United States Patent

Riley

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[54] **FLUID SPINNING PROCESS FOR NOVEL YARNS**

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[51] **Int. Cl.** **D01h 1/12**, D01h 13/30

[58] **Field of Search** 57/58.89–58.95, 57/164, 156

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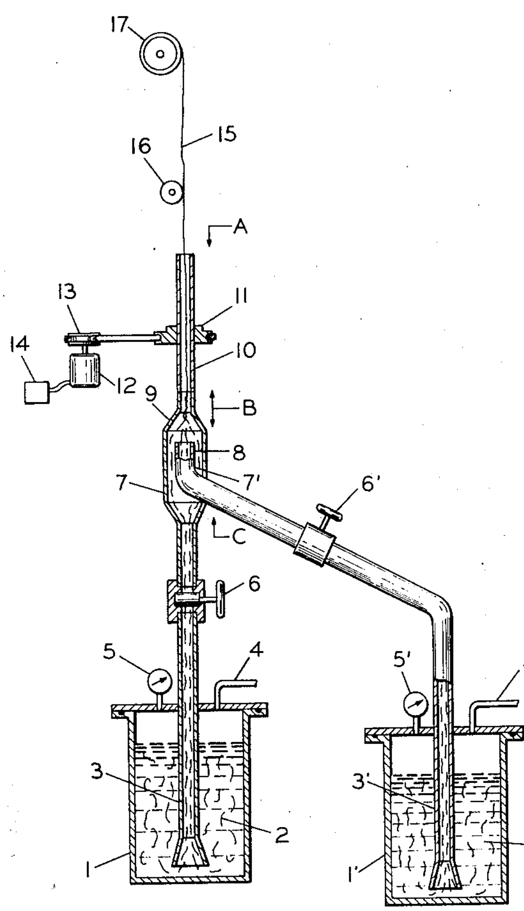
[57] **ABSTRACT**

A fluid vortex spinning process for yarns in which a dispersion of high modulus refractory fibers in a viscous carrier liquid is introduced as a flowing stream into a flowing stream of a dispersion of lower modulus fibers in a viscous carrier liquid at the center thereof and the joined stream is rotated about its axis to produce a composite yarn. Composite staple fiber core yarns with a core of compact axially aligned high modulus fibers wrapped by annular lower modulus fibers are embraced, as well as an improved fluid vortex spinning apparatus affording a high degree of control of the properties of composite yarns produced therewith.

14 Claims, 5 Drawing Figures



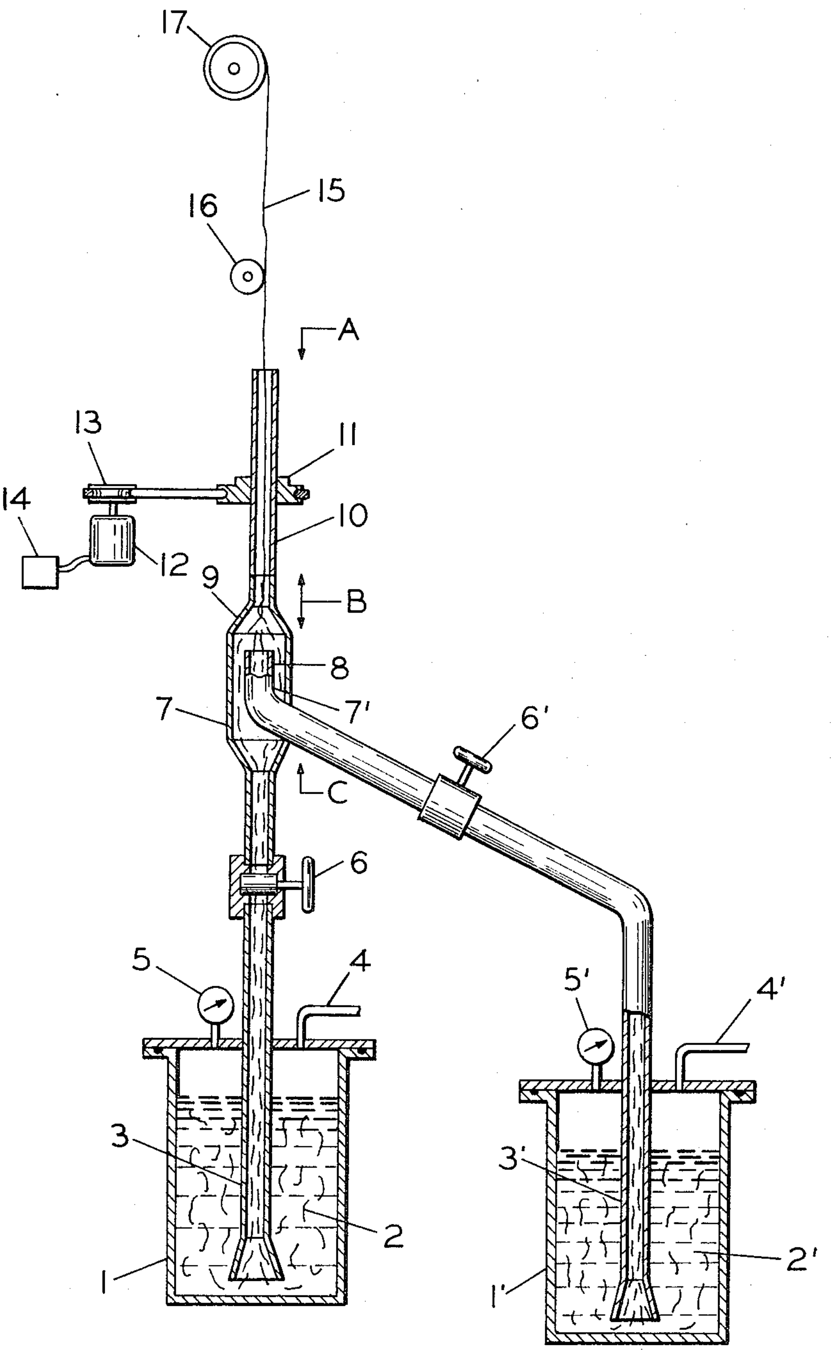


FIGURE 1

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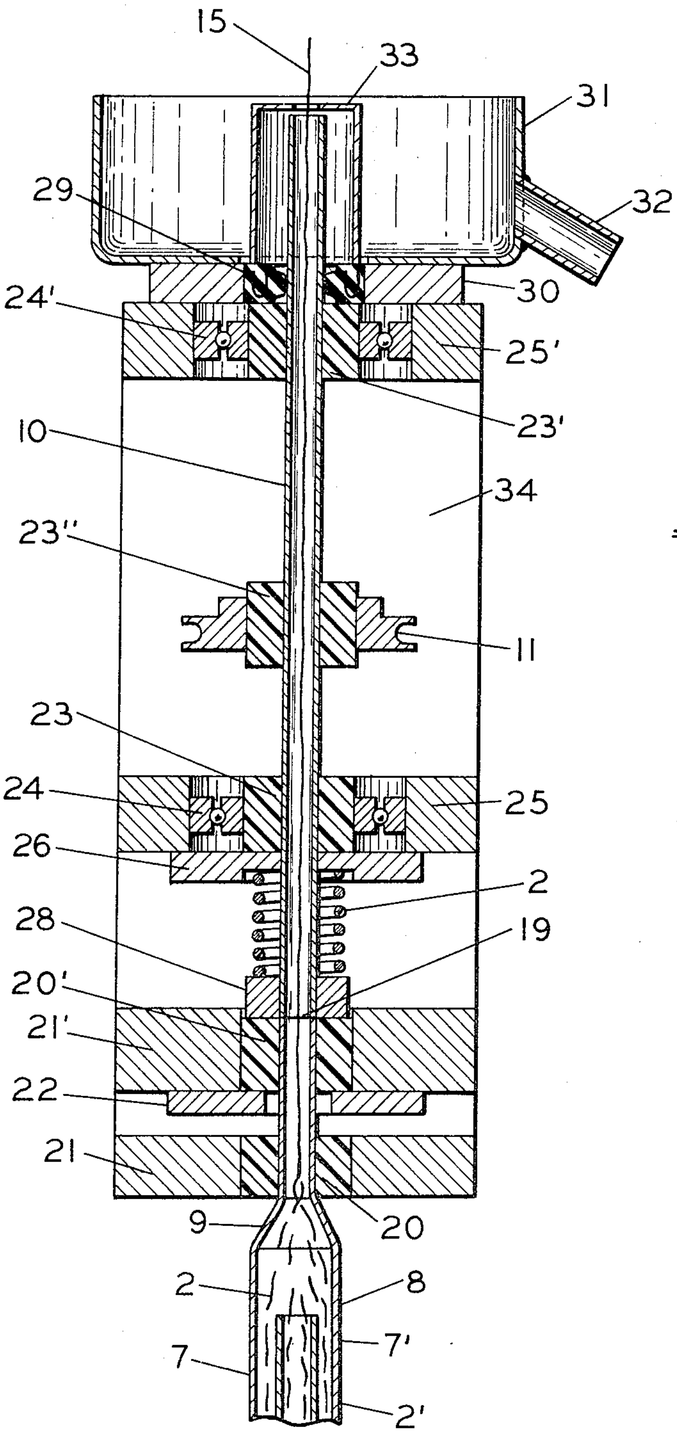

FIGURE 2

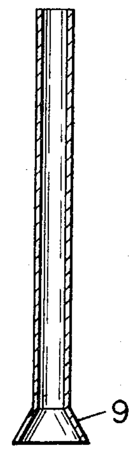

FIGURE 4

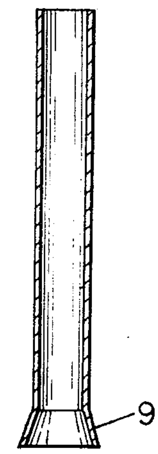

FIGURE 5

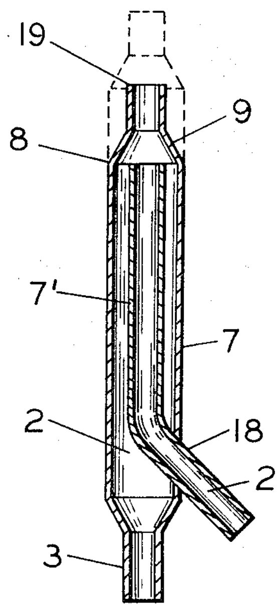

FIGURE 3

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FLUID SPINNING PROCESS FOR NOVEL YARNS

The invention described herein was made in the course of or under a contract or subcontract thereunder with the U.S. Department of Defense, Office of Naval Research.

BACKGROUND OF THE INVENTION

The field of the invention is that of yarns of low and high modulus staple fibers suited for use in the preparation of reinforced composites and the process of preparing such yarns having a core of axially aligned high modulus fibers wrapped with low modulus fibers.

Reinforced composites produced generally by molding a matrix material have been reinforced with a variety of high modulus fibers and filaments for increased strength and stiffness. But the greatest increases are only realized when the high modulus reinforcing fibers or filaments are aligned in the direction in which the greatest strength and stiffness are desired. When continuous high modulus filaments are employed this can generally be achieved by known methods. However, when high modulus staple fibers are to be employed their alignment in the desired direction or directions is much more difficult. It is particularly difficult when employing the very brittle and fragile whisker fibers of silicon carbide and other metal carbides and nitrides, graphite and the like. In fact short of fully aligning such whisker fibers by laborious hand operations and then infusing the arrangement with a setting liquid to fix the whiskers in their alignment no fully successful method for their use as aligned reinforcing fibers has been developed.

It would be very desirable if such high modulus staple fibers and particularly whisker fibers could be aligned in a continuous yarn which yarn could then be employed directly in producing a molding lay-up for later infusion with a moldable matrix material, resinous, metallic or ceramic, or in which the lay-up produced could be charred and the carrier fibers volatilized so that the fired lay-up could then be infused with the desired matrix material. Such a yarn has been produced by the present invention.

Although conventional textile processes cannot be used to produce such yarns, it was previously known to produce yarns from one or more textile type fibers of generally low modulus by various methods generally described as open-end spinning where a yarn is produced from staple fibers directly. Open-end spinning processes employ several different modes of collecting and assembling fibers including a fluid vortex, twisting by a mechanical rotating element from a collecting zone, overlapping of tufts of fibers on a collecting drum and twisting them as withdrawn, and collection on a rotating collecting surface and twisting onto a seed yarn as in so-called "pot spinners." None of these methods are adapted to handle short, stiff or fragile high modulus fibers since most of them require well crimped fibers of relatively low modulus. The fluid vortex spinning systems have not employed sufficiently strong hydrodynamic forces to handle such short, stiff or fragile uncrimped fibers.

One such fluid vortex system employing liquids such as water as a fluid has been described in which yarns of low modulus crimped textile type fibers could be produced by means of the vortex produced in a two-part tube with a rotating terminal portion. However, such processes are unsuccessful when attempts are made to spin yarns comprised of high modulus short, stiff or fragile fibers as well as textile type fibers.

It has now been found that yarns in which high modulus fibers including high modulus fibers of the whisker type forming an axially aligned core and wrapped with peripheral low modulus fibers can be produced by a fluid vortex method. These yarns are suited for use in preparing preforms for infusion by liquid or molten matrices and thereafter for molding or otherwise forming into reinforced composite structures of increased strength and stiffness in controlled desired directions. A fluid vortex method has been found by which such yarns can be produced wherein the alignment and core positioning of the high modulus fibers is subject to a high degree of control and which is adapted to the production of the multi-component wrapped core yarns which previously could not be produced either by conventional textile processes or the so-called open-end spinning techniques.

BRIEF DESCRIPTION OF THE INVENTION

The present invention embraces a process of fluid vortex spinning comprising forming a dispersion of discrete high modulus refractory fibers in a viscous carrier liquid, forming a second dispersion of low modulus fibers in a viscous carrier liquid, establishing a flowing stream of the dispersion of low modulus fibers through a passage, the end portion of which is of increased diameter, establishing a flowing stream of the dispersion of high modulus fibers through a second passage the end portion of which is concentric with the enlarged portion of the first passage and located at the axis thereof, introducing the stream of the dispersion of high modulus fibers at the axis of the flowing stream of dispersion of low modulus fibers, rotating about its axis the terminal portion of the joined stream of both dispersions thereby to produce a yarn, and separating the carrier liquid from the yarn so produced.

The invention also embraces a yarn product comprising a composite yarn having a core of axially aligned high modulus refractory fibers wrapped with low modulus fibers in a form useful as a reinforcing agent in composite matrices. The invention also embraces an improved fluid vortex spinning apparatus for spinning such composite yarns of high modulus core fibers and wrapped low modulus fibers in which the axial alignment and core location of the high modulus fibers is subject to a very high degree of control.

DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic drawing of an apparatus suitable for carrying out the process of the invention.

FIG. 2 is an enlarged sectional view of that portion of the apparatus of FIG. 1 from points A to B of FIG. 1 with a modification shown.

FIG. 3 is an enlarged sectional view of one form of a spinning head which occurs as that portion of the apparatus of FIG. 1 from points B to C.

FIGS. 4 and 5 are sectional views of modified portions of the spinning head of FIG. 3 known as the barrel.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is of a novel yarn structure and a process for producing such yarn by fluid vortex spinning. Basically the process comprises forming a dispersion of discrete high modulus refractory fibers in a viscous carrier liquid, forming a second dispersion of discrete low modulus fibers in a viscous carrier liquid, establishing a flowing stream of the dispersion of low modulus fibers through a passage, the end portion of which is of increased diameter, establishing a flowing stream of the dispersion of high modulus fibers through a second passage the end portion of which is concentric with the enlarged portion of the first passage and located at the axis thereof, introducing the stream of the dispersion of high modulus fibers at the axis of the flowing stream of dispersion of low modulus fibers, rotating about its axis the terminal portion of the joined stream of both dispersions thereby to produce a core yarn, and separating the carrier liquid from the yarn so produced.

The fibers utilized in the process and forming the yarn are of two general types, high modulus refractory fibers and low modulus fibers. The high modulus fibers are all those of high strength and stiffness useful as reinforcing fibers in composites with resinous, metallic or ceramic matrices. They include staple fibers of glass, metal such as boron, steel, aluminum and the like, graphite and high temperature resistant polymers such as aromatic polyamides and other resins as well as those occurring generally in the form of "whiskers" such as silica, silicon carbide, silicon nitride, and the carbides and nitrides of other metals of very high stiffness and strength. In general the staple fibers most useful are those of lengths from about one-fourth to 1.5 inch or somewhat longer. Likewise the whisker fibers of lengths of about one-fourth to 1 inch or greater are most useful. Fibers and whiskers of lengths less than the internal diameter of the passage leading to the rotating portion of the apparatus can be employed, but will generally not be as well aligned with the axis of the resulting yarn, but more generally dispersed at all radii throughout same and at more or less random angles of incidence to such axis. Hence, the yarns produced therefrom afford less control of the strength and stiffness in a given desired direction of composites made therefrom.

The low modulus fibers may generally comprise any staple fiber of textile type which is of a length that will not plug the passage of the apparatus used. The preferred lengths of such low modulus fibers range from about three-eighths to 1 ½ inches or longer and generally it is preferred to use low modulus fibers somewhat longer than the high modulus fibers used. Such low modulus fibers will normally possess aspect ratios ranging from about 100 to 1,000 or greater. The diameter of the low modulus fibers is not critical but may embrace any size generally useful in the production of textiles. Large diameter filaments are useful but are not preferred because of the increase in size of the yarn and the lower volume percent of high modulus fibers in the resulting yarn. The low modulus fibers may be crimped or uncrimped.

The viscous carrier liquids which can be used are any in which the fibers are dispersible, are chemically inert thereto, and which will produce relatively high hydrodynamic forces in the flowing and rotating stream formed. Fluids with viscosities of from about 30 to about 20,000 poise or high can be used. Preferably fluids of from about 50 to 5,000 poise are used. Also it is desirable to employ liquids which are easily separated from the yarns produced and such are preferred. Many viscous liquids can be employed including glycerol, and polyglycols of high molecular weight, silicone oils of suitable viscosities, polymeric carboxylic acid esters of suitable viscosities, sugar solutions such as glucose, sucrose and the like, corn syrups of various viscosities, mineral oils of various viscosities such as white mineral oil, vegetable oils such as peanut oil, rape oil, castor oil and epoxidized corn oil, soya oil and the like and other liquids and mixtures thereof falling within the above viscosity range. The sugar and corn syrups and polyglycols are particularly preferred because of the ease with which they can be washed from the yarn product with water only.

The viscous carrier liquids employed for the low modulus fiber dispersion and the high modulus fiber dispersion can be different in nature or can be the same type fluid of different viscosity. The viscosity of the viscous fluids can be controlled by varying their dilution, their temperature, or by blending different viscosities to obtain intermediate ones. It has been found that improved yarns result from the use of a viscous carrier liquid for the high modulus fiber dispersion which is about 1 or more orders of magnitude higher viscosity than that of the carrier liquid used for the low modulus fibers. The presence of the more viscous liquid in the dispersion of high modulus fibers serves to maintain the high modulus fibers in axial alignment in the core and to protect the alignment of such fibers from disturbance by the impinging and circulating less viscous fluid of the low modulus fiber dispersion when this fluid is rotated about the core stream.

The dispersion of the staple fibers in the viscous carrier liquid may be accomplished in any convenient manner, such as by stirring, kneading or other form of agitation or by blending an already prepared master batch in a miscible liquid or the same liquid. With the high modulus fibers typically employed it is generally sufficient to simply stir the fibers which have been deposited on the surface or in the carrier liquid for a short time at a few hundred rpm to substantially disperse the fibers in a relatively homogenous manner. Likewise the same procedure can be employed with a low modulus or textile type fiber. However, with some of the longer fibers, particularly the longer low modulus fibers, the use of a rotating stirrer whether round or in other form frequently results in a balling up of the low modulus fibers between the stirrer and the walls of the vessel containing the dispersion. When this happens such balls of fiber have to be removed from the dispersion and additional fiber added to make up the desired concentration. A convenient method for dispersing fragile fibers and such longer fibers is to deposit groups of the fibers on the surface of the viscous liquid and thereafter knead them by repeated vertical working of a stirring rod or cylinder so that these fibers gradually disperse downward into the viscous liquid. This avoids any balling up effect from rotational dispersion. If desired, dispersing aids such as wetting agents or other form of dispersant may be added to the fibers or the liquids to assist in obtaining relatively homogenous dispersions thereof.

With reference to the drawing an apparatus for carrying out the process is schematically illustrated in FIG. 1. Basically such apparatus consists of pressure vessels or tanks **1** and **1'** for receiving the dispersions **2** and **2'** in the viscous carrier liquids. Each vessel **1** and **1'** is fitted with an exit conduit or tube **3** and **3'**. These tubes may conveniently be adapted with flared or funnel shaped lower ends to assist in entraining the dispersed fibers with the carrier liquids. Each of the pressure vessels **1** and **1'** are likewise supplied with a source of gas pressure **4** and **4'** and gauges **5** and **5'** to determine the pressures applied. The exit conduits or tubes **3** and **3'** are desirably fitted with valves **6** and **6'** to control the flows through each of the tubes. It is not essential that either of the exit conduits **3** or **3'** be straight but they may take any position except for the end portions thereof. The end portion **7** of exit tube **3** from the low modulus dispersion vessel **1** is of increased diameter relative to the remaining portion of the tube **3** to accommodate the end portion **7'** of tube **3'** which is brought through the wall of tube **7** and axially aligned at the center thereof. Tube **7'** is terminated at the axis of the enlarged portion to tube **7**. The terminal end portion **9** of tube **7** is of decreased diameter forming what is termed a barrel and terminating in abutting relationship to the rotating tube **10**. The rotating tube **10** mounted in flexible sleeves and mounts is supplied with a pulley **11** adapted to be driven by a motor **12** with a pulley **13** through a belt, cable, chain or V-belt drive and the speed of the motor is controlled by controller **14**. The rotating conduit or tube is thus adapted for rotation at speeds varying from 100 to 5,000 rpm or more. The yarn **15** formed therein is taken up on a reel **17** which is preferably perforated and the yarn desirably traverses a snubber roll **16** prior to its final take-up.

The details of the rotating tube assembly are shown in FIG. 2 of the drawing. Reference is made to FIG. 2 showing the end or the expanded portion of increased diameter of fixed tubes **7** and **7'** and the entirety of the rotating tube **10** and the manner of their mounting and sealing. The reduced diameter terminal portion of fixed tube **7** downstream from the termination of tube **7'** carrying the dispersion of high modulus fibers and past the reducing portion **9** of tube **7** is pressed through flexible sleeves **20** and **20'** preferably of Teflon or other sealing materials and the seals **20** and **20'** are in turn mounted in mounts **21** and **21'**. The mounts are in turn fixed to a frame **34** which fixes their location. The rotating tube **10** is also carried in seals **23** and **23'** of Teflon or other sealing material and the seals **23** and **23'** are in turn mounted in bearings **24** and **24'** carried by mounts **25** and **25'**. At approximately the middle of the rotating tube **10** seal **23''** is mounted which carries a pulley **11** adapted for rotation of the tube. In order that a good seal against the end of the fixed tube is maintained the abutting end of the rotating tube is supplied with a rotating seal **28** of Teflon or even more elastic sealing material and a spring **27** which rests on metallic plate **26** carried by mount **25**. A reciprocal plate **22** carried by mount **21'** serves to fix and stabilize the seal **20'** of the fixed tube **7** and constant spring biasing pressure is maintained at the abutted sealed junction by rotating seal **28**. At the opposite or free end of the rotating tube 10 there is placed an oil seal 29 within mount 30 serving to prevent the effluent carrier liquid from running back down the rotating tube and serves to separate from the top bearing mount 25' the effluent pot 31 fitted about the exit end of rotating tube 10. This pot 31 is supplied with a exit conduit 32 to a receptacle, not shown, for the separated carrier fluid. In order to prevent the yarn 15 exiting from the rotating tube from catching and wrapping about the end of the tube, the exit end of the rotating tube 10 is supplied with a stationary cap 33 with an exit aperture just smaller than or equal to the internal diameter of the rotating tube 10. The cap 33 can conveniently be mounted on the oil seal 29, the mount 30 or on the bottom of the effluent pot 31.

The details of the spinning head or zone in which the yarn is formed are shown in FIG. 3 of the drawing which covers that portion of FIG. 1 from points B to C. In FIG. 3 there is shown the end portion 7 of tube 3 wherein the internal diameter of that tube is increased to accommodate the insertion at the axis or center thereof of the end portion 7' of tube 3' and the subsequent terminal portion 9 of tube 7 wherein the internal diameter is decreased to the same internal diameter as that of rotating tube 10. The end portion of tube 7' which is adapted to carry the dispersion of high modulus fiber 2' is passed through the wall of the expanded portion of tube 7 at point 18 and a liquid tight seal thereto is provided. This seal may take the form of welding, brazing or soldering in the case of metal tubes, fusing in the case of glass or a liquid-tight compressed seal may be employed. The terminal portion of the interior concentric tube 7' is straight and terminates at point 8 fixed at the center of tube 7. Tube 7 is continuous through a portion 9 of decreasing internal diameter to its termination at the point of abutment with rotating tube 10. Thus when in operation the flowing streams of the dispersion of low modulus fibers 2 and of high modulus fibers 2' are joined in a concentric laminar flowing stream at point 8 and this stream is condensed in area while traversing the reducing portion 9 of tube 7 and supplied to rotating tube 10. It is in this portion 9 that the vortex is formed by the rotation of tube 10 and where the low modulus fibers from the periphery of the flowing stream are condensed and wrapped about the high modulus core fibers at the center of such stream. The spinning head described above in detail represents a distinct improvement in fluid vortex spinning apparatus in that it allows the spinning of more highly condensed composite yarns and provides for the wrapping of low modulus fibers about a core of high modulus fibers in such yarns at a higher helix angle then prior fluid vortex processes employing straight supply tubes of uniform internal diameter. Improved production of composite yarns by means of this improved apparatus is more fully described hereinafter.

In a spinning head of the above-described type location of the inner concentric tube 7' at approximately the axial center of the outer tube 7 should be observed. It has been found that if the inner tube 7' is eccentrically located within the expanded portion of the outer concentric tube 7 sufficient to substantially restrict the flow of the dispersion of low modulus fibers 2 in one segment of the outer tube 7 a reversal of location of the constituent fibers takes place in the yarn produced. Thus, a substantial eccentric location of tube 7' will produce a yarn having a core of axially aligned low modulus fibers with the high modulus fibers helically wrapped about the periphery of the yarn. Although such a yarn is not normally desired, it can be produced by the expedient of pronounced eccentric location of the inner tube 7' within outer tube 7 in a spinning head of the general type described.

The apparatus described above was employed in all of the examples of the process of the invention and in the production of the novel composite yarns of this invention. Other equivalent apparatus of somewhat different design can be employed in the present process, but unless the design of the spinning heads used therewith observe the principles of the improved apparatus described and shown in FIG. 3 the composite yarns produced will vary in the helix angle of the wrapped low modulus fibers from those produced employing the above design. This form of the apparatus has been illustrated as vertically arranged which was done to minimize the gravitational effects on the spinning process and the viscous liquids employed. However this is not essential in carrying out the process and any other arrangement of the relative parts of the apparatus could be employed including horizontal disposition. The process of the present invention will hereinafter be described with reference to the apparatus described above for convenience but it is understood that some variations would be adopted when other similar apparatus of different arrangement were employed.

The process is carried out by charging the pressure vessels 1 and 1' with the separate discrete dispersions 2 and 2' of respectively high modulus refractory and low modulus fibers in highly viscous carrier liquids. The viscosity of the respective carrier liquids may be the same or different as more fully described below. It is preferred that the viscosity of the carrier liquid for the high modulus fibers be at least as high and preferably higher by one order of magnitude than that of the carrier liquid for the low modulus fibers. The spinning is initiated by pressuring the pressure vessels 1 and 1' by means of gas pressure through inlets 4 and 4' to establish flowing streams of the liquid dispersions 2 and 2' through their respective fixed tubes 3 and 3'. Very sensitive control of the process can be achieved by controlling the flow rates of the respective dispersions 2 and 2' correlated with the speed of rotation of the rotating tube 10 by adjusting the relative pressures applied to the surface of the dispersions 2 and 2'. Upon opening of the valves 6 and 6' flowing streams of each of dispersions 2 and 2' are established throughout the apparatus. The rotating tube 10 is rotated by means of motor 12 and its associated controller 14 through pulleys 11 and 13 at a speed correlated with the flow induced by pressuring the vessels 1 and 1'. Generally spinning has been successful at speeds of from 500 to 3,500 or 4,000 rpm. Higher rotational speeds are desirable and can be effected in equipment designed to sustain such rotational forces.

The dispersion 2 of low modulus fibers and 2' of high modulus fibers in the viscous carrier liquids are caused to flow through the fixed tubes 3 and 3' by pressuring the dispersions in the pressure vessels. By establishing such flowing streams both the low and high modulus types of fibers are axially aligned across the flowing streams of viscous fluids. It is essential that laminar flow in the streams be maintained so that areas of turbulence will not be developed since these will adversely affect the axial alignment of both types of fibers within their respective dispersions. Contrary to the teachings in some of the prior art processes, in the viscous fluids employed in the present process there is little or no progression to the axis of the flowing streams and the fibers aligned along the axis are found at all radii of the streams. This is likewise true in the most preferred procedure wherein the dispersion of high modulus fibers has a higher viscosity, preferably on the order of one order of magnitude higher, than that of the dispersion of low modulus fibers. Because of the higher viscosity in the high modulus fiber dispersion there is even less possibility for migration of these fibers to the center of the stream and in operation generally most of both the high modulus and low modulus fibers are present across the areas of their respective flowing streams.

The separate flowing streams of high modulus and low modulus fiber dispersions are brought together in the spinning head or stream joining zone, in such manner that the stream of high modulus fiber dispersion is maintained at the center of the joined streams. Furthermore, the manner of their junction is achieved so that laminar flow is maintained and no zone of turbulence exists at this junction. This joining of the streams can take place in any type of spinning head which provides for the exit of the high modulus fiber dispersion at the axis or center of the zone while the low modulus fiber dispersion forms an annular or peripheral flowing stream. The manner of achieving this joining is illustrated in FIGS. 1 and 3 in which it is shown that high modulus dispersion 2' carried by tube 7' flows forward at the center or axis of the zone while surrounded by the flowing stream of low modulus dispersion 2 through the annular region of tube 7, being joined and forwarded at point 8. Other means of bringing these two streams of dispersion together are available and function in the process such as brining the high modulus dispersion stream 2′ through a central straight tube while establishing the annular flowing stream 2 in the larger tube 7 by means of bringing in the low modulus fiber dispersion from a side entering tube. Yarns may be produced by this arrangement but it offers some difficulty in maintaining the usually longer low modulus fibers in axial alignment and preventing their wrapping about the central tube at the point of entry of the side tube supplying the annular region. For this reason the improved form of spinning head illustrated in FIG. 3 is preferred.

At the interface 19 with the rotating tube 10 a vortex in the now joined flowing streams of viscous fluids is formed and, depending upon the speed of rotating tube 10 the vortex is moved back upstream to a point intermediate between the tube interface and the junction point 8 of the two streams forming this single flowing stream. The yarn produced is condensed at this point which is subject to control by at least three variables: the speed of rotation of the rotating tube 10, the relative flow rates of dispersions 2 and 2′, and the relative viscosities of the two dispersion streams. At this vortex the core of axially aligned high modulus fibers progressing in the stream of viscous fluid in which they have been dispersed is condensed to form the core and peripheral low modulus fibers are caused to wrap about these high modulus core fibers in the initial formation of the yarn. The wrapping of the low modulus fibers and the helix angle increases with the additional twist imposed on the yarn as the yarn progresses through the remaining portion of rotating tube 10. In operation it has been found that excellently aligned high modulus core yarns wrapped about with the low modulus fibers are produced so long as the flow rate of the low modulus fiber dispersion 2 is maintained at least as great, and preferably somewhat greater, than that of the high modulus fiber dispersion 2′. It is apparent that the amount of desired differential between the flow rates of streams 2 and 2′ will be governed by the differential in cross-sectional areas of the concentric tubes 7 and 7′ in the spinning head. In the specific apparatus the dimensions of which are set forth below the most preferred ratio of such flow rates is from 1.1 to about 1.7 times. This ratio will, however, vary depending on the relative dimensions, and hence areas of the concentric tubes in any given spinning head. Such relative rates of flow both serve to prevent the dispersion outward of the high modulus core fibers at the junction of the two streams as well as to provide impetus for the wrapping of the low modulus fibers about the core fiber.

It has likewise been found to give improved yarns if the viscosity of the high modulus fiber dispersion 2′ is somewhat higher than that of the low modulus fiber dispersion 2. Relative viscosities with a differential of as much as 1 to 2 orders of magnitude wherein the high modulus fiber dispersion 2′ has the higher viscosity have been found to give the optimum yarn product. The high viscosity in the core fiber dispersion protects the core fibers from twisting and aids in holding them aligned together and in condensing into the core during spinning. This process will produce excellent yarns with dispersions of high modulus and low modulus fibers in viscous carrier liquids of the same viscosity, but as noted above, improved operations result from using a high modulus fiber slurry of higher viscosity.

As described above the exact location point of the vortex forming the yarns can be controlled by at least three variables. It has been found that superior wrapped core yarns are produced when this vortex point is controlled to lie within the zone of decreasing internal diameter of the tube 7′ and such operation is facilitated by use of the spinning head illustrated in FIGS. 1 and 3. With reference to FIG. 3 the most desirable wrapped core yarns with a higher helix angle in the low modulus fibers wrapped about the high modulus core fiber is achieved when the vortex is controlled to be maintained between the point 8 of junction of the streams of fiber dispersions 2 and 2′ and the end of the reducing zone 9 of tube 7. When using the spinning head illustrated in FIG. 3 this zone is relatively short and requires fine control to maintain a vortex within the zone because of the tendency of the vortex to progress back upstream and begin to entangle the forming yarn about the terminus of tube 7′. To facilitate operating with such spinning head it can be modified as illustrated by the dashed lines in FIG. 3 by extending the outer walls of tube 7 some distance beyond point 8 before the decrease in internal diameter is begun. This serves to place the decreasing zone 9 more remote from end of tube 7′ at point 8 and effectively prevent such entanglement about the end of tube 7′. A further modification of the spinning head which is effective comprises lengthening the zone 9 of decreasing diameter by varying the angle at which the outer walls converge from that illustrated in FIG. 3. A longer converging section or decreasing zone 9 affords more latitude in the location of the fluid vortex. By causing the condensation of the yarn to take place within the zone 9 of decreasing internal diameter the annular low modulus fibers are brought in an angle of incidence higher than zero or axial and thus caused to wrap about the high modulus fibers at a higher helix angle. This will generally afford a somewhat tighter more coherent yarn than if the low modulus fibers are wrapped at a lower helix angle.

For some uses it is desirable that the high modulus core fibers and the wrapped low modulus fibers be generally axially aligned, i.e., that the low modulus fibers be wrapped at a relatively low helix angle about the high modulus core fibers. This is particularly true when both the low modulus fibers and high modulus fibers are of a refractory nature, such as when both fibers are of glass or when the core fibers are whisker fibers and the lower modulus fibers are of glass. In those instances the entire yarn can be used for effective reinforcement and is used as such without any burning off or removal of the low modulus fibers. Yarns of this type are efficiently produced in a spinning head with the long barrel modifications such as is shown in FIGS. 4 and 5 of the drawing. Thus, in FIG. 4 and 5 it may be seen that tube 7 is extended by having the straight portion of the tube 7 following the decreasing zone 9 elongated three to five times in length prior to interfacing at 19 with the rotating tube 10. In such modifications the vortex point will be found within the elongated, uniform diameter portion of tube 7 rather than in the decreasing zone 9. Though this produces a less tightly wrapped yarn, entirely useful yarns can be successfully spun through such modified equipment.

In spinning the viscous carrier liquids are in most part separated from the yarn as it exits from the end of the rotating tube 10 and such fluids are trapped in the effluent pot 31 and directed by conduit 32 to a receptacle not shown. As stated above the stationary cap 33 with its opening no larger than the internal diameter of the rotating tube 8 prevents the raw yarn catching thereon and wrapping about the end of the rotating tube. Additional small amounts of the viscous carrier liquids will be thrown or drained off the yarn during its passage about the snubbing roll 16 and its take-up on the take-up reel 17. Take-up reel 17 is desirably a perforated reel, generally metal, which is adapted for draining away entrained viscous fluid and for thorough washing of the yarn by subsequent operations for removal of the final amounts of entrained fluids. The speed of the take-up reel is generally controlled to match that of production and exit of the yarn produced by the rotating tube assembly so as not to apply unusual forces to the yarn during its formation. However, a high degree of control of the volume percent of high modulus core fibers present in the yarn produced and of the average helix angle of the wrapping low modulus fibers is exercised by the speed with which this take-up reel is driven, since faster take-up speeds will produce yarns of lower helix angles and, unless the flow rate of the high modulus fiber dispersion is adjusted, will produce yarns of lower volume percent of such core fibers. Thus, the speed of the take-up reel is an additional variable serving to offer a multiple number of interacting adjustments by which the nature of the resulting core yarn can be varied as desired.

In the apparatus described above the pressure vessels **1** and **1′** which receive the low modulus and high modulus fiber dispersions respectively were each 1,800 ml stainless steel tanks provided with lids which carried an O-ring seal effective to withstand 100 psig pressure. The conduits or tubes **3** and **3′** leading from the tanks were both ⅜-inch stainless steel tubing supplied with ball valves for controlling flow. The valve **6′** in the tube **3′** was fitted with a reducer to ¼-inch size so as to receive the ¼-inch stainless steel tube comprising the high modulus dispersion supply conduit **7′**. Flow from the pressure vessels **1** and **1′** was initiated and controlled by pressure from nitrogen gas cylinders regulated with standard nitrogen pressure regulators. In the spinning head illustrated in FIG. **3** the concentric core tube **7′** was ¼-inch stainless steel tubing with a 1/16-inch wall thickness while the annular casing **7** was ⅝-inch stainless steel tubing with a 1/16-inch wall thickness. The supply tube **3** leading to the expanded portion of the spinning head was ⅜-inch stainless steel tubing. The barrel at the upper end of the spinning head in its short form was a ⅜-inch long section **9** converging from ⅝- to 0.403-inch diameter with a ¼-inch internal diameter straight barrel five-eighths inch in length. When adapted to be lengthened to place the vortex more remote from point **8** the annular casing **7** was extended by an additional 2 inches in length before the converging section **9**. The barrel illustrated at FIG. **4** represented a converging section **9** of ⅜-inch length converging from five-eighths inch to a 5/32-inch tube 2 ½ inches in length. The barrel of FIG. **5** of the drawing comprised a ⅜-inch long section **9** converging from five-eighths inch to a 13/64-inch tube 2 ½ inches long. The rotating tube **10** used with the above spinning heads comprised either a 6 mm internal diameter glass tube 6 inches long or in most cases a 13/64-inch internal diameter stainless steel tube 6 inches long. The sizes of the respective parts of the above apparatus are not limitations on the apparatus in general but were used for convenience in that assembled. Larger and somewhat smaller tubes can be successfully employed in the apparatus described above with suitable adaptations in the sizes of seals and motor drives used.

The composite yarns of this invention comprise a core of axially aligned high modulus fibers with a wrapping of low modulus fibers about this core. The high modulus fibers, except for very short lengths of less than the internal diameter of the core tube of the spinning head are generally aligned in the core at the center of the yarn, whereas the low modulus fibers form the periphery or wrapping fibers of the composite yarns. Such composite yarns are produced from uncrimped or crimped textile length low modulus fibers and generally straight, stiffer high modulus fibers, including whisker fibers. In all of the yarns produced the degree of alignment of the high modulus fibers is such that the yarns are excellently suited for use as reinforcing members of composite matrices. Those composite yarns employing low modulus fibers of relatively low strength cellulosic or synthetic nature are generally used after charring and burn-out of the low modulus fibers. In other cases, wherein the composite yarn is entirely of refractory fiber, such as relatively lower modulus glass fibers wrapped about other higher modulus refractory fibers, the entire composite yarn is suitable as produced for use as reinforcing members without the necessity of charring and burn-off. Not only do these yarns afford a much easier physical form for producing lay-ups and preforms for subsequent infusion with matrix materials, but they also afford a much higher degree of axial alignment of the reinforcing high modulus fibers than is obtainable by other production means from staple high modulus fibers. Thus such yarns fill a definite need in the art of producing fiber reinforced composites in a more efficacious manner and at a reduced cost.

The present invention will be more fully comprehended from the examples which follow.

EXAMPLE 1

A slurry or dispersion of high modulus glass fibers in corn syrup was prepared by adding 17.5 grams of glass fiber of 0.57 mils diameter and chopped to a staple length of one-half inch, which had been fired at 600° C for 23 minutes to remove the size, to 1,200 ml of a corn syrup with a viscosity of approximately 100 poise at room temperature. These glass fibers were dispersed by rotating a 2-inch diameter Teflon cylinder at 300 rpm for 20 minutes. The dispersion, which comprises the dispersion of high modulus fibers to be used, was essentially complete and quite homogenous. Another sample of 1,400 ml of the same corn syrup of approximately 130 poise viscosity at room temperature was heated to 60° C in a heating mantle and thereafter the low modulus fibers dispersed therein. The low modulus fibers were bicomponent acrylic fibers of 0.7 mils average diameter cut to ¾-inch staple length. They were dispersed by gradually placing groups of fibers on the surface of the heated corn syrup and stroking them into the syrup by a vertical motion with a teflon cylinder. The dispersion was cooled to room temperature prior to spinning and appeared to be homogenous.

The two dispersions prepared above were spun into yarn employing the apparatus described herein and specifically wherein the spinning head employed was that illustrated in FIG. **3** not further modified and the rotating tube comprised a 6 mm internal diameter glass tube of 6-inch length. The two fiber dispersions described above were added respectively to the high modulus fiber dispersion pressure vessel **1′** and the low modulus fiber dispersion pressure vessel **1**. Spinning of yarn through the apparatus was initiated by pressuring the vessel **1** containing the low modulus fiber dispersion at 25 psig and the high modulus dispersion vessel **1′** at 18 psig and opening the two valves **6** and **6′** in the respective feed lines. The rotating tube **10** was driven initially at a rotation of 1,500 rpm and gradually increased to 2,700 rpm. The take-up reel **17** was adjusted to impose minimum tension on the yarn being formed and thus correlated with its rate of production. When the corn syrup carrier liquids appeared at the effluent cup **31**, probing of the cup with a stirring rod picked up the yarn **15** and it was led over the snubbing roll **16** and to the take-up reel **17**. Continuous spinning was established and yarn produced at the initial pressure settings on the vessels **1** and **1′** had relatively high twist increasing as the speed of the rotating tube was increased. Qualitative inspection of the yarn under a microscope revealed a core of glass fibers axially aligned with the low modulus acrylic fibers wrapped about them at a relatively high helix angle.

The flow rates were modified and spinning continued with the low modulus dispersion vessel **1** being pressurized at 40 psig while the high modulus vessel was held at the same pressure of 25 psig. Concurrently the speed of rotation of the rotating tube was increased to 3,600 rpm. With no change in the take-up velocity the yarn produced under these conditions again was found to have a core of aligned glass fibers but with the low modulus wrapping fibers of relatively low twist or helix angle because of the increased rate of flow. Both yarns produced were suitable for use as reinforcing yarns in molding reinforced composites.

EXAMPLE 2

In this example a composite yarn employing the same glass high modulus fibers as in Example 1 and triacetate low modulus fibers was produced. The same dispersion as described in Example **1** of the ½-inch staple glass fibers comprise the high modulus fiber dispersion used. The low modulus fiber dispersion comprised 12 grams of ¾-inch staple triacetate fibers of 0.94 mils diameter dispersed in a 1,400 ml sample of the same corn syrup of approximately 130 poise viscosity. The dispersion of the low modulus fibers was carried out with the corn syrup at room temperature but using the stroking technique described above with a 2-inch Teflon cylinder. A composite yarn was spun from the same apparatus described above with the exception that the spinning head illustrated in FIG. 3 employed the longer barrel illustrated in FIG. 5 and the rotating tube 10 comprised a 13/64-inch internal diameter stainless steel tube of 6-inch length. In this example the spinning was initiated by pressuring the low modulus dispersion vessel at 40 psig and the high modulus dispersion vessel at 30 psig. The spinning speed of the rotating tube was 3,100 rpm and the velocity of the take-up reel was set at 3.75 inches per second. A composite yarn was produced upon initiation of the flow and continuous yarn production ensued until the dispersion of low modulus fibers was exhausted. The composite yarn produced contained 10.6 volume percent of glass fibers and was found, upon microscopic examination, to consist of a core of aligned glass fibers with a wrapping of the peripheral low modulus fibers at a relatively low helix angle. The yarn produced was quite suitable for use in molding reinforced composites, preferably after charring and burning off of the cellulosic fibers.

EXAMPLE 3

A. A composite yarn of silicon carbide whisker fibers and triacetate fibers was produced employing the same apparatus as described in Example 2 above. The high modulus fiber dispersion was composed of 6.5 grams of silicon carbide whiskers of variable length averaging approximately 0.25 inch dispersed by rotating a 2-inch Teflon cylinder in 900 ml of a corn syrup of approximately 130 poise viscosity. The low modulus fiber dispersion was composed of 25 grams of the same ¾-inch staple length triacetate fibers employed in Example 2 dispersed in a 1,400 ml sample of a different corn syrup of approximately 350 poise viscosity by the stroking method described above. For spinning the speed of the rotating tube was set at 2,300 rpm and the speed of the take-up reel was 2.3 inches per second. Spinning was initiated by pressuring the dispersion vessels respectively at 30 psig for the low modulus dispersion and 25 psig for the high modulus dispersion. Initially no carbide whiskers appeared in the yarn until these pressure settings were varied, by increasing the pressure on the high modulus dispersion to 29 psig. The best spinning was obtained at pressures of 50 psig on the high modulus dispersion and 65 psig on the low modulus fiber dispersion while reducing the speed of rotation of the rotating tube to from 1,800 to 1,900 rpm. At these settings a composite yarn containing the whisker fibers was produced. In this yarn the whisker fibers of greater than one-fourth inch in length were generally aligned as core fibers wrapped about with the triacetate low modulus fibers, but those whisker fibers of one-fourth inch or less in length were found dispersed about the outside of the yarn as a radial fuzz. This fuzz is produced for two reasons: The length of the fibers is less than the internal diameter of the core tube in the spinning head and thus are not well aligned when presented to the vortex and secondly because the dispersion of high modulus fibers was in a corn syrup of lower viscosity by a factor of 3 than the low modulus dispersion. This allowed the short whisker fibers to be more easily displaced from their core position particularly if they were not already axially aligned because of short length.

B. A different composite yarn was produced employing the same dispersion of silicon carbide whiskers of an average 0.25-inch length dispersed in the corn syrup of approximately 130 poise as in A above. In this instance the low modulus fibers comprised glass fibers of ¾-inch staple length and 0.163 mils diameter. Twenty-one grams of these glass fibers were dispersed in a sample of 1,400 ml of a corn syrup of approximately 350 poise viscosity by the stroking method described above. Yarn was spun with the same apparatus described above in which the speed of the rotating tube was 1,050 rpm and the take-up reel speed was 0.63 inches per second. Pressures on the dispersion supply vessels were 41 psig for the low modulus slurry and 31 psig for the high modulus dispersion. Continuous spinning of 50 feet of yarn was carried out. The yarn appearance varied but chiefly was represented by a helical twist of glass and whisker fibers intermingled, with a few longer whisker fibers aligned as a core. This intermingling of whisker fibers with the glass appeared to be due to the lower viscosity by a factor of three of the corn syrup dispersion of the whisker fibers since their displacement from the core is not protected by a higher viscosity medium at the point of junction of the two dispersion streams and at the vortex.

C. A repeat of the above example with the same fibers but with the viscosity of the high modulus fiber dispersion increased by boiling such dispersion to concentrate same. The viscosity of the corn syrup dispersion of silicon carbide whiskers was increased to approximately 1,100 poise. Thereafter spinning of this dispersion along with the dispersion of low modulus glass fibers in a corn syrup of approximately 350 poise resulted in the production of an excellent composite core yarn in which all of the whisker fibers of greater than one-fourth inch were axially aligned in a compact core along with the greater portion of the shorter whisker fibers. Disturbance of the flowing stream of core fibers is thus seen to be minimized by the use of a higher viscosity carrier fluid, and particularly one of at least one order of magnitude higher. All the yarns produced in the above examples were suitable for use as reinforcing members in composite matrices, but the samples of C above were most suitable in that they give the highest reinforcement and strength values because of the greater alignment achieved in the yarn.

EXAMPLE 4

A. A composite yarn of a glass fiber core and triacetate wrapping fibers was produced in the same equipment described above except that the short barrel spinning head illustrated in FIG. 3 was employed. The dispersion of low modulus fibers comprised triacetate fibers of ¾-inch staple length and 0.94 mils diameter 18 grams of which were dispersed in 1,400 ml of a corn syrup of approximately 130 poise viscosity. The high modulus fiber dispersion consisted of 9 grams of glass fiber of ¾-inch staple length and 0.41 mils diameter dispersed in 700 ml of a corn syrup of approximately 18,000 poise viscosity. Both types of fibers were dispersed in their respective carrier liquids by the respective stroking and rotation methods described above. Spinning was conducted with a rotating tube speed of 1,100 rpm and a take-up reel speed of 1.1 inches per second. The pressures on the respective dispersion vessels were 35 psig on the low modulus dispersion and 54 psig on the high modulus dispersion. Continuous spinning ensued and a well twisted composite yarn was spun having 12.6 volume percent glass concentrated as the axially aligned core thereof.

B. A composite yarn was produced using the same equipment described except that the long barrel spinning head illustrated in FIG. 5 was employed. In this case the same low modulus fiber dispersion in the same viscosity corn syrup was employed. The high modulus fiber dispersion consisted of the same glass fibers in the amount of 16.2 grams dispersed in 1,280 ml of a corn syrup of 350 poise viscosity. In this case the spinning was carried out with a rotating tube speed of 2,250 rpm and a take-up reel speed of 1.4 inches per second. The pressures were 30 psig on the low modulus dispersion and 40 psig on the high modulus dispersion. Continuous spinning resulted and the conditions appeared to be very close to optimum for the production of an excellent composite yarn with a compact core of glass fibers wrapped with low modulus acetate fibers.

C. An additional composite yarn was spun under varied conditions but using the same equipment as in B above. In this case of the high modulus fiber dispersion was the same as that described in B above but the low modulus dispersion consisted in 18 grams of ¾-inch triacetate fibers dispersed in 1,400 ml of a corn syrup of a viscosity of approximately 18,000 poise. The spinning conditions were a rotating tube speed of 1,000 rpm, a take-up reel speed of 0.85 inch per second and respective pressures of 84 psig on the low modulus dispersion and 66 psig on the high modulus fiber dispersion. Although in this instance the viscosity of the annular dispersion was higher by two orders of magnitude successful spinning was carried out. The higher flow rate of the low modulus fiber dispersion appeared to serve to help align the high modulus fibers in the core. Some twisting of the core fibers in the composite yarn was observed but they were axially aligned.

Samples of the composite yarn produced in A and C above were burned off at 600° C. Both samples, Sample A having a volume percent of glass fibers of 12.6 and Sample C having a volume percent of glass fibers of 15.2, show glass fiber cores of consistently axially aligned fibers after the removal by burning off of the cellulosic low modulus fibers.

EXAMPLE 5

A. Additional samples of composite yarns of glass fiber and cellulosic peripheral fibers were produced employing the same equipment described above with the long barrel spinning head of FIG. 5 employed.

The fiber dispersions employed were respectively a low modulus fiber dispersion of ¾-inch staple length triacetate fibers in the amount of 18 grams dispersed in 1,400 ml of a corn syrup of viscosity of 350 poise at room temperature and the high modulus fiber dispersion of two types of glass fibers, 16 grams of ¾-inch staple length glass fibers of 0.41 mils diameter and 4 grams of ¾-inch staple glass fiber of 0.5 mil diameter dispersed in 1,400 ml of a corn syrup with a viscosity of approximately 18,000 at room temperature. Both types of fibers were dispersed by the stroking technique described above. Spinning was conducted at a speed of the rotating tube of 860 rpm and a take-up reel speed of 0.45 inch per second with the pressure on the low modulus dispersion vessel of 50 psig and on the high modulus dispersion vessel of 75 psig. Under these conditions a very successful continuous spinning ensued in which a composite yarn with a compact core of glass fibers wrapped with the low modulus fiber was produced containing 35.9 volume percent of glass fiber. This yarn was subsequently employed in molding a composite.

B. An additional yarn sample from the same low modulus and high modulus fibers described in A was conducted under the same conditions with the exception that the speed of the rotating tube was increased to 930 rpm and a take-up reel speed increased to 1.1 inches per second. Under these conditions an excellent compact core composite yarn was produced containing a lower volume percent of glass fiber, 15 volume percent of glass. The yarn was very uniform and quite suitable for use as a reinforcing material for molded composites.

C. An additional example of composite yarn was produced under contrasting viscosity conditions. In this instance the same dispersion of the low modulus fibers as described in A above was employed but the high modulus fiber dispersion consisted of 19.4 grams of ¾-inch staple length red glass fiber of 0.5 mil diameter dispersed in 1,400 ml of a corn syrup of viscosity of 350 poise at room temperature. The spinning conditions employed were a rotating tube speed of 860 rpm, a take-up reel speed of 1.1 inches per second and the respective pressures of 60 psig on the low modulus dispersion and 75 psig on the high modulus fiber dispersion. Under these conditions a composite yarn was produced but the core fibers were not as compact nor uniformly aligned as in Samples A and B above. This may be attributed to the fact that the annular fiber dispersion having the same viscosity as that of the core fiber dispersion caused a certain dislodgement of the outer core fibers at the zone of juncture and at the vortex. Improved results with fluid vortex spinning of yarns is realized when the core fiber dispersion has a higher viscosity than that of the annular fiber dispersion by preferably a factor of one order of magnitude or greater.

EXAMPLE 6

In this example samples of composite core yarns of all glass composition were produced suitable for use directly as reinforcing fibers under high temperature molding conditions. The dispersions employed consisted of: a low modulus fiber slurry of 17 grams of ¾-inch staple length glass fiber of 0.163 mil diameter dispersed in 1,400 ml of a corn syrup of approximately 150 poise viscosity, while the high modulus fiber slurry consisted of 18.45 grams of red ¾-inch glass fiber of 0.5 mil diameter dispersed in 1,400 ml of a corn syrup of approximately 18,000 poise viscosity. These respective dispersions were spun using the same equipment as described above with the spinning head of FIG. 5.

A. The first sample was spun with a rotating tube speed of 1,400 rpm, a take-up reel speed of 1.25 inches per second and respective pressures of 64 psig on the low modulus fiber slurry and 71 psig on the high modulus fiber slurry with the core high modulus fiber dispersion having a viscosity 1 to 2 orders of magnitude higher than the annular fiber dispersion. A composite yarn of definite condensed core red glass fibers was produced. The spinning conditions employed were very nearly optimum for this type yarn as continuous spinning was carried out.

B. Another sample of composite yarn employing the same fiber dispersions as in A above was spun in which the spinning conditions were varied slightly. The same dispersions were spun employing a rotating tube speed of 1,400 rpm, a take-up reel velocity of 2.17 inches per second and pressure on the low modulus dispersion of 80 psig and on the high modulus dispersion of 70 psig. These conditions were maintained for the collection of one full layer of yarn on the take-up reel and then the speed of the rotating tube was increased to 2,200 rpm and an additional layer of yarn collected for one full reel width. The composite yarn produced was uniform, of good appearance and had a highly condensed red glass fiber core with the lower modulus clear glass fibers wrapped about same. After washing on the take-up reel the double layer of yarn was cut therefrom to form a mat which was molded as detailed below as a reinforcing medium in a composite molded structure.

EXAMPLE 7

Herein molded samples were produced from some of the yarns produced in the examples above. The all glass yarn sample of Example 6B and the glass core with triacetate yarn sample of Example 5A were molded into composite samples as produced without any subsequent burn-off or other treatment. The molded composites having a matrix of epoxide resin cured by amine curing agents (Shell Epon 828 with curing agent Z) had good flexural strength and flexural moduli comparable to an extruded composite structure of the same epoxide resin reinforced with ⅛-inch glass fibers oriented by such extrusion. The molded composite sample of all glass yarn of Example 6B measuring ¼ × 4 × 0.06 inches had an average flexural strength of 66,000 and an average flexural modulus of 3,000,000 in two tests on an Instron tester. The molded composite sample of glass and triacetate yarn of Example 5A, molded without burning out the triacetate fibers into the same size sample with the same epoxide resin matrix had an average flexural strength of 42,700 and an average flexural modulus of 3,100,000 in two tests on the Instron tester. Thus, it is seen that the composite yarns of the present invention serve to produce molded composite structures of good strength and modulus when reinforced with such yarns.

It will be understood that the foregoing details of apparatus, process and composite yarns of the invention are given by way of example only and that modification can be made to suit the requirements of various fibers and viscous fluids without departing from the scope of the invention as defined by the claims.

I claim:

1. A process of fluid vortex spinning which comprises

a. forming a dispersion of discrete high modulus refractory staple fibers in a viscous carrier liquid,
b. forming a second dispersion of discrete lower modulus staple fibers in a viscous carrier liquid,
c. establishing a flowing stream of the dispersion of lower modulus fibers through a passage the end portion of which is of increased internal diameter,
d. establishing a flowing stream of the dispersion of high modulus refractory fibers through a second passage the end portion of which is concentric with and terminates within the enlarged portion of the first passage and is located along the axis thereof,
e. introducing the stream of the dispersion of high modulus refractory fibers axially into the center of the flowing stream of the dispersion of lower modulus fibers,
f. rotating about its axis the terminal portion of the joined stream of both dispersions thereby to produce a yarn of an axially aligned core and helically wrapped annular fibers, and
g. separating the carrier liquids from the yarn so produced.

2. The process of fluid cortex spinning of claim **1** wherein the high modulus refractory fibers have a staple length of from about one-fourth inch to about 1.5 inches.

3. The process of fluid vortex spinning of claim **1** wherein the high modulus refractory staple fibers are glass fibers.

4. The process of fluid vortex spinning of claim **1** wherein the high modulus refractory staple fibers are whisker fibers.

5. The process of fluid vortex spinning of claim **1** wherein the high modulus refractory staple fibers are silicon carbide whisker fibers.

6. The process of fluid vortex spinning of claim **1** wherein the lower modulus fibers have a staple length of three-eighths inch to about 1.5 inches.

7. The process of fluid vortex spinning of claim **1** wherein the lower modulus staple fibers are glass, cellulosic or synthetic polymeric staple fibers.

8. The process of fluid vortex spinning of claim **1** wherein the carrier liquids have viscosities of from about 30 to about 20,000 poise.

9. The process of fluid vortex spinning of claim **1** wherein the carrier liquids are corn syrups.

10. The process of fluid vortex spinning of claim **1** wherein the carrier liquid of the dispersion of high modulus fibers has a higher viscosity than the carrier liquid of the dispersion of lower modulus fibers.

11. The process of fluid vortex spinning of claim **1** wherein the carrier liquid of the dispersion of high modulus fibers has a higher viscosity by at least an order of magnitude than the viscosity of the carrier liquid of the dispersion of lower modulus fibers.

12. The process of fluid vortex spinning of claim **1** wherein the rate of flow of the dispersion of lower modulus fibers is at least equal to that of the dispersion of high modulus fibers.

13. The process of fluid vortex spinning of claim **1** wherein the rate of flow of the dispersion of lower modulus fibers is from 1.1 to 1.7 times the rate of flow of the dispersion of high modulus fibers.

14. The process of fluid vortex spinning of claim **1** wherein in Step (f) the fluid vortex produced by the rotation of the terminal portion of said joined stream is caused to form within a zone of reducing internal diameter of said first passage downstream from the enlarged portion of said first passage.

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