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(56) Documents cited
GB 2144973 A GB 1569322 A US 4287607 A
US 3891996 A

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Online databases: WPI, CLAIMS

(54) **Penetration-resistant laminate**

(57) A penetration-resistant laminate suitable for use in protective articles such as helmet shells comprises a resin matrix (12) containing respective first (14) and second (18) layers of high-modulus fabric and a middle layer (16) of ballistic fabric different from the first and second layers. In one preferred embodiment, a first layer of fibreglass or graphite and a second layer of graphite are separated by a middle layer of nylon, while in a second preferred embodiment an additional fibreglass layer is provided on the other side of a first graphite layer from the nylon layer.

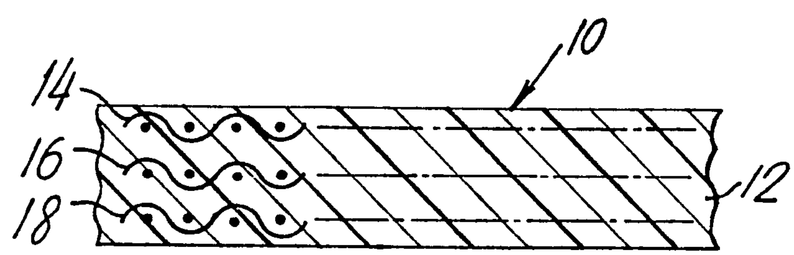

FIG. 1

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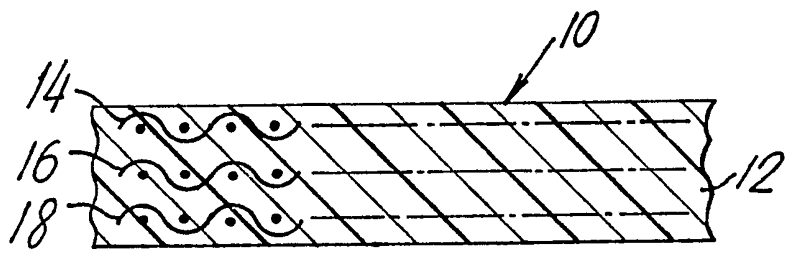

FIG. 1

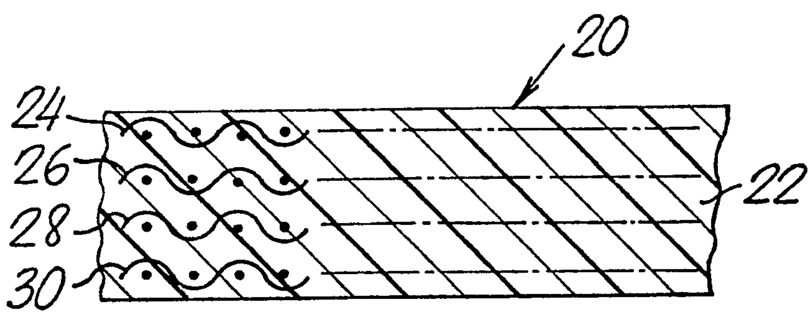

FIG. 2

Title of the Invention

PENETRATION-RESISTANT LAMINATE

Background of the Invention

This invention relates to a penetration-resistant laminate for use in such protective articles as helmets or the like.

A helmet is generally made of four main components. The first component is a hard outer shell, which distributes impact loads over a large area and prevents objects from penetrating into the helmet interior. It also serves as the platform for helmet-mounted accessories. The second component is the energy-absorbing liner, which absorbs the energy of impacts. This function of energy absorption can sometimes also be accomplished by the third component, the suspension-retention system, which properly positions the helmet on the head and retains the helmet on the head during an accident. The fourth component is the sound-attenuating system, which typically comprises a pair of earcups mounted on the retention system.

The method used to make a helmet shell is typical of that used to make other similar composite structures. A resinous matrix is introduced to layers of fabric; the result is either a wet "lay-up" or, if the impregnation is performed in advance by the fabric supplier, what is known as a "pre-preg". A helmet is formed by forcing the fabric and resin into the desired shape under heat and pressure. When the resin cures, the resulting structure is a raw helmet, which is finished through further operations in the manufacturing process. The general method is shown in such references as

White U.S. Patent No. 4,778,638, Grick U.S. Patent No. 4,596,056, Frieder U.S. Patent No. 3,582,990 and Frieder et al U.S. Patent No. 3,018,210, owned by the assignee herein.

Currently available laminates for protective helmets or the like typically utilize layers of structural fabric, formed to a desired shape and bonded together with resin. The most commonly used structural fabrics in these laminates are fiberglass, aramid such as that sold by E.I. du Pont de Nemours & Company under the trademark KEVLAR, and graphite. Helmets are commonly made from one or more of these fabrics, either singly or in combination.

Helmet shells made from structural fabrics are generally desirable, since structural fabrics can be used to create relatively stiff helmet shells at relatively low weights. Stiff shells by definition do not flex easily, and offer a stable platform for mounting helmet accessories. Further, since they distribute the impact force over a broader area of the energy-absorbing liner, stiff shells can make use of lower-density liners for impact protection.

A problem arises when a helmet shell of typical construction must resist penetrating objects. The type of energy the fibers of the fabric must resist is a tearing energy, one that pulls and stretches the fibers until breaking. The stiff structural materials used in helmet composites are generally of low ductility; elongations that the fibers can experience before breaking are small. Therefore, a penetrating object forces the fibers to snap before large amounts of energy are absorbed. For these reasons, standard composites used in helmet shells require extra layers of fabric to control a penetrating object. However, increasing the fabric layers used to make a shell results in added cost, weight and bulk, none of which is desirable in, for example a lightweight aircraft helmet.

Certain laminates of the prior art contain multiple layers of high-modulus fabric whose fibres are stretchable so as to function also as a "ballistic", or penetration-resistant, fabric. One such laminate is formed from layers of the ultrahigh-molecular-weight polyethylene fabric available from Allied Chemical Corporation under the trademark SPECTRA. However, such a high-modulus ballistic fabric is very expensive, can melt while moulding and is flammable.

Still other laminates, such as described in Smith U.S. Patent No. 4,732,803 contain fabric layers that are arranged with zones of decreasing Young's modulus and increasing elongation characteristics. Although such arrangements represent a partial solution to the problem of combining structural rigidity with penetration resistance, they require many layers of structural fabric to provide acceptable rigidity.

According to the present invention there is provided a penetration-resistant laminate comprising a resin matrix containing respective first and second layers of high-modulus fabric and an intermediate layer of ballistic fabric different from said first and second layers.

The preferred embodiments of the invention provide a structure that is penetration resistant, is lightweight, is sufficiently stiff to serve as a platform for mounting accessories, and is reasonable in cost.

In general, my invention contemplates a penetration-resistant laminate for use in protective articles such as helmet shells which comprises a resin matrix containing respective first and second layers of high-modulus fabric and a middle layer of ballistic fabric different from the first and second layers. In one preferred embodiment, a first layer of fiberglass or graphite and a second layer of graphite are separated by a middle layer of nylon, while in a second preferred embodiment a fiberglass layer is provided adjacent to a first layer of graphite on the other side from the nylon layer.

By "high-modulus" fabric is meant a fabric whose individual fibers have a high Young's modulus of elasticity, preferably at least about 1,000,000 pounds per square inch (psi). By "ballistic" fabric is meant a fabric whose fibers are stretchable, and therefore capable of absorbing large amounts of impact energy, preferably at least about 16,000 foot-pounds per pound of fiber, before breaking. The absorbed energy for this purpose is the area under the curve of tension versus elongation. Suitable high-modulus fabrics include those formed from aramids such as those sold by E.I. du Pont de Nemours & Company under the trademarks KEVLAR and NOMEX, boron, fiberglass, or graphite. Preferably, fiberglass is used as the outer, or exposed, structural layer for ease in finishing. Suitable ballistic fabrics include those formed from nylon, polyolefin or polyester.

Although the particular choice of resin is not critical, a highly suitable resin is epoxy resin. Other thermosetting resins such as thermosetting polyester could also be used. Alternatively, thermoplastic resins such as polyester thermoplastic (PET), polyetherimide (PEI), polyetherether ketone (PEEK) and nylon 6/6 could be used. If a thermoplastic resin is used, any ballistic layer of nylon or other low-melting material should be replaced by a suitable ballistic fabric, such as S-glass, which can withstand the temperatures used to plasticize the resin.

Laminates constructed in accordance with my invention have an added advantage besides those mentioned above. Graphite is extremely brittle in comparison to other structural materials and can shatter under hard impact. If used as a middle layer, nylon acts to contain the shattered pieces, much in the manner of automotive safety glass, in which a plastic layer is sandwiched between two glass layers. This containing action of the nylon helps to prevent personal injury from the sharp edges of the shattered graphite.

Brief Description of the Drawings

In the accompanying drawings to which reference is made in the instant specification and which are to be read in conjunction therewith and in which like reference numerals are used to indicate like parts in the various views:

FIGURE 1 is a fragmentary section of one laminate constructed in accordance with my invention.

FIGURE 2 is a fragmentary section of a laminate similar to that shown in FIGURE 1, but containing an additional layer of high-modulus fabric.

Description of the Preferred Embodiments

EXAMPLE 1

FIGURE 1 shows an embodiment of my invention in which a single layer of ballistic fabric is sandwiched between two layers of high-modulus fabric. More particularly, a penetration-resistant laminate indicated generally by the reference numeral 10 comprises an epoxy resin matrix 12 containing a first layer 14 of high-modulus fiberglass or graphite fabric, a second layer 18 of high-modulus graphite fabric, and a middle layer 16 of ballistic nylon fabric between layers 14 and 18. In forming laminate 10, layers 14 to 18, which are impregnated with resin 12, are molded into a shell or other article in the manner disclosed in the patents identified above, owned by the assignee herein, the specifications of which are incorporated herein by reference.

The fiberglass fabric may be 120 woven fiberglass from Clark Schwebel Fiber Glass Corporation, White Plains, New York. The nylon fabric may be a 14-oz./yd.^{2} weave such as made by Gentex Corporation, the assignee herein. The graphite fabric may be G104 graphite, from Textile Technologies, Inc., Hatboro, Pennsylvania, a plain 5.7-oz./yd.^{2} weave of MAGNAMITE (trademark) Type AS4 graphite fiber from Hercules Inc., Wilmington, Delaware. The choice between fiberglass and graphite for the first layer 14 depends on the requirements of the user. On the one hand, fiberglass is preferable to graphite for ease of finishing. On the other hand, graphite is approximately four times as stiff as fiberglass and is slightly less dense. Thus, graphite is preferable where weight and stiffness considerations predominate over ease of finishing.

EXAMPLE 2

FIGURE 2 shows an alternative embodiment, indicated generally by the reference character 20, in which an epoxy resin matrix 22 contains respective graphite, nylon and graphite layers 26, 28 and 30, similar to layers 14, 16 and 18 of Example 1, together with an additional layer 24 of fiberglass on the other side of layer 26 from nylon layer 28.

EXAMPLES 3 TO 25

The penetration resistances of various laminates constructed in accordance with my invention were compared with those of laminates comprising multiple layers of aramid fabric. A test stand was used to hold test samples, which were molded from a 5½-inch-radius spherical section that was 1 inch high. At the 1-inch plane, the laminate changed to a flat plate, which was used to keep the test samples immobile in the tracks of the test stand.

An impactor of 11 pounds was raised to the indicated level above each sample and dropped. The impactor edge was a flat piece of hardened bar stock. On impact, it struck the sample at a 45° angle to the sample surface. The length of the tear in each sample is indicated in the following table:

Example	Laminate	Drop Height (ft.)	Sample Weight (g)	Tear Length (in.)
3	7K	6	77.0	2-3/4
4	6K	6	55.8	2-15/16+
5	5K	6	47.0*	3-1/16+
6	4K	6	44.3*	2-3/8+
7	3K,2S	6	45.5	1-7/8
8	4K,2S	6	61.7	1-1/4
9	2K,2S	6	41.9	3-1/4
10	3K,2N	6	62.0	0
11	3K,2N	6	47.3	0
12	2K,1N	5	36.7	**
13	1K,1N,1G	5	38.2	**
14	1K,2S,1G	5	34.8	**
15	1F,1N,1G	5	36.1	1-1/4
16	1F,1N,1G	5	33.4	1-3/4
17	1F,2S,1G	5	32.6	**
18	1F,1S,1G	5	23.7	**, 1-1/2
19	1F,1n,1G	5	29.0	**
20	7K	5	53.9	2-5/8+
21	4K	5	35.8	2-3/4+
22	5K,2S	not rec.	67.8	1-1/2
23	3K,1N	5	43.9	1-3/8
24	1F,2G,1N	5	41.1	< 1/8
25	1F,3K,1N	5	48.0	< 1/8

In the table: K = 348 KEVLAR (trademark) aramid fabric (E.I. du Pont de Nemours & Co.); S = SPECTRA 1000 (trademark) ultrahigh-molecular-weight polyethylene fabric (Allied Chemical Corp.); N = 14-oz./yd.^{2} ballistic nylon

(Gentex Corp.); G = G104 graphite fabric (Textile Technologies, Inc., Hatboro, Pa.); F = 120 fiberglass (Clark Schwebel Fiber Glass Corp., White Plains, N.Y.); n = 8-oz./-yd.^{2} ballistic nylon (Gentex Corp.); + = would have exceeded recorded tear length; * = weight without sheared tab; ** = sample bottomed against test stand. In each of Examples 7 to 19 and 22 to 25, the ballistic (S, N or n) layers were sandwiched between the other layers.

In general, laminates constructed in accordance with my invention (Examples 7 to 19 and 22 to 25) exhibited superior penetration resistance in comparison with conventional designs (Examples 3 to 6, 20 and 21) of comparable weight and thickness containing identical layers of structural fabric. Thus, a three-layer sample (Example 15) containing respective layers of fiberglass and graphite and a middle layer of nylon had a weight of 36.1 g and a tear length of 1-1/4 inches. A second three-layer sample (Example 16) containing similar materials had a weight of 33.4 g and a tear length of 1-3/4 inches. A four-layer sample (Example 24) containing successive layers of fiberglass, graphite, nylon and graphite had a weight of 41.1 g and a tear length of less than 1/8 inch. By contrast, a seven-layer laminate (Example 20) containing all aramid layers had a sample weight of 53.9 g and a tear length of greater than 2-5/8 inches.

It will be seen that I have accomplished the objects of my invention. My laminate is penetration-resistant and is sufficiently stiff to serve as a platform for mounting accessories. At the same time, it is lightweight and is reasonable in cost. Although the detailed description herein relates to helmet shells, it will be apparent that similar laminates could also be used in other applications requiring stiff, penetration-resistant materials. Such other applications include, for example, ballistic and structural aircraft panels, automotive gas tanks and automotive door panels.

It will be understood that certain features and subcombinations are of utility and may be employed without reference to other features and combinations. This is contemplated by and within the scope of my claims. It is further obvious that various changes may be made in details within the scope of my claims without departing from the spirit of my invention. It is, therefore, to be understood that my invention is not to be limited to the specific details shown and described.

Having thus described my invention, what I claim is:

CLAIMS

1. A penetration-resistant laminate comprising a resin matrix containing respective first and second layers of high-modulus fabric and an intermediate layer of ballistic fabric different from said first and second layers.

2. A laminate as in claim 1 in which each of said first and second layers comprises aramid, boron, fibreglass or graphite.

3. A laminate as in claim 1 in which said first and second layers comprise graphite.

4. A laminate as in any preceding claim in which said intermediate layer comprises nylon, polyolefin or polyester.

5. A laminate as in claim 1 in which said intermediate layer comprises nylon.

6. A laminate as in any preceding claim comprising an additional layer of high-modulus fabric on the other side of said first layer from said intermediate layer.

7. A laminate as in claims 6 in which said additional layer comprises fibreglass.

8. A laminate as in any preceding claim in which the individual fibres of said first and second layers have a Young's modulus of at least about 1,000,000 pounds per square inch.

9. A laminate as in any preceding claim in which the individual fibres of said intermediate layer have an energy-absorbing capability of at least about 16,000 foot-pounds per pound of fibre.

10. A laminate as in claim 1 in which said first layer comprises fibreglass or graphite, said second layer comprises graphite, and said intermediate layer comprises nylon.

11. A laminate as in claim 10 in which said first layer comprises fibreglass.

12. A laminate as in claim 10 in which said first layer comprise graphite.

13. A laminate as in claim 12 comprising an additional layer of fibreglass on the other side of said first layer from said intermediate year.

14. A laminate, substantially as hereinbefore described with reference to the accompanying drawings.

Patents Act 1977
Examiner's report to the Comptroller under Section 17 (The Search Report)

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9203569.0

Relevant Technical fields

(i) UK Cl (Edition K) B5N

(ii) Int Cl (Edition 5) B32B, F41M

Search Examiner
R J MIRAMS

Databases (see over)

(i) UK Patent Office

(ii) ONLINE DATABASES: WPI, CLAIMS

Date of Search
6 APRIL 1992

Documents considered relevant following a search in respect of claims 1 TO 14

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X	GB 2144973 A (FIGGIE) eg page 4 line 63 - page 6 line 1	1 to 3, 8,9,11, 12,13
X	GB 1569322 A (TIG BICORD) whole document	1,2
X	US 4287607 A (LEACH) eg figures 2 and 3	1,2,4,5, 6,8,9
X	US 3891996 A (LEACH) whole document	1,2,4 to 6,8 and 9

Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

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