United States Patent [19]
Saffadi

[11] 3,819,461
[45] June 25, 1974

[54] **UNIDIRECTIONAL, HIGH MODULUS KNITTED FABRICS**

[75] Inventor: **Richard R. Saffadi,** Ridgefield, N.J.

[73] Assignee: **J. P. Stevens & Co., Inc.,** New York, N.Y.

[22] Filed: **Oct. 8, 1971**

[21] Appl. No.: **187,674**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 851,408, Aug. 19, 1969, abandoned.

[52] **U.S. Cl.** **161/58,** 8/116.2, 66/193, 66/202, 161/89, 161/91, 161/182, 423/447, 423/448

[51] **Int. Cl.** **B32b 5/12**

[58] **Field of Search** .... 161/59, 57, 58, 89, 50, 161/91; 66/193, 202; 423/447, 448; 8/116 R, 116.2

[56] **References Cited**

UNITED STATES PATENTS

3,105,372	10/1963	Whitehead	66/193
3,235,323	2/1966	Peters	8/116.2
3,283,389	11/1966	Nisbet et al.	161/89
3,367,812	2/1968	Watts	423/447
3,462,340	8/1969	Hough	161/59
3,466,219	9/1969	Schwartz	161/57
3,484,183	12/1969	Dickson et al.	8/116 R
3,527,564	9/1970	Moore et al.	423/447
3,541,582	11/1970	Johnson et al.	423/447
3,556,712	1/1971	Yoneshige et al.	423/447
3,637,446	1/1972	Elliott	156/69

OTHER PUBLICATIONS

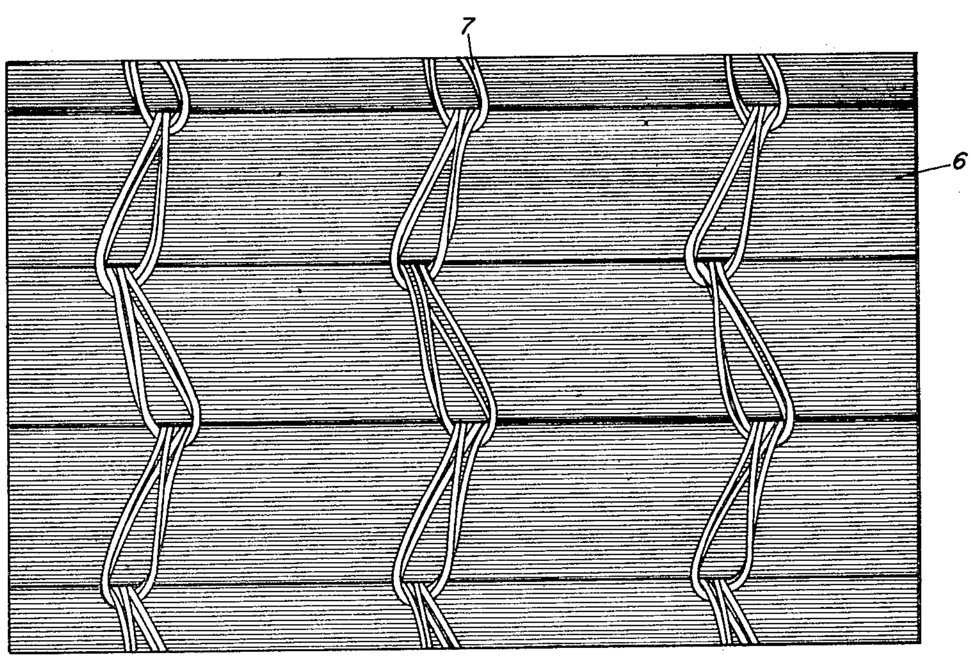
Webber, Modern Textiles Magazine, Vol. 47, 5/66, pp. 72–75.

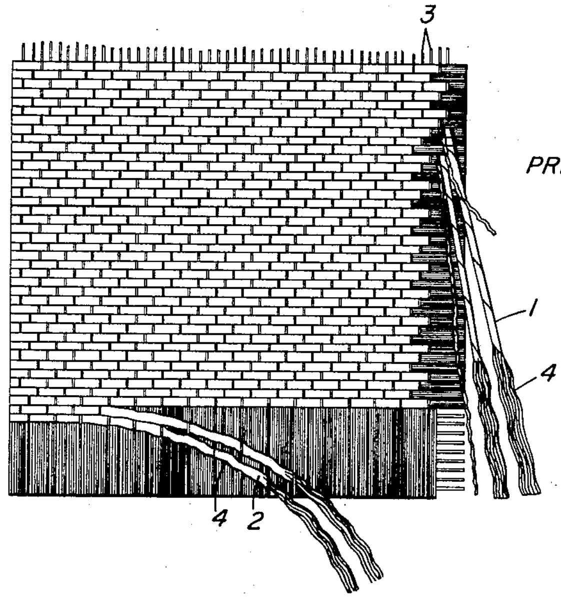
Primary Examiner—George F. Lesmes
Assistant Examiner—James J. Bell
Attorney, Agent, or Firm—Robert Ames Norton; Michael T. Frimer; Saul Leitner

[57] **ABSTRACT**

Unidirectional reinforcing fabric for resin laminates and the laminates including it, in which parallel yarns of fibers of very high modulus of elasticity, in excess of 8 million pounds per square inch, such as high modulus graphite yarn, with or without some glass fiber yarn, are maintained parallel and uncrimped by knitting them together using a fine, flexible knitting yarn. None of the knitting stitches penetrate any of the high modulus yarns. The wales are very widely spaced relative to high modulus yarn cross-section, in excess of two and one-half times with the coarsest material. The stitches are chain stitches, and the very brittle high modulus graphite is not bent or crimped and is maintained parallel by the chain stitches of fine, flexible knitting yarn.

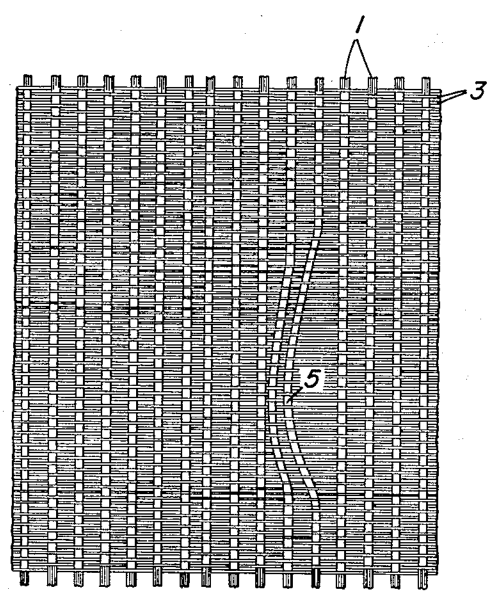
4 Claims, 6 Drawing Figures





PRIOR ART

FIG. 1



PRIOR ART

FIG. 2

INVENTOR.
RICHARD R. SAFFADI

BY Robert Ames Norton
ATTORNEY

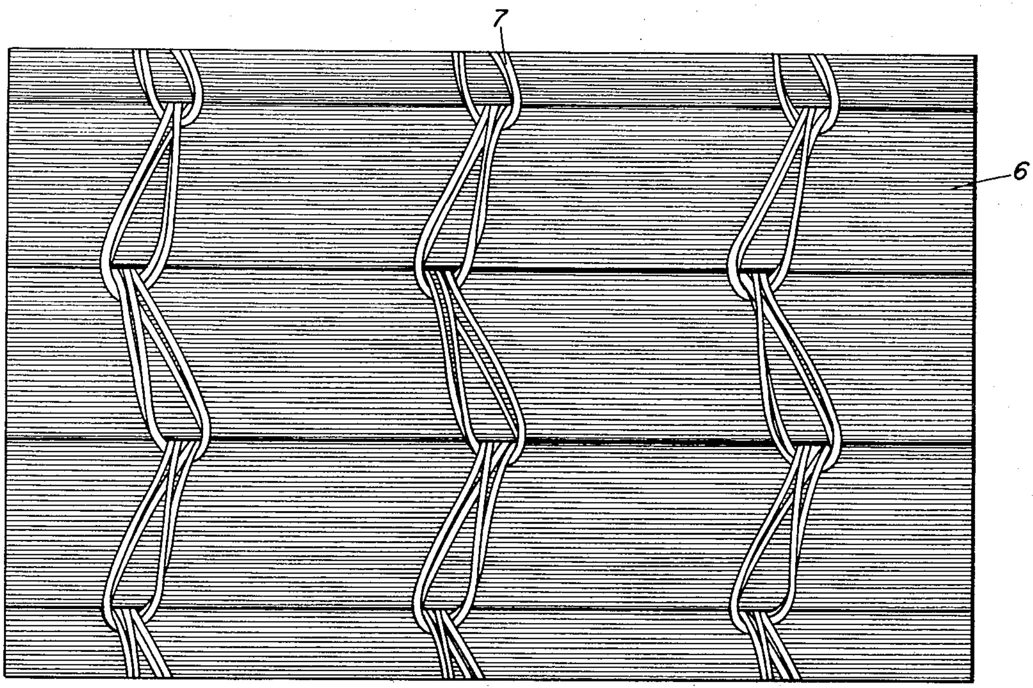


FIG. 3

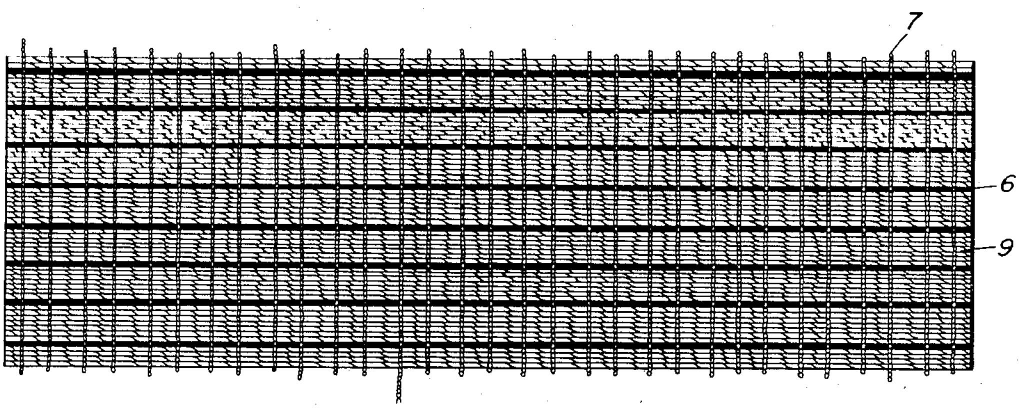


FIG. 4

INVENTOR.
RICHARD R. SAFFADI

BY Robert Ames Norton
ATTORNEY

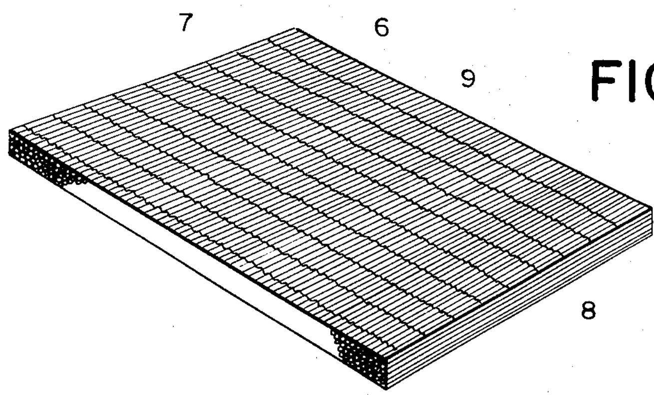
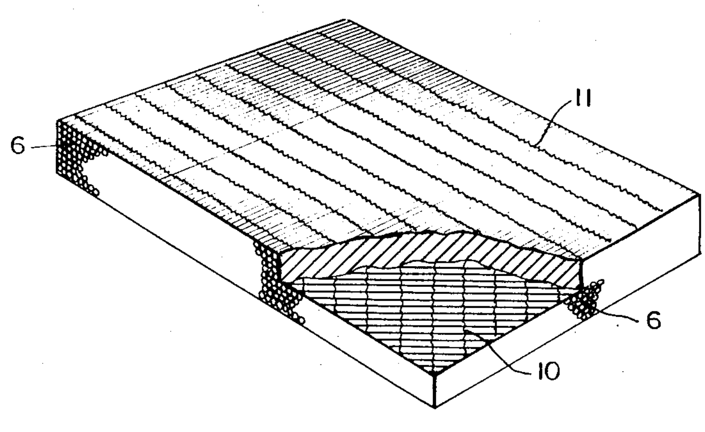


FIG. 5

FIG. 6



UNIDIRECTIONAL, HIGH MODULUS KNITTED FABRICS

RELATED APPLICATION

This application is a continuation-in-part of my copending application Ser. No. 851,408, filed Aug. 19, 1969, and now abandoned.

BACKGROUND OF THE INVENTION

Resin laminates have been reinforced with fibers and fabrics, especially glass fibers in the form of woven fabric, mats and the like. Glass fiber reinforced laminates have been extensively used as a covering for boats, molding of boat hulls and other articles. The glass fibers have a fairly high modulus of elasticity. Throughout the present specification the term "modulus of elasticity" will be used for Young's modulus, i.e., the stress required to produce unit strain. This is usually measured in pounds per square inch or dynes per square centimeter. For simplicity Young's modulus of elasticity will be briefly referred to as "modulus" throughout the present specification. This property should not be confused with tensile strength. For example, nylon fibers or filaments have an extraordinarily high tensile strength; their modulus, however, is very low, much less than a million pounds, because they stretch under stress. Certain other materials, such as certain elastomers, also have high tensile strength but negligible modulus. The best non-metallic high modulus fibers are those of high modulus graphite, produced by graphitizing highly crystalline stretched cellulosic fibers, such as rayon. Some of these have moduli in excess of 50 million pounds psi. However, they are extremely brittle. They are usually referred to in the art as high modulus graphite. It should be understood that they are a particular form of graphite. Many graphites have very low modulus of elasticity and are quite flexible and pliable.

In recent years, starting about a decade ago, a demand arose for reinforcing fabrics for laminates of very high modulus for turbine blades, helicopter rotors and the like where extremely high modulus in a single direction is essential. Even the strongest woven fabrics from glass fiber threads lose modulus because the threads cross over and under each other during weaving and are crimped or bent on a short radius. Even with fine glass fibers strength losses in the laminate of 25 percent and more may result.

An attempt was made to improve the strength of reinforcing fabrics by the weave, described in the Genin U.S. Pat. No. 2,893,442. This patent describes laying high modulus thread, such as glass fibers, across each other without crimping them as would be the case if the fabric were woven in the ordinary manner. The fabric was held together loosely by weaving with much thinner and more flexible yarn. Crimping of the glass threads was reduced, and the Genin fabric therefore represented an improvement, with less loss of modulus, but crimping was not eliminated as the binding warp and weft threads caused some crimp and so loss in strength still took place. It is impossible to weave even with flexible binding threads without producing some crimp, and the Genin fabric also paid a price for its reduced crimping by the fact that the threads can readily slide out from the binding threads, they are not woven over each other, and raveling at the edges can take

place. For some uses this is not a serious objection, for example in reinforcing fabrics for boat hulls and the like. Genin fabrics, of course, are bidirectional and so are the reinforced laminates produced therefrom.

As has been stated, high modulus graphite fibers have been produced with moduli of 50 million to 60 million pounds, whereas the maximum for glass does not exceed 15 million pounds. High modulus graphite threads are extremely brittle and cannot be woven practically as they break.

For certain important uses, such as airplane propellers, blades for jet engine fans or compressors, helicopter rotors and the like, laminates reinforced with unidirectional or substantially unidirectional, extremely high modulus materials are needed. For these purposes reinforcing fabrics with unbroken, substantially parallel, high modulus fibers are needed.

Excellent laminates have been prepared by laying on a flat surface parallel fibers or yarns of high modulus graphite. The surfaces can be quite long, and the exactly parallel bands or stripes of high modulus graphite yarn have to be laid by precisely controlled, very expensive machinery, which lays a stripe, then moves over and lays another stripe, until finally the desired width has been achieved. These parallel strands are yarns treated with a thermosetting resin, which is coated onto the yarn in liquid form. This resin is permitted to set slightly to the beginning of the "B" stage and is slightly tacky though not sticky or so soft that the yarns can be moved out or parallelism. The tapes of coated yarns are then refrigerated because they have to be kept quite cold to slow down the further setting of the resin, because if it once gets to the "C" stage the resulting tapes cannot be practically molded to form strong laminates. Even when kept refrigerated the tapes do not have an indefinite storage life, but can be kept for many months. Transportation of the refrigerated tapes also presents a serious problem because, of course, they must be transported in refrigerated containers or vehicles. This presents a further problem, involving both the expense of the carefully refrigerated transport and, what is much moree important, in case of an accident, if the temperature rises tapes are spoiled, and with the extremely high price of high modulus graphite this can result in a serious monetary loss. Of course the laminater receiving the tapes coated with the "B" stage resin must keep them refrigerated until they are molded or otherwise formed into the final laminates. Once a laminate, such as a blade for a jet engine fan or airplane propeller or helicopter rotor, has been molded and the resin transformed into the "C" stage, i.e., cured, the resulting products are of very high quality: the high modulus graphite yarns are not broken and adhesion is excellent. This result in a very high interlaminar shear strength, which is of course essential for final products of maximum strength. In other words, when resin preimpregnated high modulus graphite yarns or tapes are laid, the resulting product is of excellent quality, the only drawback being high cost of machines of extreme precision for laying the yarns parallel and the costs and problems of refrigerated storage and transportation together with the somewhat limited storage life under refrigeration, although this storage life is adequate for most uses.

For certain other forms, such as curved fan or propeller blanks, some problems arise. It is not practical to cut the tapes to exact form and it is difficult to produce blanks, such as those for propellers and certain fan blades, with taper in thickness and particularly if they are curved. Thus it is common to make up blanks of laminates which are somewhat squared off and in general cannot be readily produced in a feathered form to thin edges or ends. These blanks, which have excellent unidirectional strength in the direction of the high modulus graphite fibers, are then machined to the final precise curved form. The final product is of the highest quality, but the machining adds very substantially to the cost of the final product, both from the standpoint of the additional cost of the added machining step and also from the fact that if a blank is made which is thicker in some places than needed, the machining off of course uses up very expensive high modulus graphite. All in all the refrigerated "B" stage resin impregnated tapes can be used to produce final products of the highest quality, but only at a markedly increased cost. In the trade these tapes of high modulus graphite yarns coated or preimpregnated with thermosetting resin hich is subsequently slightly "B" staged are usually referred to as "prepregged" tapes. There thus remains a need for the same high quality material at lower costs and with still longer or substantially indefinite storage life.

The requirement for parallelism and straightness is an important one because sinuous curved yarns do not produce extremely high strength in laminates because under stress in the laminate the curved threads can stretch, and so, even though individual yarns or threads may have fairly high moduli of elasticity, for example glass fibers, the laminate itself is weak. Such fabrics with sinuous threads are described, for example, in the Nisbet et al. U.S. Pat. No. 3,256,130. Very beautiful fabrics can be produced, but for the special use of extreme high tension and high modulus in a particular direction, such fabrics are not of value as reinforcing fabrics.

It should be emphasized that the extremely high modulus material, such as high modulus graphite, is not necessarily of high modulus merely because of its chemical nature. Many graphites, in fact most, are soft, flexible and pliable and have very low modulus. Such fabrics are described in the Peters U.S. Pat. No. 3,235,323. Fabrics which are made by heat treating nitrogenous salt impregnated rayon have high melting points, are very pliable, and can be used for high temperature filters or, in the case of tapes made therefrom, fireproof tapes, which are useful for many purposes. The material is not a graphite as it contains large amounts of oxygen, the carbon content not exceeding about 61%. It has also been proposed to further carbonize these fabrics or fibers, and when this is done, electrically conductive materials are produced, but, as Peters states, they are not graphitized carbon and they are of low modulus through pliant, strong and very flexible. These products are not practically useful for the specialized reinforcements that require maximum laminate strength in a single direction as has been described above. They bear no relation to the extremely high modulus graphite produced from oriented crystalline fibers and they do not have extreme brittleness, which is, unfortunately, a characteristic of high modulus graphite.

SUMMARY OF THE INVENTION

The present invention produces unidirectional high modulus laminate reinforcing fabric of maximum modulus with substantially parallel fibers, for example of high modulus graphite fibers or yarns. It is possible to produce reinforcing fabric, not prepregged tapes, which can be made into laminates of as high quality. The fabrics have indefinite storage life in the unrefrigerated state and without risk or breakage of the high modulus graphite yarn or departure from parallelism, the importance of which has been brought out in the discussion of the background of the invention. Cost can be markedly lower as expensive machines for laying exactly parallel yarns are no longer needed, the cost of refrigeration, refrigerated transport, and the risk of losses if refrigeration breaks down are also eliminated. The present invention, therefore, permits the production of final laminate products of the highest quality at a very substantial saving in operations and in costs.

In the present invention the reinforcing fabric is produced by knitting on a warp knit knitting machine fabrics with insertion of wefts. The wefts are of high modulus graphite yarns which are held in exact parallelism by the knit stitches, which are preferably in the major amount chain stitches. The warps can be of soft textile yarns, such as nylon, polyester, cellulosics and the like, which are preferably of very much finer denier than the inserted high modulus graphite weft. The chain knit stitches surround the high modulus graphite yarn inserted weft without crimping or otherwise bending the yarns to the point where breakage can occasionally occur. The resulting fabric, of course, has an indefinite storage life in a completely unrefrigerated state. Transportation problems are eliminated and the cost of final laminate products is markedly reduced and number of operations from raw material to final product also reduced, without reducing quality of final laminate.

The wales of stitches must be spaced quite widely so that relatively long spaces of unknit fabrics are present so that finally when resin laminates are formed there is a large surface extent of the high modulus graphite in contact with the thermosetting resin and in contact with graphite yarn surfaces of the other fabric layers to form the final laminate. This requires certain minimum spacings which can best be expressed in terms of spacing of wales as compared to high modulus graphite inserted weft yarns cross-section. Even for the coarsest inserted high modulus grahite weft yarn, for example one which may contain as many as 10,000 graphite fibers, the ratio of spacing to cross-section should be at least about 2.5, and in such a case the wales are spaced about four to the inch of weft length. While the absolute spacing lower limit is not critical, it should not be much less than one-quarter inch regardless of the cross-section of the inserted high modulus graphite weft yarns. There is no theoretical upper limit on wale spacing as far as resin adhesion and hence interlaminar shear strength of the final laminate is concerned. The upper limit is dictated only by the fact that there must be wales sufficiently near together so that the fabric produced does not permit significant departure of parallelism of the high modulus graphite yarns. This practical upper limit is not at all critical, which is an advantage of the present invention. The minimum relative spacing of wales to cross-section of high modulus graphite inserted wefts occurs with the coarsest wefts. With finer wefts the ratio may be four, eight, or considerably more times the cross-section of the inserted wefts.

At this point a very brief discussion of desirable properties of high unidirectional strength and modulus laminates is appropriate. The principal field of use is in rapidly rotating elements, such as air compressor blades in jet engines, airplane propellers, helicopter rotors and the like. The stresses to which these final products are put depend on their density, and so modulus and tensile strength alone are not the ultimate measure. Specific tensile strength and specific modulus, i.e., tensile strength or modulus divided by density, are the important factors. This can be well brought out for as a number of materials in the following table, which compares two well known types of high modulus and high strength graphite with other materials. Type 1 is maximum modulus with good ultimate tensile strength and Type 2 maximum ultimate tensile strength with adequate modulus. The comparisons appear in the following Table 1, in which both tensile strength and Young's modulus are expressed in millions of psi.

TABLE 1

Material	Specific Modulus in × 10^6	Specific Tensile Strength in × 10^6	Density lbs per in^3	Young's Modulus lbs per in^2× 10^4	Ultimate Tensile Strength lbs per in^2× 10^3
Graphite					
Type I High Modulus	760–900	2.8–4.1	0.072	55–65	200–300
Type II High Strength	560–710	5.6–7.1	0.063	35–45	350–450
Steel (drawn wire)	104	1.4–2.1	0.280	30	400–600
E-Glass	104	2.7	0.092	10	250
S-Glass	104	5.5	0.092	10	500
Boron	530	5.3	0.095	50	500
Aluminum	102	0.72	0.097	10	70
Beryllium	470	2.3	0.066	45	150

Note:
1. Specific modulus is defined as: Young's Modulus/Density
2. Aluminum and beryllium figures are for massive material
3. Gauge length for tests on Morganite Fibre - 5cm.

It will be noted that the higher specific modulus is obtained with the high modulus graphites, the only other material even approaching them being boron. Specific modulus is much higher than either steel, glass or aluminum; and even in the case of beryllium, which has a fairly high specific modulus, the specific tensile strength is considerably lower. Most of the metals show very poor adhesion to the laminating resins, whereas graphite has a high adhesion. Glass can be coated to produce a fair adhesion, but still not as good as graphite. However, glass when properly coated can be used, particularly in small quantities in admixture with inserted high modulus graphite wefts, and for certain products where the ultimate in strength and modulus is not required such mixtures are included within the broader aspects of the present invention. Where the ultimate properties of the final laminates do not require the maximum, some admixture of glass fibers has an advantage in markedly lowering the cost because the cost of glass fibers is insignificant compared to that of high modulus graphite.

If a fabric is prepared by knitting with most of the wales knit with a lock stitch, i.e. warps crossing from wale to wale, adhesion of the resin in the final laminate suffers because the area of contact with the graphite is reduced and, particularly when final curing of the resin results in decomposition of certain warp yarns, significantly lowered adhesion and hence interlaminate shear strength results. A high interlaminar shear strength is necessary because the final laminates are made up of a large number of lamina and these lamina should not slide one over the other. Preferably all or substantially all of the wales should be of chain stitches. However, an occasional pair of wales may be formed with occasional lock stitches without seriously compromising interlaminar shear strength. The vast majority of the wales, however, should be chain stitched as significant deterioration in interlaminar strength results if more than 20% lock stitch wales are present. As chain stitch knitting is at least as conomical or more economical than lock stitch knitting, there is no economic reason for departing significantly from the preferred all chain stitch form of fabric. As has been pointed out above, compatibility of metals, such as steel, with laminating resin is so poor that steel reinforced laminates are practically useless even though their combination of specific modulus and specific tensile strength is not greatly inferior to some glasses.

Another advantageous property of laminates reinforced with fabric of the present invention is that for equal weight they show superior beam stiffness. In other words, it reduces the weight of the final part when compared to the weight of a part manufactured from a metal to produce equivalent specific modulus and/or specific strength as that of the high modulus graphite laminate. This, of course, is a very desirable characteristic and can be of great importance in the case of airplane structures, propeller and helicopter rotors, and of course can also reduce vibration in high speed rotating compressor blades.

Another advantage of the reinforcing fabrics of the present invention is that it is possible to cut or stamp out desired shapes of the fabric before lamination. This is of importance where curved or compound shapes of final products, such as an airplane propeller or fan blade, are desired. The wastage of expensive high modulus graphite is less than if thicker block laminates have to be shaped by machining, and of course the higher costs of machining are eliminated. This is another instance where the present invention permits producing high quality products with reduction in required operations for producing the final product.

It is an advantage of the present invention that the strength of the reinforcing fabric is for all practical purposes independent of the strength of the relatively fine denier warp yarns and the wide spacing of chain knit wales. Essentially the knitting is only for the purpose of holding the high modulus graphite wefts parallel during lamination. After resin preimpregnation and once the resin has begun to set, the knitted wales could decompose completely without any significant effect on the strength of the final laminate. Thus warps may be of materials which are destroyed or seriously weakened at the temperature of final lamination.

The important distinction between modulus of elasticity and tensile strength is another facet of the problem of adhesion discussed above. Even if there is good adhesion, if reinforcing fibers, no matter how high their tensile strength, have a low modulus of elasticity, under extreme stress they stretch, but the resins do not and so there is a tendency for the resins to break loose from their reinforcing material. The high modulus material, however, does not stretch and therefore makes for greater overall laminate strength. The difference between tensile strength and modulus can be clearly brought out by considering the Whitehead U.S. Pat. No. 3,105,372. This patent deals with body armor, in which nylon threads, or in some cases high tenacity rayon threads, are knitted on a warp knit machine. The nylon threads, although of great tensile strength, have low modulus of elasticity. This is, of course, exactly what Whitehead wanted. The function of a body armor is to absorb the energy of a bullet. This requires that the fabric give, so that the bullet is slowed down over a finite distance. For this purpose nylon is ideal. It is very strong, it stretches, i.e., it is elastic but has a low modulus, and the bullet, therefore, is slowed up and in many cases will not continue its path. High modulus graphite is exactly the opposite. If it were attempted to make a body armor, it is so brittle that it would break and be of little use. It is of interest to note that the Whitehead patent has knitted stitches which go through the nylon and it is also knit with lock stitches. All of these increase the strength for a reasonable stretch when a bullet hits. In propellers or turbine blades, however, these characteristics result quickly in failure. Any penetration of the high modulus graphite weft by the knitted stitch, and of course the needle forming it, results in breaking the graphite yarn.

While the present invention produces fabrics which have enormous modulus in a single direction, and this is the vital matter for the laminates which have to primarily resist great forces in a single direction, such as high centrifugal forces, it is sometimes desirable to have multiple laminates in which the reinforcing fabrics, while having their high modulus threads parallel in any particular layer, may be at a small angle, for example up to as much as 30% from one reinforcing layer to another. This gives somewhat increased shear strength without significantly reducing the primary strength in the single direction, and such laminates are included in the present invention.

In general the present invention does not change laminating procedure in any significant manner and only a very general and typical lamination will be described in the more specific description which follows. The particular laminating technique used, therefore, is not the distinguishing feature of the present invention, which is an advantage because well known techniques can be used.

The nature of the laminating resin is also not changed by the present invention and any of the well known resins, such as alkyds, epoxies and the like, may be used. Where an all high modulus graphite reinforcing fabric is used, it is often desirable to protect it during shipment and so a suitable backing sheet of polyethylene or the like may be employed. The fabric, of course, should not be wound on packages with too small a radius and care should be taken in laying it up for laminating as the fabric is much more brittle than fabrics made of glass fiber yarns.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a plan view of a typical Genin fabric of the prior art with some of the glass fiber yarns at the edge unraveled;

FIG. 2 is a plan view of a modification not described by Genin in which glass fiber yarns are used in one direction only;

FIG. 3 is a plan view of a fabric according to the present invention made of high modulus graphite and enormously magnified to show the knitted stitching;

FIG. 4 is a plan view, unmagnified, of a mixed high modulus graphite, glass fiber fabric;

FIG. 5 is an isometric of a laminate using a fabric of FIGS. 3 or 4, and

FIG. 6 is an isometric of a laminate using fabrics in which one layer has the inserted wefts at an angle to the other.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 shows a typical glass fiber fabric according to the Genin patent. The glass fiber threads are shown at (1) and (2) crossing each other but not woven over each other, and thin binding yarn is shown at (3) weaving together the glass fiber yarns. As can be seen at the edge where several yarns are shown raveled off, the edges are quite unstable and tend to ravel easily, which is a serious problem in forming laminates of material for uses such as propellers, rotors, fan blades, and the like where edge stability is of major importance. Also, at the point where the yarns have been raveled off, the glass fiber yarns show areas (4) where they have been crimped to some degree by the binding yarns (3). As has been stated above, the Genin fabric represented an improvement, even though crimping is not entirely eliminated.

If it is attempted to make a woven fabric which is unidirectional, as is shown in FIG. 2 with the glass fiber yarns (1) and the binding yarns (3), the glass fiber yarns are not held rigidly in parallel alignment as they can slide along the woven binding threads. This is shown in somewhat exaggerated form in the case of the glass fiber yarn (5). Unless extraordinary care is taken, some of these yarns will depart from parallelism, with loss of strength in the final laminate because under tension the distorted yarn straightens out, as has been described above. Of course even with a unidirectional woven fabric the problems of edge raveling remain and so does the small amount of crimping from the binding yarns which have been described above in connection with FIG. 1.

FIG. 3 shows in a greatly magnified form a fabric according to the present invention with high modulus graphite yarns (6) held together with chain stitches knit of a yarn (7) on a warp knitting machine. It will be seen that the high modulus graphite yarns are held in exact parallelism firmly but gently since the stitches of much lighter, soft thread surround them and do not crimp them at all. Such a fabric, and of course a laminate made from it as a reinforcing fabric, utilizes the maximum modulus and tensile strength of the high modulus graphite yarns. It will also be apparent that since the stitches hold the yarns together, there can be no raveling at an edge, and this problem, which is a serious one with a woven fabric if it is to be used for propeller blade laminates or the like, does not occur. In other words, the great advantage of elimination of crimping is obtained without any offsetting disadvantages and, in fact, with a greatly improved edge effect which does not ravel.

FIG. **3** represents the preferred modification with no lock stitched wales at all and shows very thick threads of high modulus graphite, for example up to about 10,000 individual graphite filaments. It therefore represents one extreme, but even here the wales are spaced slightly over three times the cross-section of the high modulus graphite threads.

Because of the markedly higher cost of the high modulus graphite as compared to glass fibers, it is often desirable, where the absolute maximum of laminate tensile strength is not needed, to use a mixture of high modulus graphite and glass fiber, and this is shown in FIG. **4,** the glass fiber yarns being shown at (**9**) whereas the high modulus graphite yarns bear the same number, (**6**), as in FIG. **3.** FIG. **4** illustrates very much finer laid-in wefts and hence the ratio of the spacing of the wale is considerably greater, approximating eight times the cross-section of the high modulus yarn. This is not the limit for with even finer high modulus yarns and somewhat greater wale spacing, usable fabrics may have a ratio of wale spacing to cross-section of high modulus fibers as high as 80 or 100 times.

FIG. **5** illustrates, in isometric form, laminates of a fabric such as that of FIG. **3** or FIG. **4,** the resin, such as epoxides, alkyds, etc., being shown at (**8**). The isometric view permits showing one edge of the laminate substantially in section, illustrating the ends of the high modulus yarns. FIG. **5** illustrates a laminate in which all of the high modulus yarns are in the same direction. FIG. **6** shows a two-layer laminate and is partly broken away at an edge, the bottom layer (**10**) shows the high modulus yarns (**6**) in one direction and the second layer (**11**) shows the high modulus yarns (**6**) at a slight angle, about 30°, which produces a laminate which has some strength in a direction at an angle to the high modulus yarns of the first layer. This improves the resistance to shear in propeller or fan blades.

FIG. **5** is a sample of laminate and not a portion of a propeller or compressor fan blade. The reinforcing fabric is shown in one direction only, whereas, as has been pointed out above, often in the case of a propeller or a fan blade there may be more than one layer of reinforcing fabric at an angle, such as 20° to 30°. In FIG. **5** this would only confuse the drawing and so an additional layer at an angle is not shown.

While the present invention does not change the procedure of lamination, the following brief description of a typical process is given:

Twelve layers of the resin preimpregnated fabric of the present invention, (resin used was a dispersion of high performance cycloaliphatic epoxy resin), were placed into a press and cured, using a standard curing cycle, until the resin had completely set. Two samples were made, one with the epoxy resin sold by Union Carbide Company under their designation ERLA-4617 and another with a similar resin sold by the Shell Company under their designation EPON-826. The fabrics were knit with fine soft nylon with chain stitched wales four to the inch, the high modulus graphite in both cases having 780 filaments. The resulting laminates were then tested and compared to the same high modulus grahite yarn in a laminate form produced by a filament winding of the prepregged graphite yarn, prepregged with the same resin, the number of laminae being the same. Results of these tests are shown in Table 2:

TABLE 2

MECHANICAL PROPERTIES	PREPREGGED FABRIC OF INVENTION RESIN EPON-826			PREPREGGED FABRIC OF INVENTION RESIN ERLA-4617			PREPREGGED YARN FILAMENT WOUND ON TWO SIDED MOLD RESIN ERLA-4617		
	Range	Ave.	No. Tests	Range	Ave.	No. Tests	Range	Ave.	No. Tests
Flexural Modulus × 10⁶ psi	24.7–28.0	26.4	5	27.2–30.2	28.9	8	27.2–31.8	29.6	12
Interlaminar Shear Strength × 1000 psi	9.3–9.9	9.6	5	7.4–9.7	8.8	16	6.5–10.7	9.1	12
Volume Fractions %	Not Determined			57–62	60	4	50–63	57	12

It will be noted that the interlaminar shear strength is comparable in each case but with a somewhat closer range for the laminates produced with fabrics of the present invention. This is a small but not insignificant advantage as it shows a greate uniformity of properties. In other words, products with as good flexural modulus and interlaminar shear strength are obtained with all of the advantages, economic and operational, of the present invention which have been set out above.

In the tests for interlaminar shear strength set out above the graphite yarns were all in the same direction. When products according to FIG. **6** are produced the layers, of course, are not parallel, although the fibers in each layer are.

Another method of lamination which is usable with the reinforcing fabrics of the present invention is to place a resin film in a mold, then a layer of fabric, then one or more layers of resin film, another layer of fabric, and so on. This method produces final laminates of the same excellent physical properties as when layers of prepregged fabric are used as is described above. As an example, the Bloomingdale Epoxy Resin film B.P. 907 has been used successfully to manufacture laminates described in this paragraph.

I claim:

1. A reinforcing fabric suitable for laminates formed of parallel, continuous filaments yarns of high modulus graphite, the modulus of elasticity thereof, of more than 8,000,000 lbs. per square inch, the graphite being extremely brittle, the yarns being bound together with chain stitch knit wales which surround the outside of the continuous filament parallel yarns, the parallel yarns being held firmly by the knit stitches and maintained thereby in strict parallelism, wale spacing being at least about three times parallel filament yarns' cross-sectional diameter in same units and the majority of the wales being chain stitch.

2. A fabric-reinforced resin laminate, the resin having bonding affinity for high modulus graphite, and the laminate being for articles requiring high tensile strength primarily in one direction only in which the reinforcement is a fabric according to claim **1.**

3. A multi-layer resin laminate according to claim **2** in which at least one layer has its yarns of high modulus graphite at a small angle to those of another layer.

4. A resin laminate according to claim **2** in which the small angle is from 20° to 30°.

* * * * *