The instant invention involves a process used in preparing fibrous tows which may be formed into polymeric plastic composites. The process involves the steps of (a) forming a tow of strong filamentary materials; (b) forming a thermoplastic polymeric fiber; (c) intermixing the two tows; and (d) withdrawing the intermixed tow for further use.
METHOD OF FORMING COMPOSITE FIBER BLENDS AND MOLDING SAME

This invention relates to processes for preparing fibers useful in forming composite articles. Particularly, this invention relates to fiber blends containing strong reinforcing fibers which are useful in preparing composite articles.

Fiber-reinforced products have been known for several years. See, for example, U.S. Pat. Nos. 3,914,499, 3,969,171 and 4,214,931, as well as U.S. Pat. No. 4,341,835.

Also, it is known to intermix two similar or different types of fibers, particularly to obtain high bulk. See, for example, U.S. Pat. Nos. 4,219,997, 4,218,869, 3,959,962, 3,968,638, and 3,958,310. And the combining of different types of fibers has been facilitated using various types of fluid jets. See, e.g., the '310 patent and U.S. Pat. No. 4,147,020. However, in the '020 patent, after combining the yarns are cut into short lengths.

U.S. Pat. No. 4,226,079, issued Oct. 7, 1980, discloses the combining of two different types of fibers, in order to produce a bulk yarn. The fibers are intermixed in a jet intermixing zone. However, the fibers disclosed in the patent are polyester and polyamid. No disclosure is made in the combining of carbon and thermoplastic fibers.

U.S. Pat. No. 3,175,351 discloses a method of bulking continuous filament yarns. In addition, it is disclosed that the two yarns which are combined may be of different compositions. However, none of the compositions is a carbon fiber.

U.S. Pat. No. 3,859,158 discloses the preparation of carbon fiber reinforced composite articles by forming an open weave of a carbon fiber and coating with a carbonaceous material. U.S. Pat. No. 4,368,234 discloses complex woven materials used for reinforcement which are formed from alternating bands of graphite fibers and low modulus fibers. However, the woven materials disclosed in this patent are subsequently impregnated with a thermosetting resin and cured. Commonly assigned U.S. patent application Ser. No. 368,491 to Buckley and McMahon, discloses an improved woven fabric comprised of fusible and infusible fibers wherein the infusible fibers include graphite or carbon fibers, and the fusible fibers are thermoplastic in nature. According to the patent application, fusible and infusible fibers are woven into a fabric and thermally bonded together by heating above the melting point of the fusible fiber. This patent application does not disclose, however, the preparation of linearly intermixed yarn tow products or that such products are useful in forming composite articles. The patent application also does not disclose the preparation of such materials using a gas jet intermixing means.

In the prior art, there were two distinct methods of forming fiber-reinforced composites. The first and older method involved simply forming a tape or fabric prepreg by painting or coating reinforcing fiber tows or fabric with a solution and/or low viscosity melt of a thermosetting material which was then cured. The second process involved the extrusion of reinforcing fiber tapes impregnated with high melting, thermoplastic polymers. These tapes or fabrics were then used in forming the composite. However, the prepreg formed by both of these processes were somewhat difficult to handle. Specifically, prior art thermoplastic tapes were stiff and "boardy" and could not be draped across intricately shaped molds. While thermoset prepregs were somewhat more flexible, they were often quite tacky and difficult to handle. As a result, the use of both types of tapes was limited.

Accordingly, it is an object of this invention to prepare flurable blends which are useful in forming fiber-reinforced composites.

It is another object of this invention to prepare materials, e.g., fabrics, which may be formed into composites.

These and other objectives are obtained by employing the process of the instant invention.

SUMMARY OF INVENTION

Basically, the process of this invention involves (a) forming a fiber tow from a multitude of strong filamentary reinforcement materials; (b) forming a thermoplastic polymeric fiber tow; (c) intermixing the two tows; and (d) withdrawing the intermixed tows for use. The filamentary reinforcing material is preferably non-thermoset.

The intermixed tows may then be employed in forming various fiber-reinforced composites.

The fiber blends prepared according to the instant invention are flexible and handleable and have good draping properties, so that they can be used to form intricately shaped articles. In addition, because of the intermixing of the two fibers, good wetting of the reinforcing fiber by the thermoplastic material is obtained when appropriate heat and pressure are applied to the mold. Good wetting is obtained in large measure because of the substantially uniform distribution of the thermoplastic fiber and the reinforcing fiber within the fiber blend. Specifically, the products of the instant invention find particular utility in end-use applications where a small radius of curvature in the final product is desired. For example, using the prior art tapes, it was not possible in many instances to prepare articles which had 90° bend, because the tapes would crack or deform at the bend line. However, the processes of the instant invention may be employed with radii of curvature as low as 0.002 in.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagramatic view of the various devices used in carrying out one of the processes of the instant invention.

FIG. 2 is a diagramatic view of the various devices used in carrying out another version of the processes of the instant invention.

FIG. 3 is a perspective view of the gas spreading means used in carrying out a part of the process of the instant invention.

FIG. 4 is a perspective view of the same device with the top removed.

DETAILED DESCRIPTION OF INVENTION

The thermoplastic polymers which are useful in carrying out the instant invention constitute virtually any type of relatively high molecular weight thermoplastic.
polymer, including polyethylene, polypropylene, poly-
ester, the various polyamides, polymides, polyamidi-
mides, polyetherimides, polysulfones (e.g., polyether
sulfones), polyether ketones, polyethylene tere-
thalate and the like. The melting point of the polymer
must be at least 50° F. and preferably at least 200° F.
above ambient conditions. Higher melting temperatures
insure that there will be no undue sticking or binding of
the spun fibers prior to use. In addition to one com-
ponent polymer systems, mixtures of various thermo-
plastic polymers may also be employed to advantage
where specific combinations of properties are desired.

Of particular importance are the liquid crystal poly-
mers or LCP’s. Examples of these polymers include the
wholly aromatic polyester resins which are discussed in
the following publications: (a) Polymers of Hydroxyben-
zoic Acids, by Russell Gilkey and John R. Caldwell, J. of
Applied Polymer Sci., Vol. II, Pages 198 to 202 (1959);
(b) Polyarylates (Polymers From Aromatic Dicarboxylic
Acids and Bisphenols), by G. Bier, Polymer, Vol. 15,
Pages 527 to 535 (August 1974); (c) Aromatic Polyester
Plastics, by S. G. Cottis, Modern Plastics, Pages 62 to 65
(July 1975); and (d) Poly(o-Xylenyl Systems): Homo-
opolymer for Coatings: Copolymers for Compression and
Injection Molding, by Roger S. Storm and Steven G.
Cottis, Coatings Plast. Preprint, Vol. 34, No. 1, Pages
194 to 197 (April 1974). See also, U.S. Pat. Nos.
3,039,994; 3,169,121; 3,231,437; 3,553,167; 3,657,595;
3,651,014; 3,723,388; 3,759,870; 3,767,621; 3,778,410;
3,787,370; 3,790,528; 3,829,406; 3,890,256; 3,975,487.

Other polymers are disclosed, for instance, in (a)
Polyester X7GOA Self Reinforced Thermoplastic, by
W. J. Jackson, Jr., H. F. Kuhfuss, and T. F. Gray, Jr.,
30th Anniversary Technical Conference, 1975 Rein-
forced Plastics/Composites Institute, The Society of
the Plastics Industry, Inc., Section 17-D, Pages 1 to 4;
(b) Belgian Pat. Nos. 838,935 and 828,936; (c) Dutch
Pat. No. 750551; (d) West German Pat. Nos. 2520819;
2520820; 2722120; 2834535; 2834536 and 2834537; (e)
Japanese Pat. Nos. 43-223; 2132-116; and 3021-293; and
(f) U.S. Pat. Nos. 3,991,083; 4,991,014; 4,057,597;
4,066,620; 4,067,852; 4,075,262; 4,083,829; 4,093,595;
4,112,212; 4,118,372; 4,130,545; 4,130,702; 4,146,702;
4,153,779; 4,156,070; 4,159,365; 4,160,755; 4,161,470;
4,169,933; 4,181,792; 4,183,895; 4,184,996; 4,188,476;
4,191,681; 4,201,856; 4,219,461; 4,224,433; 4,226,970;
4,230,817; 4,232,143; 4,238,589; 4,236,600; 4,239,913;
4,242,496; 4,245,082; 4,245,804; 4,247,514; 4,256,624;
4,265,802; 4,267,289; 4,269,965; 4,279,803; and 4,299,756.

The polymers and copolymers which are preferred
consist essentially of structural units having recurring
groups of the formula

(I) \( \text{O} \rightarrow R_1 \rightarrow \text{O} + \) and

(II) \( \text{OC} \rightarrow R_2 \rightarrow \text{CO} \) and/or

(III) \( \text{O} \rightarrow R_3 \rightarrow \text{O} \)

wherein units I and II, if present, are present in sub-
tantially equimolar amounts; R1, R2 and R3 are radicals
selected from the group of (1) single and fused six-mem-
bered aromatic carboxylic ring systems wherein the
chain-extending bonds of the ring system if attached to
the same ring, are positioned 1,3- or 1,4- (preferably
1,4-) to each other, and if attached to different rings,
are preferably in positions parallel and oppositely directed,
and (2) multiple six-membered aromatic carboxylic
ring systems in which the individual rings are joined by
a chemical bond or a trans-vinylene group and in which
the chain extending bonds of each ring are in the 1,3- or
1,4- (preferably 1,4-) positions; R2 may also be

\[
\text{H} \quad \text{H} \\
\text{C} = \text{C} \\
\text{A} \\
\text{or} \\
\text{A}
\]

wherein A is a divalent radical containing one or two
bicyclic in-chain atoms; and R3 may also be

\[
\text{H} \quad \text{H} \\
\text{C} = \text{C} \\
\text{C} = \text{C} \\
\text{H} \\
\text{H} \\
\text{H}
\]

wherein the aliphatic portion is attached to the carboxyl
group. Preferred group (1) radicals are phenylene and
Preferred group (2) radicals are two-ring systems. Illustra-
tive of (1) are

\[
\text{H} \quad \text{H} \\
\text{C} = \text{C} \\
\text{C} = \text{C} \\
\text{H} \\
\text{H} \\
\text{H}
\]

and of (2) are

\[
\text{H} \quad \text{H} \\
\text{C} = \text{C} \\
\text{C} = \text{C} \\
\text{H} \\
\text{H} \\
\text{H}
\]

The foregoing ring systems, except for R2 as indicated
below, are also intended to include one or more substi-
tuents, e.g., chloro, bromo, fluoro, or lower alkyl (1-4
carbon atoms) on the ring or rings. The R2 aromatic
ring systems should preferably be unsubstituted when
only one kind of unit I and one kind of unit II are used,
except, when a homopolymer is formed to insure obtaining
oriented fibers. In the case of copolymers, it is preferred
that the R2 aromatic ring systems be unsubstituted be-
cause of thermal or hydrolytic instability and/or cost of
the R2-ring substituted copolymers.

Also included are those (co)polymers wherein up to
25 mol %, preferably up to 5 mol %, based on the total
I, II and III units, are aromatic polymer-forming units
(i.e., units wherein the chain extending functional
groups are attached to aromatic rings) not conforming
to those described above and which do not interfere
with the anisotropic melt forming capability of the poly-
mers. A non-limiting list of these units includes

\[
\text{H} \quad \text{H} \\
\text{C} = \text{C} \\
\text{C} = \text{C} \\
\text{H} \\
\text{H} \\
\text{H}
\]
The (co)polyesters, as mentioned above, may comprise units I and II in substantially equimolar amounts or may comprise unit III or may comprise a combination of units I, II, and III and, of course, more than one kind of unit (I, II and/or III) can be present in the polymer.

Preferred (co)polyesters of the invention consist essentially of units I and II. In such polymers, it is preferred that R₁ is selected from the group of 1,4-phenylene; chloro-, dichloro-, bromo-, dibromo-, methyl-, dimethyl- and fluoro-1,4-phenylene; 4,4'-biphenylene; 3,3',5,5'-tetramethyl-4,4'-biphenylene and R₂ is selected from the group of trans-1,4-cyclohexylene; trans-2,5-dimethyl-1,4-cyclohexylene; trans-vinylenebis(1,4-phenylene); 4,4'-biphenylene; 2,6-naphthylene; and 1,4-phenylene and with the proviso that more than one kind of unit I or II are present. Of such copolyesters, two types are particularly preferred because of properties and cost. In the first type, the polymers consist of essentially of the recurring units

wherein X is selected from the group of chloro-, bromo-, fluoro-, and methyl radicals; n is 1 or 2; and Y is selected from the group of 4,4'-biphenylene and 2,6-naphthylene, the ratio of units being within the range of 4:1 to 1:4. In the second type, the polymers consist essentially of the recurring units

wherein Z is selected from the group of 4,4'-biphenylene, 2,6-naphthylene, and 1,4-phenylene, the ratio of units being within the range of 4:1 to 3:2. With each type of polymer, up to 25 mol percent of non-conforming units may be present as described above.

A list of useful dicarboxylic acids includes terephthalic acid, 4,4'-bibenzoic acid, 4,4'-oxydibenzoic acid, 4,4'-thiodibenzoic acid, 4-carboxyphenoxyacetic acid, 4,4'-trans-tlbenedicarboxylic acid, 2,6-naphthalenedicarboxylic acid, ethylenedioxy-4,4'-dibenzoic acid, isophthalic acid, the halogen and methyl substituted derivatives of the foregoing dicarboxylic acids, 1,4-trans-cyclohexanedicarboxylic acid, 2,5-dimethyl-1,4-trans-cyclohexanedicarboxylic acid, and the like.

A nonlimiting list of phenolic carboxylic acids includes 6-hydroxy-2-naphthoic acid, 4-hydroxy-4'-carboxy azobenzene, ferulic acid, 4-hydroxybenzoic acid, 4-(4'-hydroxyphenoxy)benzoic acid and 4-hydroxycinamic acid and the alkyl, alkoxy and halogen substituted versions of these compounds.

Of the (co)polyesters containing only type III units, the polymers consisting essentially of the recurring units

are preferred.

The (co)polyesters are prepared preferably by melt polycondensation of derivatives of dihydric phenols and aromatic-aliphatic, aromatic and cycloaliphatic dicarboxylic acids or their derivatives. A convenient preparative method is the melt polycondensation of the diacetate of a dihydric phenol with a dicarboxylic acid. Alternatively, phenolic carboxylic acids or their derivatives may be used as coreactants in the preparation of polyesters and copolyesters.
A list of useful dihydric phenols, preferably in the form of their diacetate derivatives includes hydroquinone, chlorohydroquinone, bromohydroquinone, methylhydroquinone, dimethylhydroquinone, dichlorohydroquinone, dibromohydroquinone, 4,4'-oxydiphenol, 4,4'-isopropylidendiphenol, 4,4'-thiodiphenol, 4,4' -biphenol, 3,5,3',5'-tetramethyl-4,4'-biphenol, 3,5,3',5'-tetrachloro-4,4'-biphenol, 2,6-dihydroxynaphthalene, 2,7-dihydroxynaphthalene, and 4,4'-methyleneedianilinophenol and the like.

In addition, it is possible to prepare anisotropic polymers by polymerizing methacrylic acid utilizing an alkali metal hydroxide and free radical initiators as described in U.S. Pat. Nos. 4,112,212, 4,130,702 and 4,160,755.

Useful phenolic-carboxylic acid derivatives include p-acetoxybenzoic acid and p-acetoxycinnamic acid and the like.

A nonlimiting list of various polymers and copolymers includes: poly(methyl-1,4-phenylene, 2,5-dimethyl-trans-hexahydroterephthalate); copoly(methyl-1,4-phenylene trans-hexahydroterephthalate/terephthalate) (8/2); copoly(chloro-1,4-phenylene trans-hexahydroterephthalate/isophthalate) (9/1) and (8/2); copoly(ethyl-1,4-phenylene terephthalate/2,6-naphthalate) (7/3); copoly(tert. butyl-1,4-phenylene/-3,3',5,5'-tetramethyl-4,4'-biphenyl-terephthalate) (7/3); copoly(chloro-1,4-phenylene/-3,3',5,5'-tetrachloro-4,4'-biphenyl-terephthalate) (7/3).

The liquid crystal polymers including wholly aromatic polyesters and poly(ester-amide)s which are suitable for use in the present invention may be formed by a variety of ester forming techniques whereby organic monomer compounds possessing functional groups which, upon condensation, form the requisite recurring moieties are reacted. For instance, the functional groups of the organic monomer compounds may be carboxylic acid groups, hydroxyl groups, ester groups, acryoxy groups, acid halides, amine groups, etc. The organic monomer compounds may be reacted in the absence of heat and pressure sufficient to melt the thermoplastic material but not sufficient to melt the reinforcing material but not sufficient to melt the reinforcing material.
material. Thus, the use of relatively high melting thermoplastic materials are contemplated as reinforcing fibers of the present invention, although such materials are referred to as "non-thermoplastic" throughout the specification and claims solely for the sake of brevity.

The reinforcing fibers useful herein are metallic or ceramic, amorphous, polycrystalline or single-crystal reinforcing fibers or filaments. Common examples are carbon, glass, boron and boron nitride, ceramic fibers, such as silicon carbide, silicon nitride and alumina, aramides, ordered polymers, etc. However, the use of carbon fibers as reinforcing fibers are specifically described and claimed in co-pending application Ser. Nos. 589187, 589823, 589825, 589928, and 589929, all filed contemporaneously herewith.

The glass fibers utilized are manufactured and marketed commercially. The fibers are drawn from a molten supply of glass contained in a platinum container having a large plurality of very fine holes in the bottom thereof from which the molten glass is drawn at high rates of speed which attenuate the glass into extremely fine diameter. The glass filaments are pretreated as drawn from the platinum container, usually called a "bushing" with a size serving to enhance the compatibility of the ultimate glass yarn with the thermoplastic fiber which is utilized.

The glass fibers contemplated are continuous glass fibers in the form of unstranded filaments, stranded glass filaments, untwisted bundles of stranded glass filaments including twistless roving all hereinafter referred to as glass fibers.

Size compositions are contemplated herein and those preferred for use in the practice of the present invention are those conventionally used in the treatment of glass fibers. Such size compositions contain, as the essential component, a glass fiber anchoring agent such as an organo silicon compound or a Werner complex compound.

Preferred anchoring agents are the amino silanes, such as gamma-aminopropyltrimethoxysilane, N-(betaaminoethyl)gamma-aminopropyldimethoxysilane, etc. However, use can also be made of any of the organo silanes as well as the corresponding silanols and polysiloxanes. Representative of other suitable anchoring agents which can be used in the practice of this invention are the organo silicons, their hydrolysis products and polymerization products (polysiloxane).

Instead of organo silicon as described above, use can also be made of Werner complex compounds containing a carboxylato group coordinated with the trivalent nuclear chromic atoms, and in which the carboxylato group may also contain an amino group or an epoxy group. Suitable Werner complex compounds include stearato chromic chloride, methacrylato chromic chloride, amino propylato chromic chloride, glycine chromic complex or glycato chromic chloride.

Ceramic fibers contemplated for use herein include silicon carbide (composed of ultrafine beta-SiC crystals), silicon nitride (Si₃N₄) and alumina (Al₂O₃) fibers.

Any silicon carbide fiber system with the requisite strength can be used, although a multi-filament silicon carbide yarn with an average filament diameter up to 50 microns is preferred and yarn with average filament diameter of 5 to 15 microns is especially preferred. If a silicon carbide monofilament is used, a typical silicon carbide monofilament of approximately 140 microns diameter is available from AVCO Systems Division, Lowell, Mass. This fiber exhibits an average tensile strength of up to 3450 MPa, has a temperature capability of over 1300°C and is stable in oxidizing environments.

Alumina fibers have been available for several years. They have been of particular interest for application in metal matrix composites because of their excellent strength and modulus, especially at high temperature. The two principal types of alumina fiber had been, however, the large diameter (>350μ) single crystal rods or alumina whiskers. The problems of handling and processing of whiskers and the very high cost of the single crystal fiber dampened the enthusiasm for their use in composites. The situation changed, however, with the advent of high quality alumina yarns which, because of their low potential cost and attractive mechanical properties, could be seriously considered for use in composites. In general, these fibers are produced by E.I. DuPont de Nemours, Inc., 3M Corporation and in the USA and Sumitomo Chemicals Co., Japan.

The DuPont fiber, referred to as fiber FP, is a round cross section, 20 μm diameter, continuous length yarn having 210 fibers per tow. It is available in two forms. Type I is pure alpha alumina while Type II is similar but coated with a thin layer of glass. Type II was originally intended for resin matrix composites and Type I for metal matrix composites; however, it is found by this invention that both are suitable for ceramic composites. Although the initial fiber strength is not particularly high, on the order of 1380 MPA (200,000 psi), it is very important to note that this strength is stable and not affected by handling and is not much different from that realized in composites reinforced with alumina rods of initially higher unhandled "pristine" strength.

The Sumitomo Chemicals fibers are also produced in yarn form; however, there the similarity with fiber FP ends. This fiber is not pure alumina and in fact, it is the presence of some SiO₂ and a very fine structure which permit a claimed use temperature to be 1350°C.

On the basis of specific mechanical properties this fiber is attractive. Its low density and high tensile strength provide a specific strength nearly twice that of fiber FP while the specific modulus approximately equals the FP property. The Sumitomo fiber appears to have superior handleability.

The known properties of boron nitride, properties such as exceptionally high heat resistance (1800°F. in oxidizing 5000°F. in reducing atmospheres), dielectric strength (950 v./mil), high surface and volume resistivity and low dissipation factor over a wide temperature range, make it a potentially attractive high temperature reinforcing fiber candidate. The fibers may vary in diameter, although those preferred are about 10 microns in diameter and fibers having diameters up to about 30 microns may be used. Continuous boron nitride fibers (99-% boron nitride) are available commercially from the Carborundum Corporation.

The fibers also should exhibit a tensile strength of at least about 100,000 psi and a tensile modulus of about 10-12Ox 10⁶ psi.

The thermoplastic fibers which are particularly useful herein have bundle cross-sectional areas ranging from about twice that of the reinforcing fiber to about one-half of that of the reinforcing fiber tow to about one-half of that of the reinforcing fiber tow. Bundle or tow denier will be in the range of 1 to 50 and the fiber count will depend on single filament denier (higher counts are required with lower denier filaments). However, in general, from about 10 to about 150,000 filaments, preferably 100 to 10,000 filaments, are employed.
The modulus of the fiber should be in the range of 50,000 to 500,000 psi. The thermoplastic fiber also must exhibit a melting point of more than 50°F, preferably more than 200°F, above ambient temperatures. And of course, the fiber must melt and fuse at temperatures no higher than about 1,000°F, preferably no higher than 800°F, in order to be useful herein.

The weight ratio of the two fibers which are intermixed can vary widely. However, in order to prepare satisfactory composites, it is necessary that sufficient thermoplastic polymer fiber be employed to obtain complete wetting of the reinforcing fibers. Generally, no less than about 30 percent, by volume, of the thermoplastic polymer fibers may be employed. The maximum amount of thermoplastic polymer depends upon the strength properties which are required. In general, when less than about ten percent, by volume of the reinforcing fiber is present, the resulting composite products have strength and stiffness properties which are poor in relation to products containing higher amounts of reinforcing fibers and exhibit little or no improvement over unreinforced matrices. Preferably about 20 to about 60 percent, by volume of the reinforcing fiber material should be present in the combined tow.

In addition to the reinforcing fiber and the thermoplastic fibers which are used herein, it is contemplated to add carbon fibers to the fiber blends of the instant invention as reinforcing fibers. In the event additional carbon fibers are added, it is possible to reduce the amount of the reinforcing fiber which is used to as low as approximately 10 percent volume. However, the maximum combined amount of the added carbon fiber plus the amount of the reinforcing fiber which is employed should not exceed the upper limit specified above for the reinforcing fiber alone.

In FIG. 1 of the instant invention, a reinforcing fiber tow (1) is obtained having the properties specified above. The fibers form the reinforcing fiber tow are passed through a fiber guide (3) and onto a first Godet roll (4). The first Godet roll is synchronized with a second Godet roll (11) at rates of speed such that the second Godet roll revolves slightly slower than the first Godet roll. Hence, the fibers between the two Godet rolls, which are subsequently spread and intermixed during the process of the invention remain in a low tensioned (approaching tension-free) state which provides for effective fiber intermixing. Individual thermoplastic polymer fibers, such as polybutylene terephthalate fibers, are mounted on a bobbin rack (2) and the fibers are fed through a fiber guide (3) onto the first Godet roll (4). A tension comb may be employed after the fibers leave the bobbin and before they are brought into contact with the Godet roll. This tension comb serves to improve the contact of the fiber with the Godet roll and to increase the width of the fibers. On the other hand, after leaving the fiber guide (5), are directed into a gas banding jet (7).

The gas banding jet showing in FIGS. 3 and 4 is used to uniformly spread the fiber tows. A gas "banding" jet can also be used as an intermixing means whereby the gas jet serves to uniformly intermix the two fiber tows. The banding jet consists of a gas box (40) into which compressed air or another gas is fed through a conventional adjustable gas metering means (41). The preferred pressure of gas flow into the gas jet is in the range of approximately 0.5 to 10 psi. One, or more than one, gas exit ports (44) are provided to cause gas from within the gas box to impinge in a generally perpendicular fashion upon the fiber tow which passes across the exit ports. Preferably, the exit ports are V-shaped and pointed in the direction of movement of the fiber tow across the box.

As shown in FIG. 4, the gas banding jet is provided with shims (46) or other means to allow a gas box cover (48) to be attached, so that a flow channel for the fibers is provided. The gas box cover is held in place by conventional attachment means, such as clamps (49).

In an alternative process shown in FIG. 2 both the thermoplastic fiber and the reinforcing fiber are subject to gas banding jet treatment (26) and (27). However, particularly with lower molecule weight, less high melting polymers, such as polyethylene terephthalate, a fiber comb having a plurality of spaced-apart fingers, as described above, may be employed in place of the banding jet.

After the fibers are spread by banding jets or banding jets in combination with combs, they are intermixed using an intermixing means (8). In FIG. 1 the intermixing means is a pair of stationary rods or bars. The fibers from the spread reinforcement fiber tow and the fibers from the spread thermoplastic tow or yarns both initially come into contact together on the bottom of the first stationary rod or bar. The fibers then are deflected across the top of the second stationary bar or rod and, as a result, are intermixed. In order to ensure complete intermixing, it is necessary that both fibers be uniformly spread across their entire width and that the area within which both fibers are spread be virtually identical. Finally, it is necessary that intermixing be undertaken in a relatively tension-free state. If high tension is imparted to either of the fiber tows, full (or optimal) intermixing may not occur. After passing over and under the stationary bars, the combined fiber tow may be further intermixed using an air entanglement jet as described above.

After intermixing, the fibers pass through a comb (9) to maintain dimensional stability and through twist guides (10) to impart a slight twist to the intermixed fibers. The twist is imparted in order to maintain the intermixing of the fibers. Instead of using an actual half-twist, false-twisting of the fibers using methods well known in the art may be employed. In the alternative, a fiber wrap may be used to hold the intermixed fibers together. The overlap may be of any convenient type of fiber. However, it is preferred that the overlap consist of a relatively small quantity of thermoplastic fibers.

The mixed fibers are then wrapped around a second Godet roll (11) which, as pointed out above, serves in conjunction with the first Godet roll to provide a relatively tension-free zone to allow fiber intermixing. The fibers are then taken up by a take-up roll (12) for storage. Of course, it is possible to impart false-twisting or actual twisting or to wrap the fiber tow with another
fiber either before or after the Godet roll. In addition, the intermixed fibers may be made stable by application of an appropriate fiber finish which serves to hold the intermixed fibers together and enable easier handling in subsequent operations, such as weaving.

FIG. 2 is similar to FIG. 1 but is the process most preferred when a liquid crystal type polymer or other higher melting point polymer is used. In FIG. 2 a roll of reinforcing filamentary material (21) feeds fiber through tension comb (22) and onto Godet roll (25). Liquid crystal fibers from a roll (23) are fed through a guide (24) and onto the same Godet roll (25). Separation is maintained between both fibers on the Godet roll. As pointed out above, the first Godet roll (25), when used in combination with the optional second Godet roll (35), serves to maintain the fibers in a relatively tension-free state during the intermixing process. High tension during intermixing must be avoided to assure that complete intermixing occurs.

After the reinforcing fibers and the liquid crystal fibers leave the first Godet roll they are both fed into gas banding jets (26) and (27) and (28), respectively. In the gas banding jet the fibers are spread to a uniform width. The fibers then pass through a second set of fiber guides (30) and (31) and are intermixed using stationary, longitudinally extended bars shown at (32). In general, intermixing occurs as the thermoplastic bundle is fed onto the same bar in the same areas as is the reinforcing fiber. At this point in the processing, the width of both tows is the same, and as they are brought simultaneously into contact with the same area of the bar, intimate intermixing occurs. In an alternative intermixing process, the two fiber tows are fed simultaneously into a gas jet or other gaseous intermixing device in a relatively tension-free state. In addition, the fibers may be fed into a gas jet for further intermixing after they have been treated on the stationary bars. In the gas intermixing means a jet of air impinges on the fibers, preferably perpendicular to their direction of flow.

Following intermixing, the fibers are fed through twist guides (33) to add at least a half-twist per yard to the fiber to ensure dimensional stability. Fibers then pass through a guide (34) onto a second Godet roll (35) and from there onto a take-up roll (36).

Utilizing the process of the instant invention in a modified filament winding procedure, it is possible to prepare intricately shaped articles when the fiber blends are oriented in directions not parallel to the long axis of the article, utilizing thermoplastic polymers in conjunction with fiber reinforcements. This modified filament winding process begins with the use of the intermixed tows of the instant invention. These tows may be fed directly to a filament winder. As the filament winder moves around or up and down the mandrel or form, the reinforcing fiber/thermoplastic fiber tow is applied directly to the mold and heated using a radiant heater or other suitable means for immediately melting and fusing the thermoplastic polymeric fibers within the reinforcing fiber tow. In other words, the reinforcing fiber/thermoplastic fiber tow should be heated under pressure as soon as or soon after it meets the mandrel. After full melting and resolidification occurs, the mandrel either may be dissolved using a suitable solvent, may be pulled from the product, or the mandrel may actually become a part of the product.

Another unique use for the fiber blends prepared according to the instant invention is in forming woven fabrics utilizing standard techniques. According to this process, the tow of the instant invention is used either alone or in combination with other tows or fibers to form a woven mat. The woven fabrics prepared according to the process of this invention may be applied to the desired mold or otherwise used in forming a composite. The previous method of choice of forming such materials involved laying down a layer of reinforcing fibers, e.g., glass fibers, followed by a layer of thermoplastic film, followed by another layer of glass, etc. Now the materials can be combined in a solid woven layer and much more readily applied to a mold. After the composite is formed, it is then heated under pressure above the flow point of the thermoplastic polymer, and a composite having good mechanical strength and stiffness properties results. The strength and stiffness enhance-
The resulting material contains about 50% by volume polymer. The fiber prepared from the PEEK has a thermal and compression properties separately from the glass fiber which is also wrapped around the mold pressure. The mold pressure is then increased to 500 psi and held at about 315°C temperature and under such increased pressure for thirty minutes. The material is then cooled at 70°C. and removed from the mold. An approximate 50/50% by volume blend of 50/50 by volume glass fiber/PBT.

The polyethylene terephthalate tow is fed through a fiber comb having approximately 30 teeth, while the glass fiber tow is fed through a gas banding jet operating as described in Example 1, at a pressure of about 24 to 34 psi. The two tows are then intermixed over and under parallel extending rods by feeding both tows into the same area on the bars. Intermixing is aided by the use of a second gas banding jet of the type described in Example 1, operating at 24 to 34 psi. After leaving the banding jet, the fibers are fed through a second fiber comb which was arranged parallel to the direction of flow of the fiber, so as to provide a tensioning path to aid in intermixing. After leaving the comb, the fibers are fed through twist guides to provide approximately a one-half twist per yard, so as to maintain the fibers in their intermixed state. The fibers are then wrapped around a second Godet roll and taken up at a speed of 7-8 m/min. In order to minimize tension during the intermingling process, the second Godet roll is operated at a slightly lower speed than the first Godet roll. 34 x 10" panel composites are prepared generally as described in Example 1 and evaluated satisfactorily.

A sample of the PBT/glass fiber blend prepared above is wrapped with 90 denier polybutylene terephthalate yarn as described above at four wraps per in. to form a compact yarn suitable for fabric weaving. The PBT fabric wrap is chosen, so that it would form a part of the matrix upon composite fabrication. The resulting wrapped yarn is then divided into 96 different yarn segments and placed on spools mounted on a special creel. A 6" wide fabric is then woven on a modified Draper XD loom, using a plain weave pattern. The resulting woven product has dimensions of 16 ends per inch x 15 picks per inch and weighs ca. 0.05 oz./yd². The fabric is ca. 10 mils in thickness, is soft but compact, and exhibits good dimensional stability. Satisfactory fiber composites having irregular shapes are prepared from the resulting fabric. Example 3

An approximate 50/50% by volume blend is prepared based upon the glass fiber described in Example 1 and a polyether ether ketone (PEEK) thermoplastic polymer. The fiber prepared from the PEEK has a density of 1.34 g/cc and a denier of 1520 g/9000 m. The polybutylene terephthalate has a draw ratio of 2.25:1, an initial modulus of 24 g, a tenacity of 5.3 g/denier, an elongation of 28%, a melting point of 227°C. and a denier per filament of 2.7. Ten packages of 33 filament count yarn are employed on a creel, and all packages are merged into a single polybutylene terephthalate fiber tow on a Godet roll. Maintained separately, but on the same Godet roll, ten packages of 408 filament count glass fiber (Type ECK 75 2/1) to provide a total approximate blend of 50/50 by volume glass fiber/PBT.

The polyethylene terephthalate tow is fed through a fiber comb having approximately 30 teeth, while the glass fiber tow is fed through a gas banding jet operating as described in Example 1, at a pressure of about 24 to 34 psi. The two tows are then intermixed over and under parallel extending rods by feeding both tows into the same area on the bars. Intermixing is aided by the use of a second gas banding jet of the type described in Example 1, operating at 24 to 34 psi. After leaving the banding jet, the fibers are fed through a second fiber comb which was arranged parallel to the direction of flow of the fiber, so as to provide a tensioning path to aid in intermixing. After leaving the comb, the fibers are fed through twist guides to provide approximately a one-half twist per yard, so as to maintain the fibers in their intermixed state. The fibers are then wrapped around a second Godet roll and taken up at a speed of 7-8 m/min. In order to minimize tension during the intermingling process, the second Godet roll is operated at a slightly lower speed than the first Godet roll.

34 x 10" panel composites are prepared generally as described in Example 1 and evaluated satisfactorily. A sample of the PBT/glass fiber blend prepared above is wrapped with 90 denier polybutylene terephthalate yarn as described above at four wraps per in. to form a compact yarn suitable for fabric weaving. The PBT fabric wrap is chosen, so that it would form a part of the matrix upon composite fabrication. The resulting wrapped yarn is then divided into 96 different yarn segments and placed on spools mounted on a special creel. A 6" wide fabric is then woven on a modified Draper XD loom, using a plain weave pattern. The resulting woven product has dimensions of 16 ends per inch x 15 picks per inch and weighs ca. 0.05 oz./yd². The fabric is ca. 10 mils in thickness, is soft but compact, and exhibits good dimensional stability. Satisfactory fiber composites having irregular shapes are prepared from the resulting fabric.
at a pressure of about 3 psi. After leaving the jets the fibers are intermixed above and below two parallel, longitudinally extended rods and are fed through a second parallel fiber comb, twisted to maintain dimensional stability, fed over a second Godet roll and taken up at a speed of 7-10 m/min. A satisfactory composition results.

What is claimed is:

1. A process for preparing a composite article which comprises:
   (a) forming a continuous tow of continuous non-thermoplastic reinforcing fibers;
   (b) forming a continuous tow of continuous thermoplastic polymer fibers having a melting point of at least about 50°C;
   (c) uniformly and continuously spreading the thermoplastic polymer fiber tow to a selected width;
   (d) uniformly and continuously spreading the non-thermoplastic reinforcing fiber tow to a width that is essentially the same as the selected width for the thermoplastic polymer fiber tow;
   (e) intimately, uniformly and continuously intermixing the spread non-thermoplastic reinforcing fiber tow and the spread thermoplastic polymer fiber tow in a relatively tension-free state by employing a gas intermixing means which directs a generally perpendicular gas flow onto the fibers and by bringing the tows into simultaneous contact with each other in substantially the same area such that there is provided a substantially uniform distribution of the thermoplastic fibers and the non-thermoplastic reinforcing fibers within an intimately intermixed tow;
   (f) continuously withdrawing the intimately intermixed tow;
   (g) applying the intimately intermixed tow to a mold; and
   (b) heating the intermixed tow to a temperature above the melting point of the thermoplastic fibers.

2. A process for preparing a composite article which comprises:
   (a) forming a continuous tow of continuous non-thermoplastic reinforcing fibers;
   (b) forming a continuous tow of continuous thermoplastic polymer fibers having a melting point of at least about 50°C;
   (c) uniformly and continuously spreading the thermoplastic polymer fiber tow to a selected width;
   (d) uniformly and continuously spreading the non-thermoplastic reinforcing fiber tow to a width that is essentially the same as the selected width for the thermoplastic polymer fiber tow;
   (e) intimately, uniformly and continuously intermixing the spread non-thermoplastic reinforcing fiber tow and the spread thermoplastic polymer fiber tow in a relatively tension-free state by employing a gas box which directs a generally perpendicular gas flow onto the fibers and by bringing the tows into simultaneous contact with each other in substantially the same area such that there is provided a substantially uniform distribution of the thermoplastic fibers and the non-thermoplastic reinforcing fibers.

3. The process of claims 1 or 2 wherein the reinforcing fibers are formed from the group consisting of metallic, ceramic, amorphous, and polycrystalline fibers.

4. The process of claim 3 wherein the reinforcing fibers are formed from glass, boron or ceramic fibers.

5. The process of claims 1 or 2 wherein the tow of reinforcing fibers has a bundle denier of about 100 to 100,000.

6. The process of claims 1 or 2 wherein the tow of reinforcing fibers has a bundle denier of about 1,000 to 16,000.

7. The process of claims 1 or 2 wherein the tow of reinforcing fibers contains about 100 to 300,000 filaments.

8. The process of claims 1 or 2 wherein the tow of reinforcing fibers contains about 3,000 to 24,000 filaments.

9. The process of claims 1 or 2 wherein the thermoplastic polymer fibers are selected from the group consisting of polyethylene, polypropylene, polyesters, nylon, polyamidimides, polyetherimides, polysulfones, polyester ether ketones and wholly aromatic polyester resins.

10. The process of claims 1 or 2 wherein the thermoplastic polymer fibers are liquid crystal polymer fibers.

11. The process of claims 1 or 2 wherein the thermoplastic polymer fibers are wholly aromatic polyester fibers.

12. The process of claims 1 or 2 wherein the denier of the individual thermoplastic fibers is in the range of about 1 to about 50 and wherein the tow of thermoplastic fibers contains from about 10 to about 150,000 filaments.

13. The process of claims 1 or 2 wherein the intimately intermixed tow contains about 10 to about 70 percent by volume of non-thermoplastic reinforcing fibers.

14. The process of claim 13 wherein the intimately intermixed tow contains about 20 to about 60 percent by volume of non-thermoplastic reinforcing fibers.

15. The process of claim 14 wherein the intermixed tow contains about 60 percent by volume of non-thermoplastic reinforcing fibers.

16. The process of claims 1 or 2 wherein the intimately intermixed tow is continuously applied to a mold employing a filament winding process.

17. The process of claims 1 or 2 wherein the intimately intermixed tow is applied to a mold in the form of a woven fabric.

18. The process of claims 1 or 2 wherein the composite article is a recreational article.

19. The process of claim 18 wherein the composite article is a tennis racquet frame.
It is certified that an error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the cover page, in the Inventors, after "Summit" delete ", both" and insert ---; Lincoln Ying, Bridgewater, all---


Column 2, line 39, delete "mold" and insert ---mold---

Column 10, line 57, before the word "The" insert ---The reinforcing fibers which are particularly useful herein have bundle or tow deniers in the range of from 100 to 100,000 and filament counts of from 100 to 300,000, preferably deniers of 1,000 to 16,000 and filament counts of 3,000 to 24,000.---

Column 10, line 63, delete "Bundle"

Column 10, line 64, delete "or tow" and insert ---The--- before the word "denier" and ---of individual thermoplastic fibers--- before the word "will"
It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 11, line 39, delete "form" and insert --from--
Column 12, line 26, delete "molecule" and insert --molecular--
Column 14, line 12, delete "gold" and insert --golf--
Column 14, line 38, delete "th" and insert --the--

Signed and Sealed this
Nineteenth Day of November, 1991

Attest:
HARRY F. MANBECK, JR.

Attesting Officer
Commissioner of Patents and Trademarks