vest constructions can be inadvertently worn inside-out, or inserted the wrong way into a tactical vest, providing less than optimal protection from projectile threats. Hence there is value in monolithic (comprised of all the same plies of anti-ballistic material) or front-back symmetric ballistic resistant armor constructions.

The need exists for a lightweight, all woven fabric body armor that can reduce the blunt trauma associated with ballistic impact. Prior to the advent of the inventive biaxial (comprised of interlaced fiber yarns having two distinct orientations within the plane of the fabric) fabric architectures, and soft body armor constructions described herein, no documented, all-woven, p-aramid fabric ballistic body armors had existed having an areal density less than about 1 lb/ft^2 fulfilling the NIJ Standard-0101.04 backface requirement for a 44 caliber deformable projectile (backface signature below 44 mm for projectile velocities of 1430±30 ft/s (436±9 m/s)).

SUMMARY OF THE INVENTION

In one embodiment, the invention is directed to a biaxial fabric woven from yarn for use in the manufacture of ballistic projectile or puncture resistant articles, said biaxial fabric, comprising a first plurality of yarns oriented parallel within the plane of the fabric, interwoven with a second plurality of parallel oriented yarns within the plane of the fabric having a direction/orientation within the plane of the fabric different from that of the first plurality, where the crossing of any fiber yarn from the first plurality with a fiber yarn from the second plurality forms a pair of acute vertical angles having an angular measurement less than 90 degrees.

In another embodiment, the invention is directed a multi-layer ballistic projectile or puncture resistant article assembled from a plurality of substantially unattached non-woven or woven fabric layers comprising yarns selected, either alone or in combination, from the group comprising aromatic polyamide, polyolefin, polyareneazole, polyester, rayon, liquid crystal polymer, fiberglass, carbon fiber, ceramic, polyacrylonitrile and polyvinyl alcohol, in which at least one of the layers in the assembly is a biaxial fabric comprising a first plurality of yarns oriented parallel within the plane of the fabric, interwoven with a second plurality of parallel-oriented yarns within the plane of the fabric having a direction/orientation within the plane of the fabric different from that of the first plurality, where the crossing of any fiber yarn from the first plurality with a fiber yarn from the second plurality forms a pair of acute vertical angles having an angular measurement less than 90 degrees.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a prior art example of a woven fabric.

Figure 2 is a magnified image of one embodiment of the inventive ballistic resistant fabric construction.

Figure 3A is an illustration of the preparation of bias-oriented fabric strips from a roll of conventional woven fabric

Figure 3B shows the fabric cut from the roll shown in 3A clamped in a trellising apparatus.

Figure 3C shows the fabric clamped in the trellising apparatus and extended.

DETAILED DESCRIPTION OF THE INVENTION

Glossary Of Terms Used Herein

Acute angles - angles measuring less than 90 degrees.

Woven fabric - a fabric comprised of one plurality of fiber yarns oriented in one direction, interwoven with a second plurality of yarns oriented in a direction different from that of the first plurality. The first plurality of parallel yarns aligned in the machine direction are referred to as warp yarns. Those interwoven yarns oriented 90 degrees to the warp are referred to as the fill or weft yarns.

Bias woven or bias-oriented fabric– a two dimensional woven or braided fabric that when oriented in the XY plane, where X is the machine direction (length), and Y is the transverse direction (width) of the fabric, contains interlaced yarns that are oriented in a different direction from the X and Y axes within the plane of the fabric.

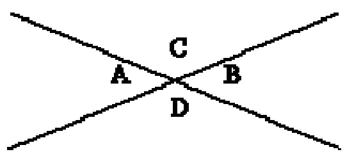
Bias orientation - In a biaxial woven fabric comprised of a plurality of yarns oriented in one direction within the plane of the fabric, interwoven with a second plurality of yarns having an orientation different from the first, the direction parallel to any ray bisecting any angle formed between a fiber yarn from the first plurality with that of a yarn from the second plurality.

Unidirectional fiber layer - a layer having fibers arranged substantially parallel along a common fiber direction

Composite fabric ply– a combination of one woven fabric layer and at least one second layer which could be another fabric layer, a unidirectional fiber layer, a polymeric film, a polymeric resin impregnated into the fabric structure, etc. The one woven fabric layer can be united with the second layer through stitching, melt adhesives, pressure sensitive adhesives, compression molding, coating.etc.

Supplementary angle - Two angles are called supplementary angles if the sum of their degree measurements equals 180 degrees. One of the supplementary angles is said to be the supplement of the other.

Vertical angles- For any two lines (rays) that cross, such as in the diagram below, angle A and angle B are called vertical angles. Vertical angles have the same degree measurement. Angle C and angle D are also vertical angles.



Trellis angle - in biaxial fabrics, the acute angle formed between any two yarns having different orientation within the plane of the fabric, observed in biaxial braided structures or achieved by in-plane extension of biaxial woven structures in either bias direction.

Trellis direction – a direction parallel with the line bisecting acute vertical angles..

Cover Factor - the fraction of the surface area of the fabric that is covered by yarns assuming a round yarn shape.

V50 - V50 ballistic limit testing is a statistical test, originally developed by the U.S. military to evaluate hard armor. V50 testing experimentally identifies the velocity at which a bullet has a 50 percent chance of penetrating the test object.

Backface signature (BFS) – The depth of the depression made in the backing material, created by a non-penetrating projectile impact. The backface signature is measured from the plane defined by the front edge of the backing material fixture. In accordance with the National Institute of Justice (NIJ) Standard-0101.04 Ballistic Resistance of Personal Body Armor, the value is not allowed to exceed the limit of 44 mm.

The present invention is directed in various embodiments at a new class of ballistic resistant fabric architectures, as well as ballistic layers and multi-layer body armor constructions made therefrom that exhibit improved ballistic backface deformation over traditional woven ballistic fabrics. One embodiment of this invention involves generating ballistic fabric architectures that can impart significant backface signature improvements to body armor that have never been achieved using traditional ballistic fabrics. A second embodiment of this invention is the generation of balanced ballistic layers from the ballistic fabric architecture for use in body armor assembly. A third embodiment of this invention is the fabrication of specific multilayer vest constructions incorporating the inventive ballistic fabric architectures.

The first embodiment of this invention can be described by first referring to Fig 1 that shows a prior art example of a woven fabric 10. The figure shows a magnified example of a plain weave construction comprised of multifilament yarns, where the intersection of a first set of yarns 1 parallel in direction within the plane of the fabric as indicated by line X is interwoven with a second set of yarns 2 parallel within the plane of the fabric and oriented 90 degrees from that of the first set as indicated by line Y. Intersections of yarns from the first set with those in the second set form angles A – D, each measuring 90 degrees. A line L is shown as bisecting angles A and B.

The first embodiment of this invention is a woven fabric architecture comprising a first plurality of parallel oriented yarns within the plane of the fabric, interwoven with a second plurality of parallel oriented yarns within the plane of the fabric having a direction/orientation within the plane of the fabric different from that of the first plurality, where the intersection of any fiber yarn from the first plurality with a fiber yarn from the second plurality forms a pair of acute vertical angles, having an angular measurement less than 90 degrees and necessarily a pair of obtuse vertical angles, supplementary to the aforementioned acute angles, having a measurement greater than 90 degrees. This inventive ballistic fabric arrangement 10' is shown in Fig. 2. comprised of a first plurality of parallel yarns 1' oriented within the plane of the fabric as indicated by line X', interwoven with a second plurality of parallel yarns 2' within the plane of the fabric as indicated by line Y' having orientation different from the first plurality where the intersection of any fiber yarn from the first plurality 1' with any fiber yarn from the second plurality 2' forms a pair of vertical angles within the plane of the fabric, where the angular measurements of the acute vertical angles A' and B' are equal in value and less than 90º, and the angular measurements of the obtuse vertical angles C' and D' are equal in value and greater than 90º. This inventive fabric can be achieved by extending the original woven fabric in the trellis direction as explained below by reference to Figs 3A-3C. For the purpose of this disclosure, we will refer to the orientation, or trellis extension direction, of these fabrics as the directions parallel to the line L' bisecting the acute vertical yarn crossing angles A' and B' as illustrated in Fig. 2

The scope of this invention is not limited to a construction consisting of yarns interlaced in a one over-one under every other yarn alternating structure as illustrated in Fig. 2, analogous to the interlacing for plain woven fabric illustrated in Fig. 1.. Rather, the scope of this invention includes, but is not limited to architectures where yarns in one direction in the plane of the fabric may alternatively pass over the top of, or beneath two or more adjacent yarns oriented in the second direction in any particular repeat pattern conceivable, including, for example fabric architectures which can be constructed through bias-direction extension of satin weaves (including but not limited to 3-harness satin weaves, 4-harness satin weaves (crow's foot), 5-harness satin weaves, and 8-harness satin weaves, etc.), basket weaves, and twill weave structures..

The fiber yarns used in constructing the ballistic resistant architectures described in this disclosure, would have a tensile strength greater than about 8 g/denier or more preferably greater than about 12 g/denier. In an embodiment of this invention, the fibers in the fabric yarn will be made of an aromatic polymeric material. Aromatic polymers include aromatic polyamides such as poly(para-phenylene teraphthalamide), sold under the trade names Kevlar® available from E.I. du Pont de Nemours and Company, Wilmington, DE (DuPont) and Twaron® available from Teijin, and poly(metaphenylene isophthalamide) sold under the trade name Nomex®, p-phenylene benzobisoxazole (PBO available from Toyobo), polybenzoxazole, polybenzothiazole. Other aromatic polymers include aromatic unsaturated polyesters such as polyethylene terephthalate, liquid crystalline thermotropic polyesters such as those sold under the trade name Vectran® available from Kuraray, aromatic polyimides, aromatic polyamideimides, aromatic polyesteramideimides, aromatic polyetheramideimides and aromatic polyesterimides. Copolymers of any of the above mentioned classes of materials can also be used.

Other ballistic grade fiber yarns having tenacity greater than 12 g/denier that could be used to fabricate these woven architectures include polyolefins, most notably high molecular weight polyethylene, sold under the trade names Dyneema® available from DSM and Spectra® available from Honeywell International, high molecular weight polypropylene and copolymers thereof.

For the example cases presented in this disclosure, bias-oriented fabric strips were obtained through cutting ballistic fabrics from fabric rolls having warp fibers oriented in the machine (longitudinal) direction, and fill fiber yarns oriented 90 degrees to that of the warp direction (transverse to the machine direction, parallel to the axis of the fabric roll). These strips were prepared through cutting along a bias direction, as illustrated in Fig. 3A. The fabrics were then extended to form the ballistic resistant bias fabric architecture once clamped into the trellising apparatus illustrated in Figs. 3B and 3C.

While the above method was adequate for generating the examples herein, a process to economically generate these structures would require the manufacture of bias-oriented fabric extended to create the desired trellis angle having continuous running lengths and enough width to provide for vests to be cut therefrom. Methods of generating bias-oriented fabrics have been disclosed in the patent literature. Examples include US 6,494,235, US 6,494,238, US 4,907,323 and WO 99/55519. Bias-oriented woven structures can also be generated using braiding processes known in the industry, to either directly generate continuous fabric sheets, or tubular constructions that can be slit along one side parallel to the axis of the tube to produce a flat continuous sheet of bias-oriented fabric. A second means of fabricating a continuous sheet of bias oriented fabric would be to helically cut a tubular fabric generated from a tubular loom, where warp fibers are oriented parallel to the axis of the tube and fill fiber is oriented circumferentially, also described in US Pat. 4,299,878

A second embodiment of this invention is the generation of a free-standing trellised fabric architecture, or trellised fabric composite ply that can be used in the construction of a ballistic body armor. Such a stabilized layer of the trellised ballistic architecture could be provided as a continuous rolled good for use by ballistic body armor manufacturers. It must be understood that individual fabric layers having this inventive architecture with no means of stabilization are inherently unbalanced due to their anisotropic nature. That is, the fabric layers have the tendency to readily revert (bounce back) to a more balanced structure (as represented by an increase in acute angle measurement) with little perturbation. This makes these fabric architectures difficult to handle without unwanted reversion during body armor assembly. One method used to maintain the trellised state in an individual fabric layer is stitching through a sewing operation once the desired trellis angle is achieved. Though stitching in any direction may afford some stability to the ballistic fabric, most effective stitching to impede the "bounce-back" tendency is stitching in a direction perpendicular to that of the trellis direction. Stitching in this fashion at regular intervals across a long piece of bias-oriented fabric extended to the desired acute trellis angle provides a stabilized single fabric sheet. Alternatively, a polymeric layer (having an adequate degree of dimensional stability/reversion resistance to oppose the tendency of the trellis fabric "bounce-back") could be adhered to the trellised fabric layer to help maintain the structure. Such a polymeric layer could be in the form of a thin film that is melt-bonded to the fabric (via heated platen compression or heated calendering) or a polymer coating (solvent based or emulsion/latex) applied and then dried to one or both sides of the fabric while held in the extended state. Such polymeric layers could be continuous in that they cover the entire surface of the fabric, or could be discontinuous across the surface of the fabric architecture to minimize weight and stiffness contribution to the ballistic layer. Discontinuous coatings of resins include open patterns or lines of resin on the fabric, or discrete spots. This can be achieved using melt adhesive films cut into open patterns that can be welded to the fabric surface. Alternatively, solvent based polymer coatings or polymer emulsions/latexes can be transfer printed in the aforementioned discontinuous fashion onto the trellised fabrics using gravure printing processes or the like.

The individual inventive trellised fabric layers and/or composite plies described above can be used to construct the entire ballistic body armor, or could be used in conjunction with other anti-ballistic materials in a ballistic body armor. The sewn or adhered polymer film or coating stabilized structures could be stacked in various arrangements within the body armor.

Balanced composite fabric plies can also be generated by the union of two of the trellised fabric architectures, assembled in such a way to have the acute angle or trellis direction of one fabric (defined as being parallel to the line bisecting the acute vertical angles formed by two interwoven yarns) oriented at a 90 degree angle with respect to the acute angle direction of the second trellised fabric architecture. The resulting two layers of fabric could be bound together through stitching with a sewing operation, adhesive bound using a pressure sensitive adhesive, adhered together through melt adhesion by placing a polymeric or thermoplastic elastomer films between the layers, compressing the layers together in a press or via a calendaring operation while heating above the melting point to promote adhesion. Thermosetting resins or elastomers could also be used to unite the two layers of materials together. As with the polymer coating stabilized single fabric layer architectures, discontinuous coatings are most preferred as a means of reducing stiffness and weight of these two fabric sandwich structure laminates.

EXAMPLES

Comparative Example 1.

A 15 in x 15 in (38 x 38 cm) square ballistic test panel was prepared from 25 layers of style 726 greige fabric available from JPS Industries Inc, Anderson, SC. This is a plain weave fabric made from 840 denier Kevlar® 129 fiber yarns, having a yarn count of 26 ends per inch warp and 26 ends per inch fill, measured extracted yarn tenacities of 27 g/denier warp and 26 g/denier fill, and an areal density of 6.04 oz/yd^2 (205 g/m^2). Individual square fabric layers were generated by cutting along the warp and fill direction (having warp and fill fiber yarns parallel to the sides of the square). Fabric layers were arranged with warp and fill fibers oriented in the same direction for all fabric layers in the stack. The fabric layers were stitched together about the perimeter of the panel 1/2 in (1.27 cm) from the edge. A 2 in x 2 in (5.1 x 5.1 cm) quilt pattern was also sewn through the thickness of the panel to mechanically bind the layers together. Ballistic backface signature impact testing was performed using 44 magnum bullets at velocities of 1430±30 ft/s on targets placed against a clay witness (Roma plastilina clay) following the protocol outlined by NIJ Standard 0101-04. The ballistic V50 for 44 magnum bullets was determined for this test panel. The backface signature and V50 results for 44 Magnum bullet ballistic testing at 1430±30 ft/s against a clay witness appear in Table 1.

Comparative Example 2

A 15 in x15 in (38 x 38 cm) square ballistic test panel was prepared from 36 layers of a plain weave fabric made from 840 denier Kevlar® 129 fiber yarns by JPS Industries Inc., having a yarn count of 18 ends per inch warp and 18 ends per inch fill, measured extracted yarn tenacities of 27 g/denier warp and 26 g/denier fill, and an areal density of 4.04 oz/yd^2 (137 g/m^2). Individual fabric layers were cut from the fabric roll having warp and fill yarns parallel to the sides of the square. Fabric layers were arranged with warp and fill fiber yarns oriented in the same direction for all fabric layers in the stack. The fabric layers were stitched together about the perimeter of the panel 1/2 in (1.27 cm) from the edge. A 2 in x 2 in (5.1 x 5.1 cm) quilt pattern was also sewn through the thickness of the panel to mechanically bind the layers together. The backface signature and V50 results for 44 Magnum bullet ballistic testing at 1430±30 ft/s against a clay witness appear in Table 1.

Comparative Example 3

A 15 in x 15 in (38 x 38 cm) square ballistic test panel was prepared from 37 layers of style 726 greige fabric having the properties described in Comparative Example 1. The target was fabricated having an alternating fabric orientation for every other layer with 19 fabric squares having the sides of the square oriented parallel with the warp and fill fiber yarn directions (0-90), and 18 layers oriented 45 degrees rotated from that of the previous fabric (-45, +45). The fabric layers were stitched together about the perimeter of the panel 1/2 in (1.27 cm) from the edge. A 2 in x 2 in (5.1 x 5.1 cm) quilt pattern was also sewn through the thickness of the panel to mechanically bind the layers together. The backface signature and V50 results for 44 Magnum bullet ballistic testing at 1430±30 ft/s against a clay witness appear in Table 1.

Comparative Example 4

A 15 in x 15 in (38 cm x 38 cm) square ballistic test panel was prepared from 53 layers of plain woven Kevlar® KM2, 600 denier fiber yarns, having a yarn count of 17 ends per inch warp and 17 ends per inch fill, extracted yarn tenacities of 25 g/denier warp, and 22 g/denier fill, and an areal density of 2.64 oz/yd^2 (89.5 g/m^2). Individual square fabric layers were generated by cutting along the warp and fill direction (having warp and fill fiber yarns parallel to the sides of the square). Fabric layers were arranged with warp and fill fibers oriented in the same direction for all fabric layers in the stack. The fabric layers were stitched together about the perimeter of the panel 1/2 in (1.27 cm) from the edge. A 2 in x 2 in (5.1 x 5.1 cm) quilt pattern was also sewn through the thickness of the panel to mechanically bind the layers together. The backface signature and V50 results for 44 Magnum bullet ballistic testing at 1430±30 ft/s against a clay witness appear in Table 2.

Comparative Example 5

A 15 in x 15 in (38 cm x 38 cm) square ballistic test panel was prepared from 26 layers of plain woven Kevlar® KM2, 600 denier fiber yarns, having a yarn count of 34 ends per inch warp and 34 ends per inch fill, extracted yarn tenacities of 21 g/denier warp, and 23 g/denier fill, and an areal density of 5.50 oz/yd^2 (186 g/m^2). Individual square fabric layers were generated by cutting along the warp and fill direction (having warp and fill fiber yarns parallel to the sides of the square). Fabric layers were arranged with warp and fill fibers oriented in the same direction for all fabric layers in the stack. The fabric layers were stitched together about the perimeter of the panel 1/2 in (1.27 cm) from the edge. A 2 in x 2 in (5.1 x 5.1 cm) quilt pattern was also sewn through the thickness of the panel to mechanically bind the layers together. Backface signature and V50 results for 44 Magnum bullet ballistic testing at 1430±30 ft/s against a clay witness appear in Table 2.

Comparative Example 6

A 15 in x 15 in (38 x 38 cm) square ballistic test panel was prepared from 33 layers of a 4-harness satin (crow's foot) weave fabric made from 840 denier Kevlar® 129 fiber yarns by JPS Industries Inc, having a yarn count of 20 ends per inch warp and 20 ends per inch fill, a warp yarn tenacity of 27 g/denier, a fill yarn tenacity of 25 g/denier, and an areal density of 4.43 oz/yd^2 (150 g/m^2). Individual fabric layers were cut from the fabric roll having warp and fill yarns parallel to the sides of the square. Fabric layers were arranged with warp and fill fibers oriented in the same direction for all fabric layers in the stack. The fabric layers were stitched together about the perimeter of the panel 1/2 in (1.27 cm) from the edge. A 2 in x 2 in (5.1 x 5.1 cm) quilt pattern was also sewn through the thickness of the panel to mechanically bind the layers together. The backface signature and V50 results for 44 Magnum bullet ballistic testing at 1430±30 ft/s against a clay witness appear in Table 3.

Comparative Example 7

A 15 in x 15 in (38 x 38 cm) square ballistic test panel was prepared from 12 composites fabricated by bonding two layers of style 726 greige fabric described in Comparative Example 1, the second layer being rotated 45 degrees relative to the first. The layers were bonded together using a nonwoven polymeric fabric adhesive (Pellon® Wonder-Under® 805 fusible nonwoven interfacing web available from Pellon® Consumer Products Group, LLC of Tucker, Georgia), at a temperature of about 130°C and compressed using a hand iron to melt the adhesive and effect a bond between the fabric layers. The 12 composite layers were stacked and sewn about the perimeter and with a 2 in x 2 in (5.1 x 5.1 cm) quilt stitch to generate the test panel. The backface signature and V50 results for 44 Magnum bullet ballistic testing at 1430±30 ft/s against a clay witness appear in Table 4.

Comparative Example 8

A 15 in x 15 in (38 x 38 cm) square ballistic test panel was prepared from 12 layers of the style 726 greige fabric having properties described in

Comparative Example 1, and 6 of the two 726 greige fabric layer composites described in Comparative Example 7. The panel was assembled with the 12 non-bonded layers in front (first impacted by the bullet), and the six composites in the rear (nearest the clay witness). The resulting stack was sewn about the perimeter and with a 2 in x 2 in (5.1 x 5.1 cm) quilt stitch to generate the test panel. The backface signature and V50 results for 44 Magnum bullet ballistic testing at 1430±30 ft/s against a clay witness appear in Table 4.

Comparative Example 9

A 15 in x 15 in (38 x 38 cm) square ballistic test panel was prepared from a stack of 17 composites fabricated by bonding two layers of the 840 denier, 18 ends per inch warp, 18 ends per inch fill greige fabric described in Comparative Example 2, the second layer being rotated 45 degrees relative to the first. The layers were bonded together using a nonwoven polymeric fabric adhesive (Pellen® 805 Wonder-Under®) under similar conditions to Comparative Example 7 to melt the adhesive and effect a bond between the fabric layers. The 17 composite layers were stacked and sewn about the perimeter and with a 2 in x 2 in (5.1 x 5.1 cm) quilt stitch to generate the test panel. The backface signature and V50 results for 44 Magnum bullet ballistic testing at 1430±30 ft/s against a clay witness appear in Table 4.

Comparative Example 10

A 15 in x 15 in (38 x 38 cm) square ballistic test panel was prepared from 17 layers of the 840 denier Kevlar® 129 yarn, 18 yarns per inch warp, 18 ends per inch fill greige fabric described in Comparative Example 2, and 9 of the two layer composite fabric plies described in Comparative Example 9. The panel was assembled with the 17 non-bonded layers in front (first impacted by the bullet), and the six composites in the rear (nearest the clay witness). The resulting stack was sewn about the perimeter and with a 2 in x 2 in (5.1 x 5.1 cm) quilt stitch to generate the test panel. The backface signature and V50 results for 44 Magnum bullet ballistic testing at 1430±30 ft/s against a clay witness appear in Table 4.

Comparative Example 11.

A 15 in x 15 in (38 x 38 cm) square ballistic test panel was prepared from 30 layers of plain weave fabric type S-17114G with a CS811 finish woven by JPS Industries Inc. from ultra high molecular weight polyethylene yarn made by the Beijing Tongyizhong Specialty Fiber Technology & Development Company Ltd., Beijing, China. This 800 denier yarn reinforcement had a yarn count of 24 ends per inch (94 ends per 10 cm.) in warp and fill and had an areal density of 4.86 oz/yd^2 (165 g/m2). Individual square fabric layers were generated by cutting along the warp and fill directions (having warp and fill fibers parallel to the sides of the square). The fabric layers were arranged with warp and fill fibers oriented in the same direction for all fabric layers in the stack. The fabric layers were stitched together about the perimeter of the panel 1/2 in (1.27 cm) from the edge. A 2 in x 2 in (5.1 x 5.1 cm) quilt pattern was also sewn through the thickness of the panel to mechanically bind the layers together. Ballistic backface signature impact testing was performed using 44 magnum bullets at velocities of 1430±30 ft/s on targets placed against a clay witness (Roma plastilina clay) following the protocol outlined by NIJ. The ballistic V50 for 44 magnum bullets was determined for this test panel. The backface signature and V50 results appear in Table 5.

Example 1

Diagonal strips were cut from a 63 in (160 cm) wide roll of the 840 denier Kevlar® 129 yarn, 18 ends per inch warp, 18 ends per inch fill greige fabric described in Comparative Example 2. The diagonal cuts were oriented along the bias direction of this plain weave fabric as shown in Fig. 3A; generating bias-oriented fabric strips 28 in (71 cm) in width. The fabric was clamped in a trellising frame as illustrated in Fig. 3B and extended to achieve a 45 degree acute trellis angle. The trellised fabric was cut into equal sections and cross-laid (stacked in an alternating layer fashion, with every layer having a trellis direction rotated 90 degrees relative to the one before it). The stack was constructed with the aid of a square pinning frame that held the trellis angle of individual fabric layers fixed during construction. This alternating cross-laid arrangement of fabric layers was repeated to create a stack with 26 trellised fabric layers. The stack of fabric layers were stitched together about their perimeter, and a 2 in x 2 in (5.1 x 5.1 cm) quilt pattern was also sewn through the thickness of the panel to mechanically bind the layers together, while the fabric layers were held in place in the pinning frame. The panel was then trimmed to have a 15 in x 15 in (38 x 38 cm) end construction. The backface signature and V50 results for 44 Magnum bullets at 1430±30 ft/s against a clay witness appear in Table 1. These panels fabricated from the inventive fabric architecture demonstrated a reduction in backface signature over Comparative Examples 1-3. V50 performance was also not compromised for these panels with this novel construction, remaining comparable in value to Comparative Examples 1-3.

Example 2

Diagonal strips were cut from a 63 in (160 cm) wide roll of the 600 denier Kevlar® KM2 yarn, 17 ends per inch warp, 17 ends per inch fill greige fabric described in Comparative Example 2. The diagonal cuts were oriented along the bias direction of this plain weave fabric as shown in Fig. 3A, generating bias-oriented fabric strips. The fabric was clamped in a trellising frame as illustrated in Fig. 3B and extended to achieve a 30 degree acute trellis angle. The trellised fabric was cut into equal sections and cross-laid (stacked in an alternating layer fashion, with every layer having a trellis direction rotated 90 degrees relative to the one before it). The stack was constructed with the aid of a square pinning frame that held the trellis angle of individual fabric layers fixed during construction. This alternating cross-laid arrangement of fabric layers was repeated to create a stack with 27 trellised fabric layers. The stack of fabric layers were stitched together about their perimeter, and a 2 in x 2 in (5.1 x 5.1 cm) quilt pattern was also sewn through the thickness of the panel to mechanically bind the layers together, while the fabric layers were held in place in the pinning frame. The panel was then trimmed to have a 15 in x 15 in (38 x 38 cm) end construction. The backface signature and V50 results for 44

Magnum bullets at 1430±30 ft/s against a clay witness appear in Table 1. This trellised fabric construction exhibited improved V50 performance over both the target fabricated of the base 17 end per inch warp, 17 end per inch fill fabric (Comparative example 5) and the plain woven fabric target of the same 600 denier yarn exhibiting equivalent individual fabric layer areal density (Comparative Example 6). The first backface measurement performed on this inventive construction also demonstrated improvement over both Comparative Examples 5 and 6, yet the integrity of this construction after this first backface test was reduced, which may have resulted in the increased deformation resistance observed in the second backface signature measurement.

Example 3

A multilayer panel comprised of a trellised fabric architecture generated using the 20 x 20 ends per inch, 840 denier Kevlar® 129 yarn crow's foot weave fabric described in Comparative Example 6 , was generated using the procedure described for Experimental example 1 above. The finished test panel was comprised of 23 layers, each having a 45 degree trellis angle, the layers being stacked in a 0 degree - 90 degree alternating orientation as done in experimental example 1. The panel was sewn about the perimeter and with a 2 in x 2 in (5.1 x 5.1 cm) quilt pattern. The backface signature and V50 results for 44 Magnum bullets at 1430±30 ft/s against a clay witness appear in Table 3.

This example exhibited improved backface without significant loss in V50 when compared with the target fabricated from the base fabric in Comparative Example 6.

Example 4

A 15 in x 15 in (38 x 38 cm) square ballistic test panel was prepared from 12 composites fabric plies fabricated by bonding two layers of the inventive trellised fabric architecture fabricated as described in Example 1, the second fabric layer being rotated 90 degrees relative to the first with respect to trellis direction. The layers were bonded together using a nonwoven polymeric fabric adhesive (Pellen® 805) under similar conditions to Comparative Example 7 to effect a bond between the fabric layers. The 12 composite layers were stacked and sewn about the perimeter and with a 2 in x 2 in (5.1 x 5.1 cm) quilt stitch to generate the test panel. As shown in Table 4, this construction demonstrated higher V50 than the comparative composite fabric ply panels described in Comparative Examples 7 through 10, while consistently demonstrating satisfactory backface signatures even after 5 backface tests performed with the 44 magnum bullet at 1430±30 ft/s.

Example 5

A 15 in x 15 in (38 x 38 cm) square ballistic test panel was prepared from 18 layers of the 840 denier Kevlar® 129 fiber yarn greige fabric described in Comparative example 2, and 6 trellised fabric composite plies fabricated from this same fabric as described in experimental example 4. The panel was assembled with the 18 fabric layers in front (first impacted by the bullet), and the six composite plies in the rear (nearest the clay witness). The resulting stack was sewn about the perimeter and with a 2 in x 2 in (5.1 x 5.1 cm) quilt stitch to generate the test panel. The backface signature and V50 results for 44 Magnum bullets at 1430±30 ft/s against a clay witness appear in Table 4.

Experimental Example 6

Diagonal strips were cut from a roll of style S-17114G, CS811 polyethylene fabric of Comparative Example 11. The diagonal cuts were oriented along the bias direction of this plain weave fabric as shown in Fig. 3A, generating bias-oriented fabric strips. The fabric was clamped in a trellising frame as illustrated in Fig. 3B and extended to achieve a 50 degree acute trellis angle. The trellised fabric was cut into equal sections and cross-laid (stacked in an alternating layer fashion, with every layer having a trellis direction rotated 90 degrees relative to the one before it). The stack was constructed with the aid of a square pinning frame that held the trellis angle of individual fabric layers fixed during construction. This alternating cross-laid arrangement of fabric layers was repeated to create a stack with 22 trellised fabric layers. The stack of fabric layers was stitched together about the perimeter and a 2 in x 2 in (5.1 x 5.1 cm) quilt pattern was also sewn through the thickness of the panel to mechanically bind the layers together, while the fabric layers were held in place in the pinning frame. The panel was then trimmed to have a 15 in x 15 in (38 x 38 cm) end construction. The backface signature and V50 results for 44 Magnum bullets at 1430±30 ft/s against a clay witness appear in Table 5. The trellis fabric construction had a 27% reduction in backface signature compared to the conventional 0/90 plain weave construction fabric.

Table 1

Example	Areal density (lbs/ft^2)	V50 (fps)	Backface Performance Velocity (fps)	BFS (mm)
Comparative Example 1	1.034	1535	1444 1421	50 51
Comparative Example 2	1.008	1558	1429 1405	49 56
Comparative Example 3	1.040	1590	1434 1428	51 45
Example 1	1.034	1559	1428 1414	39 36

Table 2

Example	Areal density (lbs/ft^2)	V50 (fps)	Backface performance Velocity (fps)	BFS (mm)
Comparative Example 4	1.03	1589	1430 1426	52 55
Comparative Example 5	1.03	1548	1435 1425	48 49
Example 2	1.033	1602	1444 1448	42 48

Table 3

Example	Areal density (lbs/ft^2)	V50 (fps)	Backface performance	
			Velocity (fps)	BFS (mm)
Comparative Example 6	1.021	1617	1435	59
			1426	63
Example 3	1.033	1602	1432	39
			1422	48

Table 4

Example	Areal density (lbs/ft^2)	V50 (fps)	Backface Performance Velocity (fps)	BFS (mm)
Comparative Example 7	1.034	1472	1427	37
			1444	39
			1433	35
			1405	34
Comparative Example 8	1.014	1473	1443	Complete **
			1408	40
Comparative Example 9	1.018	1408	1439	Complete
			1424	Complete
Comparative Example 10	1.011	1471	1427	43
			1435	56
Example 4	0.992	1510	1408	35
			1440	40*
			1417	40
			1424	36
			1446	40
Example 5	0.999	1515	1434	47
			1441	42

* denotes impact 2.5" from edge of target

** “Complete” denotes bullet passed straight through the target

Table 5

Example	Areal density (lbs/ft^2)	V50 (fps)	Backface Performance	
			Velocity (fps)	BFS (mm)
Comparative Example 11	1.090	1450	1432 1430	51 52
Example 6	1.020	1435	1444 1442	39 36

What is claimed is:

1. A fabric woven from yarn for use in the manufacture of ballistic projectile resistant articles, said fabric, comprising a first plurality of parallel oriented yarns within the plane of the fabric, interwoven with a second plurality of parallel oriented yarns within the plane of the fabric having a direction/orientation within the plane of the fabric different from that of the first plurality, where the crossing of any fiber yarn from the first plurality with a fiber yarn from the second plurality forms a pair of acute vertical angles having an angular measurement less than 90 degrees.

2. The fabric of claim 1, where the fabric is comprised of fiber yarns containing aromatic polyamides including poly(p-phenylene teraphthalamide), poly(metaphenylene isophthalamide), p-phenylenebenzobisoxazole, polybenzoxazole, polybenzothiazole, aromatic unsaturated polyesters such as polyethylene terephthalate, aromatic polyimides, aromatic polyamideimides, aromatic polyesteramideimides, aromatic polyetheramideimides and aromatic polyesterimides or copolymers of any of the above mentioned classes of materials .

3. The fabric of claim 1, where the fabric is comprised of fiber yarns containing ultra high molecular weight polyethylene.

4. The fabric of claim 1, where the angular measure of the acute vertical angles is between 80 and 89 degrees.

5. The fabric of claim 1, where the angular measure of the acute vertical angles is between 70 and 80 degrees.

6. The fabric of claim 1, where the angular measure of the acute vertical angles is between 60 and 70 degrees.

7. The fabric of claim 1, where the angular measure of the acute vertical angles is between 50 and 60 degrees.

8. The fabric of claim 1, where the angular measure of the acute vertical angles is between 40 and 50 degrees.

9. The fabric of claim 1, where the angular measure of the acute vertical angles is between 30 and 40 degrees.

10. The fabric of claim 1, where the angular measure of the acute vertical angles is between 20 and 30 degrees.

11. The fabric of claim 1, where the angular measure of the acute vertical angles is between 10 and 20 degrees.

12. The fabric of claim 1, where the angular measure of the acute vertical angles is less than 10 degrees.

13. A multi-layer ballistic projectile or puncture resistant article assembled from a plurality of substantially unattached non-woven fabric layers, woven fabric layers, or composite fabric plies in which at least one of the layers in the assembly is a biaxial fabric made of fiber yarns having a first plurality of parallel oriented yarns within the plane of the fabric, interwoven with a second plurality of parallel oriented yarns within the plane of the fabric having a direction/orientation within the plane of the fabric different from that of the first plurality, where the crossing of any fiber yarn from the first plurality with a fiber yarn from the second plurality forms a pair of acute vertical angles having an angular measurement less than 90 degrees.

14. The article of claim 13, where the angular measure of the acute vertical angles of at least one of the biaxial fabric layers is between 80 and 89 degrees.

15. The article of claim 13, where the angular measure of the acute vertical angles of at least one of the biaxial fabric layers is between 70 and 80 degrees.

16. The article of claim 13, where the angular measure of the acute vertical angles of at least one of the biaxial fabric layers is between 60 and 70 degrees.

17. The article of claim 13, where the angular measure of the acute vertical angles of at least one of the biaxial fabric layers is between 50 and 60 degrees.

18. The article of claim 13, where the angular measure of the acute vertical angles of at least one of the biaxial fabric layers is between 40 and 50 degrees.

19. The article of claim 13, where the angular measure of the acute vertical angles of at least one of the biaxial fabric layers is between 30 and 40 degrees.

20. The article of claim 13, where the angular measure of the acute vertical angles of at least one of the biaxial fabric layers is between 20 and 30 degrees.

21. The article of claim 13, where the angular measure of the acute vertical angles of at least one of the biaxial fabric layers is between 10 and 20 degrees.

22. The article of claim 13, where the angular measure of the acute vertical angles of at least one of the biaxial fabric layers is less than 10 degrees .

23. The article of claim 13, in which at least two of the biaxial fabric layers are

oriented such that the yarn orientations in one layer are offset from the yarn orientations in a second layer.

24. The article of claim 13, in which at least two of the biaxial fabric layers areoriented such that the yarn orientations in one layer are the same as the yarn orientations in a second layer.

25. A composite fabric ply comprising at least one fabric woven from yarn for use in the manufacture of ballistic projectile resistant articles, said fabric, comprising a first plurality of parallel oriented yarns within the plane of the fabric, interwoven with a second plurality of parallel oriented yarns within the plane of the fabric having a direction/orientation within the plane of the fabric different from that of the first plurality, where the crossing of any fiber yarn from the first plurality with a fiber yarn from the second plurality forms a pair of acute vertical angles having an angular measurement less than 90 degrees and one other fabric layer.

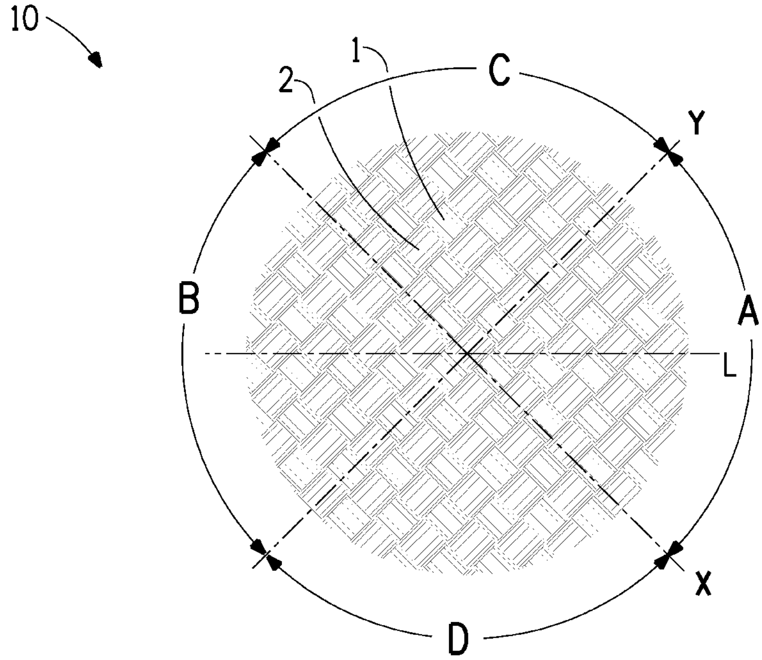


FIG. 1
(Prior Art)

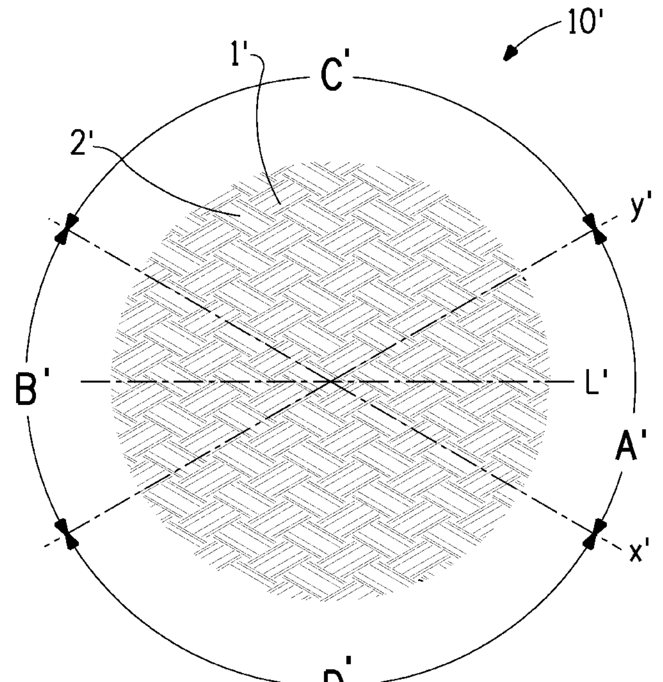


FIG. 2

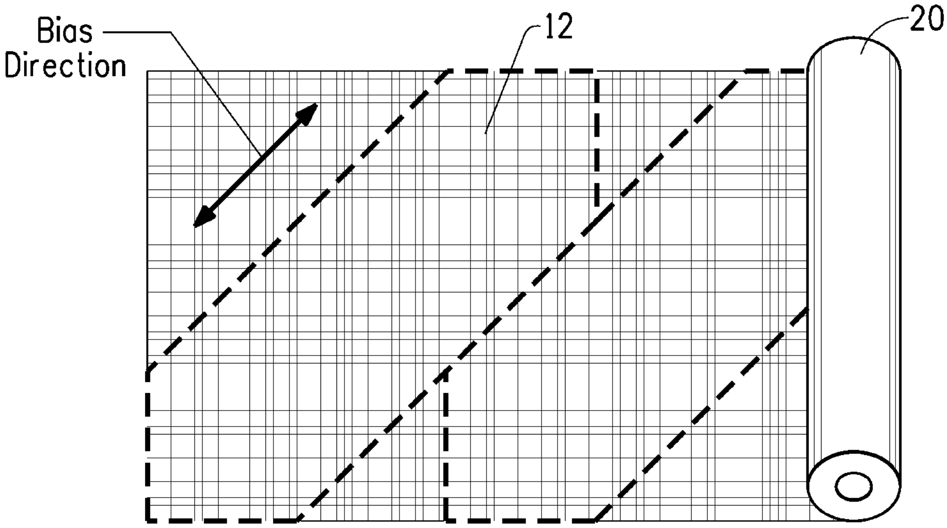


FIG. 3A

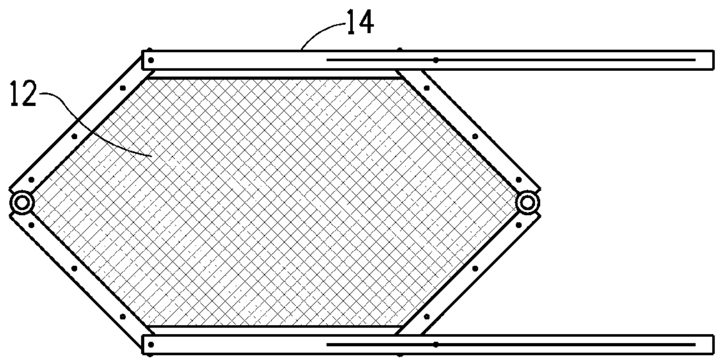


FIG. 3B

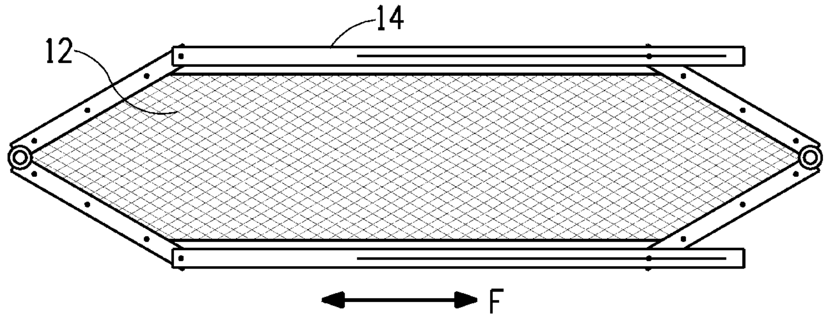


FIG. 3C