Abstract: The present invention provides a forming tube for use in a fiber winding operation, the forming tube comprising: a central region comprising a wall having a generally cylindrical configuration; and an end region extending from the wall of the central region, the first end region comprising a wall having an outer surface sloped outwardly from an inner edge of the end region to an outer edge of the end region. In one nonlimiting embodiment of the invention, the end region is a first end region, and the forming tube further comprises a second end region symmetrical to the first end region and extending outwardly from an opposing end of the wall of the central region opposite the first end region.
FORMING PACKAGES, FORMING TUBES 
AND FIBER CAKES FOR GLASS FIBERS

Cross Reference to Related Patent Application
This application claims the benefit of U.S. Provisional Application No. 
60/136,536, filed May 28, 1999.

Field of the Invention
The present invention relates generally to forming tubes for use in 
continuous fiber forming operations, and forming packages and fiber cakes 
formed therefrom.

Background of Invention
In typical glass fiber forming operations, glass fibers are attenuated 
from a fiber forming apparatus, gathered into one or more strands and wound 
continuously onto a removable sleeve or "forming tube" positioned over a 
collet of a winding apparatus. The assemblage of fibers on the forming tube 
is referred to herein as a "fiber cake". The combination of the fiber cake on 
the forming tube is referred to herein as a "forming package". Once the 
desired amount of glass (typically a certain weight) has been built upon the 
surface of the tube, the forming package is removed from the collet for further 
processing. Conventional forming tubes are cylindrical in shape and typically 
formed from reinforced paper. Methods and equipment for forming glass 
fibers and forming packages are well known to those skilled in the art.

The amount of glass that can be built upon a given forming tube will 
vary depending upon several factors, including but not limited to, the diameter 
of the glass fibers, the number of fibers in a strand, the number of strands 
being wound, the strand tension, the mass of the collet fingers and the 
winding pattern, as well as the future processing steps to which the glass will 
be subjected. For example, in typical textile glass forming operations, the 
winding pattern must be designed such that the continuous strand can be
unwound (commonly referred to as "pay-out") from the outside of the package on a twisting frame. Generally, this requires that the glass strand be built upon the surface of the forming tube such that the glass strands in each successive layer that is wound are generally oriented in a different direction relative to the preceding layer. Additionally, it is advantageous to distribute the glass as uniformly as possible across the length of the forming tube in order to maximize the size and weight of forming packages. In order to achieve both the necessary pay-out performance and the maximum utilization of the forming tube, the strand is laid onto the forming tube in a zigzag pattern by a spiral as the collet of the winder is reciprocated back and forth. Forming packages formed in this manner typically comprise fiber cakes that have a generally cylindrical central region having a generally uniform thickness, and end or shoulder regions extending generally outward from the central region and having a thickness that tapers downward from the central region toward an edge of the fiber cake. The length of the central region of the fiber cake corresponds roughly to the length of the stroke of the reciprocating collet, whereas the length of the shoulder regions corresponds roughly to about one half the length of the spiral. For more information on the effect of these parameters on forming packages, see K. Loewenstein The Manufacturing Technology of Continuous Glass Fibres (3rd Ed. 1993) at pages 180-186, which are hereby incorporated by reference.

As the continuous fiber is built upon the forming tube, the effective diameter of the central portion of the forming package is increased with each successive layer of fiber that is laid down. This results in a taper of the shoulder(s) of the fiber cake and a slope along the outer surface of the shoulder(s). If the slope along the surface of the shoulder(s) of the fiber cake becomes too steep and/or the strand forming tension is too large, the shoulders can become unstable due to slippage of the glass strands down the inclined surface of the shoulder. Such slippage (also called "sloughing" or
“rolling”) of the strands is highly undesirable as it creates pay-out problems, as well as abrades the underlying glass fibers thereby reducing the overall quality of the product. In order to prevent sloughing, the amount of glass used to form textile forming packages and the shape of the forming package is typically carefully controlled. It will be recognized by one skilled in the art that the maximum permissible weight of the forming package, i.e. the weight above which sloughing of the inclined shoulders of the fiber cake becomes a problem, will depend upon several factors, including the base collet diameter, the stroke length, the shoulder length, and the strand forming tension. For example, the maximum permissible weight of a textile forming package comprising G-75 fiber formed on a collet having a 12 inch (about 30.48 centimeters) base using a 9 inch (about 22.86 centimeter) stroke length, a 1.5 inch (about 3.81 centimeter) shoulder length, and a strand tension of about 300 grams is about 10 kilograms (about 22 pounds). Such weight limitations preclude the production of larger forming packages that would provide for increased productivity and reduced labor costs. Accordingly, there is a need for methods and apparatus that will permit large forming packages to be formed on forming tubes.

U.S. Patent 5,222,676 discloses a method of forming a yarn package (or bobbin) having a large amount of glass wound thereon and a uniform yarn draw-off tension, by winding the yarn on a tube at a constant traverse length up to a limit diameter D, and thereafter reducing the traverse length such that the length over which the yarn is laid down is shortened (column 1, lines 45-55).

U.S. Patents 4,063,688 and 4,055,311 disclose bobbins having end regions having a reduce diameter as compared to the center region of the bobbin to accommodate yarn accumulation in the end regions. When yarn is wound onto the bobbin using a reciprocating traverse device, the end regions of the bobbin tend to accumulate more yarn then the central region of the
bobbin due to the reversal of the traverse direction in the end regions. By decreasing the diameter of the bobbin in the end regions, the accumulation can be accommodated resulting in improved bobbin uniformity.

U.S. Patents 5,853,133 and 4,371,122 teach methods and apparatus for producing fiber packages having square ends. U.S. Patent 5,853,133 discloses a winding apparatus having a roller bail divided into two separate rollers each mounted to contact the package surface at one of the edges of the package as it is built to hold the strand in place on the package. U.S. Patent 4,371,122 discloses a method and apparatus for winding strand material into a package having a cam traverse mechanism, the speed of which can be continuously increased relative to that of the mandrel to counteract or eliminate reduction of the helix angle at which the strand is deposited on the package build. Reduction of the helix angle limits the winding speed at which square edge packages can be produced and prevents stable package builds at high speeds (column 2, lines 3-7).

However, there remains a need for a method and apparatus that permits the formation of large forming packages, particularly large textile forming packages, by reducing or eliminating sloughing of the fiber cake shoulders and that can be implemented without substantially changing current production equipment or methods.

**Summary of Invention**

The present invention provides a forming tube for use in a fiber winding operation, the forming tube comprising: a central region comprising a wall having a generally cylindrical configuration; and an end region extending from the wall of the central region, the first end region comprising a wall having an outer surface sloped outwardly from an inner edge of the end region to an outer edge of the end region. In one nonlimiting embodiment of the invention, the end region is a first end region, and the forming tube further comprises a
second end region symmetrical to the first end region and extending outwardly from an opposing end of the wall of the central region opposite the first end region.

The present invention further provides a forming package comprising:

(a) a forming tube comprising: (i) a central region comprising a wall having a generally cylindrical configuration; and (ii) an end region extending from an end of the central region, the end region comprising a wall having an outer surface sloped outwardly from an inner edge of the end region to an outer edge of the end region; and (b) a fiber cake comprising at least one continuous fiber wound about at least a portion of an outer surface of the wall of the central region and at least a portion of the outer surface of the wall of the end region. In one nonlimiting embodiment of the invention, the end region of the forming tube is a first end region, and the forming tube further includes a second end region symmetrical to the first end region and extending from an opposing end of the central region of the forming tube. In addition, the fiber cake comprises a central region overlaying at least a portion of the central region of the forming tube and first and second tapered shoulder regions extending outward from opposing ends of the central region of the fiber cake and overlaying at least a portion of the first and second end region of the forming tube, respectively. Each tapered shoulder region includes a first surface that slopes inwardly from an outer surface of the central region of the fiber cake and a second surface that slopes outwardly from an inner surface of the central region of the fiber cake.

The present invention also provides a fiber cake comprising at least one continuous fiber wound into a generally cylindrical configuration, the fiber cake comprising: a central region comprising a generally cylindrically shaped wall having an outer surface and an inner surface and a generally uniform wall thickness; and a shoulder region extending outwardly from an end of the central region, the shoulder region having a first surface sloped inwardly from
the outer surface of the central region of the fiber cake and a second surface sloped outwardly from the inner surface of the central region of the fiber cake such that the first and second surfaces of the shoulder region converge at an outer edge of the fiber cake. In one nonlimiting embodiment of the invention, the shoulder region is a first shoulder region and the fiber cake further includes a second shoulder region extending outwardly from an opposing end of the central region, the second shoulder region symmetrical to the first shoulder region and having a first surface tapered inwardly from the outer surface of the central region of the fiber cake and a second surface tapered outwardly from the inner surface of the central region of the fiber cake such that the first and second surfaces of the second shoulder region converge at an opposing outer edge of the fiber cake.

**Brief Description of the Drawings**

Figure 1 is a schematic of a typical glass fiber forming station. Figure 2 is a cross-sectional view of a conventional forming package incorporating a prior art forming tube. Figure 3 is a view similar to Figure 2 illustrating a forming package, forming tube and fiber cake incorporating features of the present invention. Figure 4 is an enlarged cross-sectional view of a selected portion of an alternate embodiment of a forming package, forming tube and fiber cake incorporating features of the present invention. Figures 5 and 6 are views similar to Figure 4 of additional alternate embodiments of the present invention. Figure 7 is an enlarged cross-sectional view of a selected portion of a fiber cake incorporating features of the present invention.
Detailed Description of the Invention

The present invention discloses a novel type of forming tube for use in fiber forming operations, and novel forming packages and fiber cakes formed therefrom. The forming tubes of the present invention are advantageous in providing improved package build geometries that permit formation of large forming packages having good pay-out performance and thereby provide for increased operation efficiency, reduced labor, and improved quality. In particular, improved consistency in the continuous fibers formed using forming tubes incorporating features of the present invention can be achieved.

While the disclosure of the present invention will generally be discussed in connection with its use in continuous glass fiber forming operations, it will be recognized by one skilled in the art that the present invention is suitable for use with any continuous fiber forming operation wherein the fibers are wound to form a forming package. Similarly, it will be recognized by those skilled in the art that the forming packages and fiber cakes of the present invention formed using the forming tubes of the present invention can be made using any type of continuous fiber.

The forming tubes of the present invention are particularly well suited for use in glass fiber forming operations. Glass fibers suitable for use in the present invention can be formed from any type of fiberizable glass composition known to those skilled in the art, including, but not limited to, those prepared from fiberizable glass compositions such as “E-glass”, “A-glass”, “C-glass”, “D-glass”, “R-glass”, “S-glass” and E-glass derivatives.

As used herein, “E-glass derivatives” means glass compositions that include minor amounts of fluorine and/or boron, and preferably are fluorine-free and/or boron-free. Furthermore, as used herein, “minor” means less than 0.5 weight percent fluorine and less than 5 weight percent boron. Preferred glass fibers are formed from E-glass and E-glass derivatives. Such compositions
are well known to those skilled in the art. If additional information is needed, such glass compositions are disclosed in Loewenstein at pages 30-44, 47-60, 115-122 and 126-135 and U.S. Patent Nos. 4,542,106 (see column 2, line 67 through column 4, line 53) and 5,789,329 (column 2, line 65 through column 4, line 24), which are hereby incorporated by reference.

The glass fibers can have a nominal filament diameter ranging from about 3.0 to about 35.0 micrometers (corresponding to a filament designation of B through U and above). For further information regarding nominal filament diameters and designations of glass fibers, see Loewenstein at page 25, which is hereby incorporated by reference.

As discussed above, the present invention is useful in fiber forming operations other than glass fiber forming operations (i.e. "non-glass fiber" forming operations). Suitable non-glass fibers which can be used in accordance with the present invention are discussed at length in the Encyclopedia of Polymer Science and Technology, Vol. 6 (1967) at pages 505-712, and U.S. Patent Application Serial No. 08/828,212 at page 15, line 21 through page 17, line 10, which are hereby incorporated by reference.

Referring to Figure 1, a forming station 10 of a glass fiber forming operation includes a forming apparatus 12 having a strand supply device 14 for supplying at least one strand 16 to a winder 18. As used herein, the term "strand" means a plurality of continuous fibers 20. Fibers 20 are supplied from a glass melting furnace or forehearth (not shown) containing a supply of a fiber forming molten glass 22 and having a metal bushing 24 attached to the bottom of the forehearth. The molten glass 22 is drawn through a plurality of nozzles 26 in the bushing 24 and attenuated by the winder 18 to form glass fibers 20. Water sprays 28 can be positioned below the bushing 24 to spray water at the newly formed fibers 20 to cool them after being drawn from the bushing 24. For clarity in the drawing, the refractory materials, cooling tubes and fins typically surrounding the metal bushing have been omitted.
Alternatively, the forming apparatus 12 can be, for example, a forming device for synthetic textile fibers or strands in which fibers are drawn from nozzles, such as, but not limited to, a spinneret, as is known to those skilled in the art. Typical forehearths and glass fiber forming arrangements are shown in Loewenstein at pages 85-107 and pages 115-135, which are hereby incorporated by reference.

Typically, after the glass fibers 20 are drawn from the bushing 24, they are contacted with an applicator 30 to apply a coating or sizing composition to at least a portion of the surface of the glass fibers 20 to protect the fiber surface from abrasion during processing. As used herein, the terms "size", "sized" or "sizing" refer to the coating composition commonly applied to the fibers 20 immediately after formation. Typical sizing compositions for glass fibers are aqueous and can include as components, among other constituents, film-formers, lubricants, coupling agents, and emulsifiers. Non-limiting examples of sizing compositions are disclosed in U.S. Patent Nos. 3,997,306 (see column 4, line 60 through column 7, line 57); 4,305,742 (see column 5, line 64 through column 8, line 65) and 4,927,869 (see column 9, line 20 through column 11, line 19), and U.S. Patent Application Serial Nos. 08/787,735 (see page 7, line 1 through page 12, line 13 and page 28, line 15 through page 39, line 10) and 08/984,429 (see page 10, line 1 through page 15, line 17), which are hereby incorporated by reference. Additional information and further non-limiting examples of suitable sizing compositions are set forth in Loewenstein at pages 237-291, which is hereby incorporated by reference.

The applicator 30 typically includes a roller 32 having a generally cylindrical surface positioned within an enclosure 34. The enclosure 34 further includes a sizing reservoir. The roller 32 is positioned within the enclosure 34 such that a portion of the roller surface is submerged within the sizing composition. As the roller 32 is rotated within the enclosure 34, its
surface is coated with a film of the sizing which thereafter coats at least a portion of the surface of the fibers which pass over and contact the roller surface, in a manner well known in the art. For additional information regarding applicators, see Loewenstein at pages 165-172, which is hereby incorporated by reference.

A gathering device 36 mounted at the forming station 10 in any convenient manner is used to gather selected groups of fibers 20 and form one or more strands 16. The strands 16 typically have about 100 to about 15,000 fibers per strand, and preferably about 200 to about 7,000 fibers, and are drawn through the gathering device 36 at speeds of about 2,500 to about 18,000 feet per minute (about 762 to about 5,486 meters per minute). Although not limiting in the instant invention, the gathering device 36 typically divides the fibers 20 to form up to about 20 strands.

The forming apparatus 12 also includes a spiral 38 for placing the strands 16 in a given pattern on a forming tube 40 positioned upon a reciprocating, rotatable collet 42 of the winder 18 to produce a forming package 44. Sidewalls 46 are positioned to generally enclose the forming station 10 and isolate the bushing 24, applicator 30, gathering device 36, strands 16 and fibers 20 from similar elements in adjacent forming stations.

Sidewalls 46 also provide support for other devices, such as, for example, additional water sprays and air cooling ducts, that can be used at the forming station 10 in forming the strands 16.

Figure 2 illustrates a cross section of a forming package 244 on a conventional forming tube 240. The forming tube 240 is typically a reinforced paper tube. The forming package 244 comprises a fiber cake 248 having a central region 250 which has a generally constant thickness 252 and opposing tapered end regions or shoulder regions 254 and 256 extending generally outward from the central region 250. The thickness 252 of the
central region 250 of the fiber cake 248 is typically no greater than about 1 inch (2.54 cm).

Referring now to both Figures 1 and 2, as previously discussed, tapered opposing shoulder regions 254 and 256 are the result of the spiral 38 positioning the glass fiber strands 16 across the length of the forming tube 40, 240 as is well known in the art. As the strands 16 are wound around forming tube 40, 240, the fibers are under tension. If this tension becomes too high and/or the slope of outer surface 258 and 260 of the shoulders 254 and 256, respectively, becomes too steep, the glass fiber strand 16 along inclined surfaces 258 and 260 can slide downward and outward thereby adversely effecting the formation of the forming package 240. In addition, this condition can also adversely effect pay-out and quality of the final product as previously discussed.

In the present invention, the forming tube is modified as shown in Figures 3-5 to minimize the potential for sloughing of the shoulders of fiber cakes built thereon. Referring now to Figure 3, forming package 344 of the present invention includes forming tube 340 and fiber cake 312. The forming tube 340 of the present invention comprises a central region 350 and at least a first end region 354 extending from one end of the central region 350 of the forming tube 340, and in addition, preferably a second end region 356 extending from an opposing end of central region 350. Central region 350 comprises a wall 362 having a generally cylindrical configuration and preferably a uniform thickness 364. The first end region 354 comprises a wall 366 having an outer surface 368 that is sloped outward from an inner edge 370 of the first end region 354 toward an outer edge 372 of the first end region 354 to provide a generally conically shaped outer surface 368. In the particular embodiment of the forming tube 340 shown in Figure 3, the wall 366 has a varying thickness, i.e. wall thickness changes from thickness 364 at inner edge 370 to a greater thickness 374 at the outer edge 372 of the first
end region 354. The fiber cake 312 includes a central region 320 which overlays central region 350 of forming tube 340, and first and second shoulder regions 310 and 311, which overlay at least a portion of first end region 354 and second end region 356, respectively of the forming tube 340.

The first end region 354 can be formed in a manner such that it is integral with the central region 350 of the forming tube 340, or the first end region 354 can be removably attached to the central region 350. For example, and without limiting in the present invention, the wall 362 of the central region 350 can be slotted to accept corresponding tabs on the wall 366 of the first end region 354 such that the first end region 354 and the central region 350 can be mated together to form forming tube 340.

If the forming tube 340 includes a second end region 356, the second end region 356 can be configured in a manner similar to the first end region 354 with a wall 376 having an outer surface 378 that is sloped outward from an inner edge 380 of the second end region 356 toward an outer edge 382 of the second end region 356. Although not required, preferably the configuration of the second end region 356 is symmetrical to the configuration of the first end region 354.

In the particular nonlimiting embodiment of the invention shown in Figure 3, the rate of thickness change in walls 366 and 376 is uniform. However, a nonuniform rate of thickness change is also contemplated.

Alternatively, the thickness of walls of the end regions of the forming tube can be uniform. More particularly, in the embodiment of the invention shown in Figure 4, forming package 444 of the present invention includes forming tube 440 and fiber cake 412. The forming tube 440 includes a central region 450 with a wall 462 having a uniform thickness and a first end region 454 having a wall 466 with a uniform thickness. If desired required, the thickness of walls 462 and 466 can be the same. Although not shown in Figure 4, a second end region configured similar to the first end region 454
can be positioned at the opposing end of central region 450 in a manner similar to that shown in Figure 3 and discussed above.

Referring to Figure 3, walls 362, 366 and 376 of central region 350, first end region 354 and second end region 356, respectively, are preferably formed from a flexible material. As used herein, the term “flexible material” means a material that is capable of undergoing repetitious elastic deformation without becoming permanently deformed or embrittled. While the walls are preferably formed from a flexible material that permits the walls to be at least partially collapsed during processing steps subsequent to winding (such as end finding), if desired, they can also be formed from a rigid or semi-rigid material. As used herein, the term “rigid” means that the material is not capable of undergoing repetitious elastic deformation without becoming permanently deformed or embrittled; and the term “semi-rigid” means the material is capable of undergoing a limited amount of repetitious elastic deformation before becoming permanently deformed or embrittled.

Additionally, it is preferable that the material from which the walls 362, 366 and 376 are formed be resistant to abrasion from the glass fibers. In particular, if an outer surface 384 of wall 362, outer surface 368 of wall 366 and/or outer surface 378 of wall 376 becomes abraded or rough during use, the glass fibers can snag or break on the asperities on the surface when they are wound about the forming tube 340. Such damage can decrease the quality of the final product as well as contribute to breakout of the bushing during forming.

Furthermore, the material forming the forming tube walls preferably does not expand when spinning on the winder 18 (shown in Figure 1). More specifically, if the walls of the forming tube, and in particular wall 362 of the central region 350 of the forming tube 340 expand or stretch radially during winding, the forming tube can slip-off the collet, thereby stopping production.
In addition, materials that are resistant to creasing or localized deformation are preferred.

Non-limiting examples of suitable materials from which the walls 362, 366 and 376 can be formed from include materials such as, but not limited to, rubber materials, cellulosic materials and plastic materials. A nonlimiting example of a suitable cellulosic material is paper. Nonlimiting examples of plastic materials include polyester materials, epoxy materials, polyolefin materials, and combinations thereof. In one nonlimiting embodiment, the forming tube of the present invention is made of polypropylene and has a constant wall thickness throughout of about 0.05 to about 0.06 inches (about 1.27 to about 1.52 mm). Although it is preferred that the walls of the forming tube all be made of the same material, it should be appreciated that different walls or wall sections can be formed from a different materials or combinations of materials.

If desired, one or more of the walls and/or selected portions of the walls of the forming tube of the present invention can be reinforced to increase the stability and strength of the forming tube. More particularly, referring to Figure 5 which includes a forming package 544 similar to forming package 444 shown in Figure 4, and in particular a forming tube 540 similar to forming tube 440, wall 562 of the central region 550 of forming tube 540 includes one or more reinforcements 586. The reinforcements 586 can be any suitable reinforcement, such as, but not limited to, rigid ribs, hoops or belts. Although not limiting in the present invention, preferably, the reinforcements 586 are selected from the group consisting of continuous fiber reinforcements, discrete fiber reinforcements, particulate reinforcements, and combinations thereof. As used herein, the term “continuous fiber reinforcement” means any reinforcement formed from one or more continuous fibers and includes, but is not limited to, continuous fibers that have been gathered into strands, twisted, braided and/or cored. Non-limiting examples
of preferred continuous fiber reinforcements include continuous glass fibers, continuous carbon fibers, continuous metal fibers, continuous polymer fibers, and combinations thereof. Non-limiting examples of continuous glass fibers suitable for use as reinforcements include continuous E-glass fiber strands, continuous S-glass fiber strands, and continuous basalt glass fiber strands. A non-limiting example of a continuous metal fiber suitable for use in the present invention is a continuous steel fiber. Non-limiting examples of continuous polymer fiber suitable for use as reinforcements include continuous aramid fibers (such as Kevlar<sup>®</sup> fibers which are commercially available from E.I. DuPont de Nemours of Wilmington, Delaware), continuous polyester fibers, continuous polyamide fibers, and continuous polypropylene fibers.

Examples of discrete fiber reinforcements include, but are not limited to, discrete glass fiber reinforcements, discrete carbon fiber reinforcements, discrete ceramic fiber reinforcements, discrete metal fiber reinforcements, discrete polymer fiber reinforcements, and combinations thereof. The non-limiting examples of materials suitable for use as continuous fiber reinforcements discussed above can also be used to form the discrete fiber reinforcements of the present invention. The discrete fiber reinforcements can have any configuration known in the art, for example, the discrete fiber reinforcements can be whiskers or chopped fibers.

Examples of particulate reinforcements include, but are not limited to ceramic particles, mineral particles, clay particles, metal particles, polymer particles, and combinations thereof. The particles can have any configuration and morphology known in the art. Non-limiting examples of suitable configurations include solid particles, porous particles, and hollow particles. Non-limiting examples of suitable morphologies include spheres, platelets, and acicular particles. Suitable particulate reinforcements for use in the
present invention are discussed at length in G. Wypych, *Handbook of Fillers*, (2nd Ed. 1999), at pages 15-202, which are hereby incorporated by reference.

In one non-limiting embodiment of the present invention shown in Figure 5, wall 566 of first end region 554 is also reinforced with one or more reinforcements 588 which, if desired can be made of the same material and/or have the same construction as reinforcement 586. In another non-limiting embodiment of the present invention, only the walls of the end regions of the forming tube are reinforced. In yet another non-limiting embodiment of the present invention, only the wall of the central region of the forming tube is reinforced. In addition, it should be appreciated that the reinforced walls of the forming tube can have a uniform or varying thickness as discussed earlier.

Preferably, the weight of forming tube 340, 440, 540 is less than about 5 pounds (about 2.27 kilograms), more preferably less than about 2 pounds (about 0.91 kilograms), and most preferably less than about 1 pound (about 0.45 kilograms). Lighter forming tubes are preferred for ease of handling; however, if the forming tube of the present invention is used in conjunction with an automated or robotic handling system, the forming tube can be heavier.

A forming package formed according to the present invention will now be discussed generally. As discussed earlier, the term "forming package" means a forming tube having an amount of continuous fiber wound thereabout and the term "fiber cake" means the wound assemblage of fibers. The fiber cake can be separated from the forming package by removing the forming tube to form a self-supporting structure.

The following discussion is directed to a configuration of a forming tube having a central region and a first end region of a forming tube, but it should be appreciated that the discussion applies similarly to a forming tube that further includes a second end region as discussed earlier and shown in
Figure 3. Referring now to Figure 4, the wall 466 of the first end region 454 of forming tube 440 has an outer surface 468 that is sloped in a generally outwardly direction from an inner edge 470 of the first end region 454 toward an outer edge 472 of the first end region 454. The outer surface 468 is sloped such that an angle $\alpha$ is formed between the outer surface 468 of wall 466 of the first end region 454 and a longitudinal central axis 490 of the forming tube 440, which in the embodiment of the invention shown in Figure 4 is parallel to surface 484 of central region 450 of forming tube 440. As discussed in detail below, the angle $\alpha$ is chosen to reduce the slope of the shoulder regions 410 of fiber cake 412 in order to reduce or eliminate sloughing. The angle $\alpha$ can range from about 1 degree to about 90 degrees, preferably ranges from about 5 degrees to about 60 degrees, and more preferably ranges from about 10 degrees to about 45 degrees.

With continued reference to Figure 4, the configuration of wall 466 of the first end region 454 of forming tube 440 reduces the slope of the outer surface 414 of shoulder region 410 of fiber cake 412 formed on forming tube 440, as compared to a fiber cake wound about a conventional forming tube, by raising the outer edge 416 of fiber cake 412, as will be discussed later in more detail. By reducing the slope of surface 414 of shoulder region 410, the shoulder region 410 of the fiber cake 412 is more stable and there is less of a tendency for sloughing of the fibers. This in turn will also reduce strand damage and twister breaks due to trapped ends by improving package payout. Furthermore, the forming tube 440 of the present invention permits the manufacture of larger forming package sizes than conventional forming tubes, which can substantially reduce manufacturing costs through increased productivity, because the potential for sloughing is reduced or eliminated. In addition, because of the configuration of the shoulder region 410, the speed of the yarn as it is wound around forming tube 440 will be more uniform, resulting in a more uniform forming tension and fiber diameter.
The angle $\beta$ of the outer surface 414 of the shoulder region 410 of fiber cake 412 formed on forming tube 440 depends on several factors, such as, but not limited to, strand tension, the lubricity of the coating on the fibers, the length of the spiral forming the package and the weight of the package.

Preferably, the angle $\alpha$ is chosen such that the outer surface 414 forms an included angle $\phi$ with an outer surface 418 of central region 420 of fiber cake 412 that is at least about 155 degrees, preferable at least about 160 degrees, and more preferably at least about 165 degrees. This corresponds to a slope of outer surface 414 of shoulder region 410 of fiber cake 412, i.e. an angle $\beta$, no greater than about 25 degrees, preferably no greater than about 20 degrees, and more preferably no greater than about 15 degrees.

As discussed earlier, the slope of surface 414 of end region 410 of fiber cake 412 is reduced by sloping wall 466 of first end region 454 of forming tube 454, which in turn raises outer edge 416. Although not limiting in the present invention, in the particular embodiment shown in Figure 4, the first end region 454 of forming tube 440 is configured to raise outer edge 416 of shoulder region 410 of fiber cake 412 a distance 422 above an inner surface 424 of the fiber cake 412 that is equal to approximately half the thickness 426 of the central region 420 of the fiber cake 412, i.e. edge 416 is approximately equidistant between outer surface 418 and inner surface 424 of fiber cake 412. For example, and without limiting the present invention, if the width 228 of the shoulder 254 of fiber cake 248 formed on a conventional forming tube 240 as shown in Figure 2 is 3 inches (7.62 cm) and the thickness 252 of the central region 250 of the fiber cake 248 is 1 inch (2.54 cm), angle $\phi'$ would be about 161.6 degrees and the angle $\beta$ of the outer surface 258 of shoulder region 254 would be about 18.4 degrees. In forming tube 440 of the present invention as shown in Figure 4, the edge 416 of shoulder region 410 of fiber cake 412 is raised about 0.5 inches (about 1.27 cm) by sloping first end region wall 466. This produces an angle $\phi$ of about
170.5 degrees and reduces angle $\beta$ of the outer surface 414 of shoulder region 410 of the fiber cake 412 to about 9.5 degrees. This reduction in slope of the outer surface 414 from about 18.4 degrees to about 9.5 degrees reduces the possibility of the fiber strands sliding along surface 414 and allows for the production of a larger size package.

It should be appreciated that the angle $\alpha$ required to raise edge 416 the desired distance relative to the thickness 426 of central section 420 of the fiber cake 412 depends on where surface 468 of the first end region 454 of the forming tube 440 intersects surface 484 of the central region 450, i.e. inner edge 470, relative to where shoulder region surface 414 intersects fiber cake surface 418, i.e. edge 432. More particularly, referring to Figure 4 and continuing with the example discussed earlier, if inner edge 470 is vertically aligned with edge 432, an angle $\alpha$ of about 9.5 degrees will raise edge 416 approximately 0.5 inches without changing the overall length of the fiber cake 412. If the inner edge 470 is midway between edge 432 and outer edge 416 of fiber cake 412, an angle $\alpha$ of about 18.4 degrees will raise edge 416 the desired 0.5 inch distance.

In the embodiments of the invention shown in Figures 3-5, the end regions of the forming tubes provide a conical strand supporting surface having a generally uniform slope. However, it should be appreciated that the strand supporting surface of the end regions can be irregular. For example and without limiting the present invention, referring to Figure 6, forming package 644 includes forming tube 640 and fiber cake 612. Forming tube 640 includes a central region 650 and first end region 654 extending from one end of the central region 650. Surface 668 of first end region 654 is a curvilinear strand supporting surface providing a non-uniform sloping surface. The thickness of first end region 654 can be either uniform as shown in Figure 6 or it can vary as discussed earlier. If desired, all or selected portions of
central region 650 and/or first end region 654 can include reinforcements, as discussed earlier.

A fiber cake according to the present invention will now be discussed generally. Referring to Figure 7, there is shown an enlargement of a cross-section of a selected portion of a self-supporting fiber cake 712 having a central region 720 and at least one shoulder region 710 extending generally outward from the central region 720. The shoulder region 710 has an outer surface 714 sloped generally inwardly from the outer surface 718 of the central region 720 and a inner surface 734 sloped generally outwardly from the inner surface 724 of the central region 720. The outer surface 714 and the inner surface 734 of the shoulder region 710 are sloped such that the two surfaces converge to form an outer edge 716 on the fiber cake 712. Although not limiting in the present invention, preferably the outer surface 714 and the inner surface 734 converge at a height 722 above the inner surface 724 of the fiber cake 712 that is about half the distance 726 between the outer surface 718 and the inner surface 724 of the central region 720 of the fiber cake 712.

As discussed earlier, a fiber cake can be separated from a forming package to form a self-supporting structure by removing the forming tube from the forming package. Typically, this is done by collapsing the forming tube and pulling it out from the center of the fiber cake. If the forming tube of the present invention has one or more removably attached end regions, the removably attached end region can first be detached from the central region of the forming tube and then the central region of the forming tube can be removed from the forming package by collapsing or other suitable method known in the art. The fiber cake so formed can then be subjected to additional processing steps as required.

Methods of forming a forming package and fiber cake according to the present invention will now be discussed generally. Referring now to Figures
1, 3, and 7, one or more continuous fibers 20 are attenuated from bushing 24 and gathered together to form one or more strands 16 by gathering device 36 after having a sizing composition applied to the fiber surfaces. The strand 16 is then wound onto a forming tube 340 positioned on the rotating collet 42 of winder 18. The strand 16 is built upon at least a portion of the central region 350 of the forming tube 340, preferably upon the entire length of the central region 350, and at least a portion of the end region 354 of the forming tube 340 by the spiral 38. The spiral 38 lays the strand 16 down onto the surface of the forming tube in successive layers to form a fiber cake 312 as the collet 42 reciprocates back and forth along the axis of rotation of the collet 42 to form a forming package 344. After the desired amount of continuous strand 16 has been wound upon forming tube 340, forming package 344 is removed from the collet 42 of winder 18. The forming package 344 can then be subjected to further processing steps, such as end finding, drying or twisting, as required.

It will be recognized by one skilled in the art that the amount of continuous fiber that can be built upon the surface of the forming tube will depend upon factors such as the diameter of the collet (and forming tube), the length of the forming tube, the size and density of the continuous fiber, and the requirements of the final product. For example, although not limiting in the present invention, the weight of continuous G-75 glass fiber strands built upon the surface of a forming tube of the present invention having a diameter of about 12 inches (about 30.48 centimeters) is preferably greater than about 22 pounds (about 10 kilograms) and more preferably about 30 pounds (about 13.6 kilograms).

The present invention will now be illustrated by the following specific, non-limiting example.
EXAMPLE

Rigid tubes having a central region and first and second opposing end regions extending generally outward from the central region were formed from a glass fiber reinforced epoxy resin by filament winding onto a mandrel. After winding, the forming tubes were partially cured on the mandrel. The mandrel was then removed and the partially cured forming tubes were baked in an oven at about 350°F (about 177°C) for about four hours. The outer surface of each of the end regions of the forming tubes was sloped in a generally outward direction from the central region of the forming tube to form an angle \( \alpha \) of about 12 degrees.

After being fully cured, the forming tubes were placed onto a collet of a winder having a base collet diameter of about 12 inches (about 30.48 centimeters). Forming packages were then formed using a G-75 fiber strand, a collet stroke length of about 8.75 inches (about 22.23 centimeters), a shoulder length of about 1.75 inches (about 4.45 centimeters), a package thickness of about 1 inch (2.54 cm) and a fiber tension of about 300 grams. Approximately 30 pounds (about 13.63 kilograms) of G-75 fiber strand was built upon the surface of the forming tube. The angle \( \alpha \) of the end region walls was about 12 degrees and raised the outer edge of the forming package approximately half the thickness of the package. The resulting slope of the outer surface of the shoulder regions of the forming package, i.e. angle \( \beta \), was about 16 degrees. No sloughing of the shoulders was observed.

It will be appreciated by those skilled in the art that changes could be made to the embodiments described above without departing from the broad inventive concept thereof. It is understood, therefore, that this invention is not limited to the particular embodiments disclosed, but is intended to cover modifications which are within the spirit and scope of the invention, as defined by the appended claims.
THEREFORE, I CLAIM:

1. A forming tube for use in a fiber winding operation, the forming tube comprising:
   
   a central region comprising a wall having a generally cylindrical configuration; and
   
   an end region extending from the wall of the central region, the first end region comprising a wall having an outer surface sloped outwardly from an inner edge of the end region to an outer edge of the end region.

2. The forming tube according to claim 1, wherein at least selected portions of the forming tube is formed from materials selected from the group consisting of rubber materials, cellulosic materials, plastic materials, and combinations thereof.

3. The forming tube according to claim 2, wherein at least selected portions of the forming tube are formed from polypropylene.

4. The forming tube according to claim 1, wherein at least a portion of the forming tube is formed from a flexible material.

5. The forming tube according to claim 1, wherein the wall of the end region is formed from material different from the wall of the central region.

6. The forming tube according to claim 1, wherein the outer surface of the end region has a uniform slope.
7. The forming tube according to claim 1, wherein the outer surface of the end region has a non-uniform slope.

8. The forming tube according to claim 1, wherein selected portions of the forming tube include reinforcements.

9. The forming tube according to claim 8, wherein the reinforcements are selected from the group consisting of rigid ribs, hoops, belts, continuous fibers, discrete fibers, particles, and combinations thereof.

10. The forming tube according to claim 9, wherein the reinforcements are continuous fibers selected from the group consisting of continuous glass fibers, continuous carbon fibers, continuous metal fibers, continuous polymer fibers, and combinations thereof.

11. The forming tube according to claim 10, wherein the continuous metal fibers are steel fibers.

12. The forming tube according to claim 9, wherein the reinforcements are discrete fibers selected from the group consisting of discrete glass fibers, discrete ceramic fibers, discrete carbon fibers, discrete metal fibers, discrete polymer fibers, and combinations thereof.

13. The forming tube according to claim 9, wherein the reinforcements are particles selected from the group consisting of ceramic particles, mineral particles, clay particles, metal particles, polymer particles, and combinations thereof.
14. The forming tube according to claim 8, wherein the selected portions of the forming tube include at least a portion of the wall of the central region.

15. The forming tube according to claim 8 wherein the selected portions of the forming tube include at least a portion of the wall of the end region.

16. The forming tube according to claim 1, wherein the outer surface of the wall of the end region forms an angle with a longitudinal central axis of the forming tube ranging from about 1 degree to about 90 degrees.

17. The forming tube according to claim 16 wherein the angle ranges from about 5 degrees to about 60 degrees.

18. The forming tube according to claim 17 wherein the angle ranges from about 10 degrees to about 45 degrees.

19. The forming tube according to claim 1 wherein the wall of the end region has a constant thickness.

20. The forming tube according to claim 1, wherein the wall of the end region has a varying thickness.

21. The forming tube according to claim 1, wherein the wall of the end region is removably attached to the wall of the central region of the forming tube.
22. The forming tube according to claim 1, wherein the weight of the forming tube is less than about 5 pounds (about 2.27 kilograms).

23. The forming tube according to claim 1, wherein the end region is a first end region, and further comprising a second end region extending outwardly from an opposing end of the wall of the central region opposite the first end region.

24. The forming tube according to claim 23 wherein the second end region is symmetrical to the first end region.

25. A forming package comprising:
   (a) a forming tube comprising:
      (i) a central region comprising a wall having a generally cylindrical configuration; and
      (ii) an end region extending from an end of the central region, the end region comprising a wall having an outer surface sloped outwardly from an inner edge of the end region to an outer edge of the end region; and
   (b) a fiber cake comprising at least one continuous fiber wound about at least a portion of an outer surface of the wall of the central region and at least a portion of the outer surface of the wall of the end region.

26. The forming package according to claim 25 wherein the at least one continuous fiber is a continuous glass fiber.

27. The forming package according to claim 25, wherein the fiber cake comprises a central region overlaying at least a portion of the central
region of the forming tube and a tapered shoulder region extending outward from an end of the central region of the fiber cake and overlaying at least a portion of the end region of the forming tube, the tapered shoulder region including a first surface that slopes inwardly from an outer surface of the central region of the fiber cake and a second surface that slopes outwardly from an inner surface of the central region of the fiber cake.

28. The forming package according to claim 27, wherein the first and second surfaces of the tapered shoulder region of the fiber cake intersect and form an outer edge of the fiber cake that is positioned approximately equidistant between the inner surface of the central region of the fiber cake and the outer surface of the central region of the fiber cake.

29. The forming package according to claim 27, wherein the first surface of the shoulder region of the fiber cake has a slope no greater than about 25 degrees.

30. The forming package according to claim 29, wherein the first surface of the shoulder region of the fiber cake has a slope no greater than about 20 degrees.

31. The forming package according to claim 27, wherein the end region of the forming tube is a first end region, the forming tube further includes a second end region extending from an opposing end of the central region of the forming tube, the second end region comprising a wall having an outer surface sloped outwardly from an inner edge of the second end region to an outer edge of the second end region, the tapered shoulder region of the fiber cake is a first tapered shoulder region, and the fiber cake further includes a second tapered shoulder region extending outward from an
opposing end of the central region of the fiber cake and overlaying at least a portion of the second end region of the forming tube, the second tapered shoulder region including a first surface that slopes inwardly from the outer surface of the central region of the fiber cake and a second surface that slopes outwardly from the inner surface of the central region of the fiber cake.

32. The forming package according to claim 31, wherein the second end region is generally symmetrical to the first end region, and the second tapered shoulder region is generally symmetrical to the first tapered shoulder region.

33. A fiber cake comprising at least one continuous fiber wound into a generally cylindrical configuration, the fiber cake comprising:

   a central region comprising a generally cylindrically shaped wall having an outer surface and an inner surface and a generally uniform wall thickness; and

   a shoulder region extending outwardly from an end of the central region, the shoulder region having a first surface sloped inwardly from the outer surface of the central region of the fiber cake and a second surface sloped outwardly from the inner surface of the central region of the fiber cake such that the first and second surfaces of the shoulder region converge at an outer edge of the fiber cake.

34. The fiber cake according to claim 33, wherein the outer edge of the fiber cake is positioned approximately equidistant between the inner and outer surfaces of the central region of the fiber cake.

35. The fiber cake according to claim 33, wherein the shoulder region is a first shoulder region and further including a second shoulder
region extending outwardly from an opposing end of the central region, the
second shoulder region having a first surface tapered inwardly from the outer
surface of the central region of the fiber cake and a second surface tapered
outwardly from the inner surface of the central region of the fiber cake such
that the first and second surfaces of the second shoulder region converge at
an opposing outer edge of the fiber cake.

36. The fiber cake according to claim 35 wherein, the second
shoulder region is generally symmetrical to the first shoulder region.

37. The fiber cake according to claim 33, wherein the first surface of
the shoulder region of the fiber cake has a slope no greater than about 25
degrees.

38. The fiber cake according to claim 37, wherein the first surface of
the shoulder region of the fiber cake has a slope no greater than about 20
degrees.