(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
18 February 2010 (18.02.2010)

PCT

(10) International Publication Number
WO 2010/019964 A2

(51) International Patent Classification:
B65H 81/00 (2006.01)

(21) International Application Number:
PCT/US2009/054083

(22) International Filing Date:
17 August 2009 (17.08.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/089,124 15 August 2008 (15.08.2008) US

(71) Applicant *(for all designated States except US)*: **SIGMA-TEK, LLC** [US/US]; 808 East 1910 South, Suite 3, Provo, UT 84606 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **WILSON, Erich, A.** [US/US]; 906 North 2770 West, Provo, UT 84601 (US). **RIDGES, Michael, D.** [US/US]; 122 North 750 East, American Fork, UT 84003 (US). **KIPP, Michael, D.** [US/US]; 6533 Bull River Road, Highland, UT 84003 (US).

(74) Agents: **NORTH, Vaughn, W.** et al.; Thorpe North & Western, LLP, P.O. Box 1219, Sandy, UT 84091-1219 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE,

[Continued on next page]

(54) Title: COLLAPSIBLE MANDREL TOOLS AND ASSOCIATED METHODS FOR FABRICATION OF WOUND COMPOSITE ARTICLES

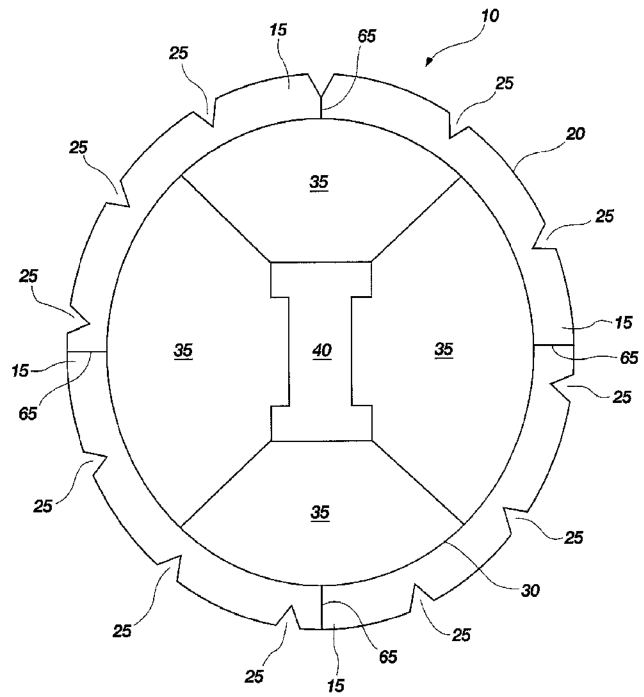

FIG. 1

(57) Abstract: Mandrels of various configuration, and action, including collapsible mandrels, to be used in forming composite articles with preselected three dimensional shapes and construction are disclosed and described. In one aspect, such a mandrel may have a plurality of discrete segments coupled about a longitudinal axis and collectively forming an enclosure with a substantially continuous exterior working surface. The working surface can have a network of intersecting grooves formed therein, and such grooves can cooperatively establish a substantially continuous interconnected lattice corresponding to the three dimensional geometric configuration to be imparted to a composite article formed. The mandrel may optionally include a removable core assembly to aid in collapse of the mandrel.

WO 2010/019964 A2

ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

Collapsible Mandrel Tools and Associated Methods for Fabrication of Wound Composite Articles

PRIORITY DATA

This application claims the benefit of U.S. Provisional Application Serial No. 61/089,124, filed August 15, 2008, which is incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates to collapsible mandrel devices and their use in methods for fabrication of wound composite articles. Accordingly, the present invention involves the fields of chemistry, materials science, and engineering technology.

BACKGROUND OF THE INVENTION

Mandrels have been used for years in a variety of industries for performing many different tasks, such as lathing. Many other tasks are aided by the use of an elongated cylinder which turns about a longitudinal axis. On example of mandrel use is in shaping metal pipes or glass. Mandrels have also been used in making jewelry such as a rings or bracelets. In addition, mandrels have been used in the formation of fiber composite articles where the fibers are wound around the mandrel to create a tube and then further cured or processed into a finished article.

SUMMARY OF THE INVENTION

The present invention sets forth mandrels for use in fabricating composite articles having desired three dimensional configurations or shapes. In one aspect, a collapsible mandrel in accordance with the present invention may include a plurality of discrete segments coupled about a longitudinal axis and collectively forming an enclosure with a substantially continuous exterior working surface. The working surface can have a network of intersecting grooves formed therein which cooperatively establish a substantially continuous interconnected lattice corresponding to the three dimensional geometric configuration to be imparted to a composite article formed using the mandrel.

The mandrel may further include a removable core assembly occupying an interior volume of the enclosure and coupling the segments together to form the enclosure. The interior volume can have a size sufficient to permit entry of a segment into a hollow portion thereof in order to allow the mandrel to collapse and be removed from the formed composite article.

In addition to the mandrel devices set forth herein, the present invention encompasses methods of shaping a fiber-based composite material to be consolidated into a three dimensional structure. In one aspect, such a method may include: 1) providing a mandrel as disclosed herein; 2) filling the grooves of the working surface of the mandrel with a composite material; 3) consolidating the composite material in the grooves into a three dimensional structure substantially corresponding to the geometric configuration cooperatively established by the grooves; 4) collapsing the mandrel into pieces inside of the three dimensional consolidated structure; and 5) removing the mandrel pieces from within the consolidated structure.

Furthermore, the present invention encompasses shaped fiber-based composite material assemblies. In one aspect, such an assembly may include: 1) a collapsible mandrel as recited herein; and 2) a fiber-based composite material preform filling the grooves of the interconnected lattice of the working surface of the enclosure on the mandrel.

There has thus been outlined, rather broadly, the more important features of the invention so that the detailed description thereof that follows may be better understood, and so that the present contribution to the art may be better appreciated. Other features of the present invention will become clearer from the following detailed description of the invention, taken with the accompanying drawings and claims, or may be learned by the practice of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a longitudinal cross-sectional view of a collapsible mandrel in accordance with an embodiment of the present invention.

FIG. 2a-h is show schematic views of various groove intersection configurations in accordance with various embodiments of the present invention.

FIG. 3a-h shows various geometric configurations for the cross-section shape of the grooves in accordance with various embodiments of the present invention.

FIG. 4 is a side perspective view of discrete segments to be assembled and collectively form an enclosure with a working surface for the mandrel in accordance with an embodiment of the present invention.

FIG. 5 is a longitudinal perspective view of a mandrel in accordance with an embodiment of the present invention.

FIG. 6 is a perspective view of a collapsible mandrel engaged with a finished composite article with one or more segments in a collapsed position for removal of the mandrel from the composite article in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

Before the present invention is disclosed and described, it is to be understood that this invention is not limited to the particular structures, process steps, or materials disclosed herein, but is extended to equivalents thereof as would be recognized by those ordinarily skilled in the relevant arts. It should also be understood that terminology employed herein is used for the purpose of describing particular embodiments only and is not intended to be limiting.

It must be noted that, as used in this specification and the appended claims, the singular forms “a,” “an,” and “the” include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to “an abrasive precursor” includes one or more of such precursors, and reference to “a pressure medium” includes reference to one or more of such materials.

Definitions

In describing and claiming the present invention, the following terminology will be used in accordance with the definitions set forth below.

As used herein, “fiber-based composite material” refers to a material comprised of carbon or other fiber (e.g., a carbon or glass fiber filament) and resin (e.g., polymer matrix) constituents.

As used herein "preform" refers to a green, uncured composite lay-up comprising the fiber material and resin composite as situated in grooves on a mandrel or other suitable mold, and that has undergone preliminary shaping but is not yet in its final consolidated or cured form.

As used herein, "working surface" refers to an exterior surface of a mandrel that is used to form, engage, sculpt, mold, hold, direct, guide, etc., a fiber-based composite material to be consolidated into a three dimensional article. Such working surface may have grooves or other technical or functional features formed therein and use of the term working surface refers to surfaces inside the grooves or other designs or features as well as those surfaces outside.

As used herein, the term "substantially" refers to the complete or nearly complete extent or degree of an action, characteristic, property, state, structure, item, or result. For example, an object that is "substantially" enclosed would mean that the object is either completely enclosed or nearly completely enclosed. The exact allowable degree of deviation from absolute completeness may in some cases depend on the specific context. However, generally speaking the nearness of completion will be so as to have the same overall result as if absolute and total completion were obtained. The use of "substantially" is equally applicable when used in a negative connotation to refer to the complete or near complete lack of an action, characteristic, property, state, structure, item, or result. For example, a composition that is "substantially free of" particles would either completely lack particles, or so nearly completely lack particles that the effect would be the same as if it completely lacked particles. In other words, a composition that is "substantially free of" an ingredient or element may still actually contain such item as long as there is no measurable effect thereof.

As used herein, the term "about" is used to provide flexibility to a numerical range endpoint by providing that a given value may be "a little above" or "a little below" the endpoint.

As used herein, a plurality of items, structural elements, compositional elements, and/or materials may be presented in a common list for convenience. However, these lists should be construed as though each member of the list is individually identified as a separate and unique member. Thus, no individual member of such list should be construed as a de facto equivalent of any other member of the same list solely based on their presentation in a common group without indications to the contrary.

Concentrations, amounts, and other numerical data may be expressed or presented herein in a range format. It is to be understood that such a range format is used merely for convenience and brevity and thus should be interpreted flexibly to include not only the numerical values explicitly recited as the limits of the range, but also to include all the individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly recited. As an illustration, a numerical range of "about 1 to about 5" should be interpreted to include not only the explicitly recited values of about 1 to about 5, but also include individual values and sub-ranges within the indicated range. Thus, included in this numerical range are individual values such as 2, 3, and 4 and sub-ranges such as from 1-3, from 2-4, and from 3-5, etc., as well as 1, 2, 3, 4, and 5, individually. This same principle applies to ranges reciting only one numerical value as a minimum or a maximum. Furthermore, such an interpretation should apply regardless of the breadth of the range or the characteristics being described.

Invention

The present invention provides mandrels for use in the fabrication of fiber-based composite articles. Examples of specific composite articles and methods for the fabrication thereof can be found in Applicants' copending U.S. Patent Applications filed August 17, 2009 under Attorney Docket Nos. 3095-002.NP, 3095-003.NP, and 3095-006.NP, each of which is incorporated herein by reference.

In some embodiments, the mandrels of the present invention may be collapsible. In other embodiments they may be solid. Referring now to Fig. 1 is shown a longitudinal cross-section view of a collapsible mandrel 10, having a plurality of discrete segments 15, coupled about a longitudinal axis and collectively forming an enclosure with a substantially continuous exterior working surface 20. The working surface has a network of intersecting grooves 25 formed therein. The network of grooves cooperatively establish a substantially continuous interconnected lattice corresponding to a three dimensional geometric configuration to be imparted to a composite article formed using the mandrel.

Referring again to Fig. 1 is shown a removable core assembly 30. In this particular embodiment, the core assembly includes a plurality of solid support members 35 and a central core 40. The removable core assembly occupies the interior volume of the enclosure formed by the assembled segments and couples the segments together to form the enclosure. Further, the interior volume of the enclosure has a volume of sufficient size to permit entry of a segment into a hollow portion thereof in order to collapse the mandrel.

The enclosure formed of segments 15 as shown in Fig. 1 is a substantially closed as the segments connect to or abut one another at the segment junctions 65. In some configurations, as with the one shown in Fig. 1, the segments can be tightly fitted leaving no gap between them, or substantially no gap. However, in other embodiments, the segments can be loosely fitted and a gap formed at the segment junctions 65.

The segments 15 used in forming the enclosure can take a variety of shapes and sizes as required in order to form an enclosure of desired dimensions and geometry and to also create a desired working surface configuration. For example, as show in Figs. 4 and 6, the segments can be elongated and arcuate. As shown in Fig. 4, the segments can be a half circle each and two of such shaped segments may be assembled opposite of one another in order to form a cylinder. By contrast, as shown in Fig. 1, four arcuate segments can be assembled in order to form a cylinder shape. In yet other aspects of the present invention, the segments may be flat and have varying lengths. In yet other aspects, the segments could have other geometric configurations which lend themselves to assembly about a longitudinal axis using a removable core, such as triangular, rectangular, square, irregular, etc. Furthermore, the segments need not be all the same shape, but can be individually shaped and matched in order to produce a specific larger overall design, such as an airfoil, a wing, a hull, etc.

The cooperation of segments 15 is relevant to the creation of the exterior working surface 20 of the enclosure as each segment has a working surface thereon. The working surface shape and dimensions will dictate at least in part, the configuration of the three dimensional composite article produced using the mandrel of the present invention. Accordingly, in one aspect of the present invention, the exterior working surface of the enclosure can have a predetermined shape that matches a shape intended for the composite article. Such shapes can be custom configured in cooperation with the shape of the segments used in order to provide a working surface having a cross-section perpendicular to the longitudinal axis with a specific geometric form. Examples of such geometric forms may include without limitation: a circle, and oval, an ellipse, a crescent, a triangle, a square, a rectangle, a pentagon, a hexagon, an octagon, a polygon, a star, and combination or variations thereof. In one aspect, the geometric form may be a circle. In another aspect, the geometric form may be a rectangle. In a further aspect, the geometric form of the cross-section may be a square.

In one aspect of the present invention, the geometric form of the longitudinal cross-section may extend for substantially the entire length of the mandrel. In such cases, mandrels with regular geometries of many different shapes may be formed, such as: a cylinder, a cone, a pyramid, a triangular prism, a rectangular prism, a pentagonal prism, a hexagonal prism, a heptagonal prism, an octagonal prism, etc. Nearly any regular and know geometric configuration can be produced. However, in one specific embodiment, the working surface shape may be a cylinder. In another embodiment, the shape may be an octagonal prism. In yet another embodiment, the shape may be a rectangular prism.

In a different aspect of the present invention, the geometric form of the longitudinal cross-section may extend for less than the entire length of the mandrel. In this case, various cross-section geometries may be assembled with appropriate transition areas there between. For example, one portion of the working surface of the enclosure may be geometrically configured with a longitudinal cross-section of a square, while the longitudinal cross-section of a different portion of the working surface may be a circle with an appropriate transition portion in between. Additionally, a single mandrel may include several sections with working surfaces each having different cross-sectional geometries and transitions as required in order to produce a composite article with a specific three dimensional configuration. This may be particularly true when forming an article with a custom geometric shape or irregular form, such as an airfoil, a wing, a propeller, a hull, a blade, etc.

Referring now to Fig. 5, is shown a longitudinal view of a mandrel 10 in accordance with one embodiment of the present invention. As shown in Fig. 5, the working surface 20 has a network of intersecting grooves 25 formed therein. The grooves cooperatively form a substantially continuous interconnected lattice that corresponds or substantially corresponds, to a three dimensional geometric configuration to be imparted to a composite article formed using the mandrel.

The lattice formed by the network of intersecting grooves may in some aspects employ several groove types, including longitudinally extending grooves (i.e. “longitudinals”), laterally extending grooves (i.e. “laterals”), or helically extending grooves (i.e. “helicals”). As a general matter, longitudinals are grooves running parallel to the longitudinal axis of the mandrel, laterals are grooves running perpendicular to the longitudinal axis of the mandrel, and helicals are grooves running in any direction that is neither parallel nor perpendicular to the longitudinal axis of the mandrel.

Figs. 2a-h show various possible intersection configurations for the grooves. For example, 2a shows an intersection of a longitudinal groove 45 and lateral groove 50. Fig. 2b shows an intersection of a longitudinal groove 45 with lateral grooves 55. Fig. 2c shows an intersection of a lateral groove 50 with helical grooves 55, and Fig. 2d shows an intersection of longitudinal groove 45 with lateral groove 50 and helical grooves 55. Other various specific cross section configurations are shown in Figs. 2e-2h.

Nearly any lattice design required to produce a three dimensional product of specific configuration can be formed by the network of interconnected grooves on the working surface of the mandrel. In addition, the extent of the lattice along the working surface of the mandrel may also be controlled. For example, in one embodiment, the interconnected lattice of grooves can be an unbroken, or substantially unbroken, lattice extending substantially around the entire enclosure created by the segments. In another aspect, the lattice can be a broken lattice that extends around only a portion of the enclosure. In yet other aspects, the broken lattice can be extended around the majority of the enclosure, around at least half of the enclosure, around about two thirds of the enclosure, around at least three quarters of the enclosure. Furthermore, the lattice may be sectioned into specific groups or designs around various portions of the enclosure as desired.

In addition to variations in the lattice configuration and intersection of the grooves, the cross-section shape of the grooves may be predetermined to correspond to a cross-section shape intended for individual supports contained in the composite article. The variation of such cross-section shapes can be used in order to impart various mechanical and physical characteristics or properties, such as certain compression strengths, etc. to the three dimensional composite article produced.

As shown in Fig. 1, the grooves 25 have a triangular cross-section shape with a sharp vertex at the bottom of the groove. However, referring to Figs. 3a-h are shown various examples of possible groove cross-section shapes. Such examples include without limitation, a T shape with a flange at the top portion of the groove, a rectangle, a square, a triangle with a single vertex at the bottom of the groove, a half circle, a trapezoid with two obtuse angles at the bottom portion of the groove, a half pentagon with two obtuse angles at the bottom portion of the groove, a half hexagon with two obtuse angles at the bottom portion of the groove, a half octagon with three obtuse angles at the bottom portion of the groove, as well as others. In some specific embodiments, the angles at the bottom of the grooves can have a sharp vertex or corners. In other embodiments, the angles at the bottom of the grooves can be rounded.

In most aspects of the present invention, the top portion of the groove will be wider than the bottom portion of the groove in order to facilitate release of the finished article out of the grooves and off the working surface upon collapse of the mandrel. This is especially true when the mandrel is made of a rigid material as more fully articulated below. In some additional aspects, the cross-section shape of the groove may be widest at a top portion of the groove and narrowest at a bottom portion of the groove. In some aspects, the width may be substantially the same at the top and bottom portions of the groove. However, in the event that mandrel of a soft or less rigid material is used, or even in certain cases where a rigid material is used, the top of the groove may actually have a smaller width than the lower portions of the groove, such as the middle or bottom of the groove. In such cases, the groove can be tapered from a narrow point at the top to a wider point at the bottom or middle.

Additional factors that can impact release of the article include the degree of vertex or draft angle at the bottom of the grooves. In some aspects, the grooves may include only obtuse angles or right angles. In another aspect, the grooves may include a plurality of obtuse angles at or near the bottom portion of the grooves. In a further aspect, the cross-section shape of the grooves may include no acute angle smaller than about 20 degrees. Specific examples of acute angles that can be used at the bottom of the groove include without limitation angles from about 15 degrees to about 90 degrees. In some aspects, such angles may be about 45 degrees. In other aspects, the angles may be about 60 degrees. In yet other aspects, the angles may be about 22 degrees.

In some aspects, the bottom of the groove may be rounded. In other aspects, the bottom of the groove may be one or more vertex. In yet another aspect, the bottom of the groove may be flat. In some aspects, the walls of the grooves may be vertical or substantially vertical. In some aspects, the walls of the grooves may be angled or substantially angled. In yet other aspects, the walls of the grooves may contain an angle, or may be rounded

As a general matter, the dimension or size of the groove longitudinal cross-section can also be controlled along with cross-section shape, for example, the width of the groove and the depth of the groove. In some aspects, such characteristics may be manipulated to provide the article formed with specific characteristics, such as compression strength, lateral strength, etc. In some aspects, the grooves may have a depth of from about 0.1 inch to about 12 inches. In another aspect, the depth may be from about 0.1 inch to about 1 inch. In yet another aspect, the depth may be from about 0.05 inches to about 0.5 inches. Similar ranges may be used for the width of the grooves. In one aspect, the width may be from about 0.1 to about 12 inches. In another aspect, the width may be from about 0.1 inch to about 1 inch. In a different aspect, the width may be from about 0.5 inches to about .5 inches. Such sizes will be selected based in part on the type of article being fabricated and the scale to which it must perform. For example, a boat hull may require grooves of a significantly different scale than those required for a bicycle handle bar. Moreover, specific groove shape can be selected to work in combination with varied groove depth and width dimensions in order to achieve required specifications for processing and performance in the final article. For example, a deep groove may have a rounded bottom to facilitate easy removal of the article.

It is of course to be understood that the grooves forming the lattice on the working surface of the mandrel can all have substantially the same cross-section shape, or they may have different cross-sections. In one aspect, the longitudinal grooves may have a cross section that is different from the lateral grooves and the helical grooves. For example, the longitudinal grooves may have T shaped sections while the lateral grooves and the helical grooves are a half circle. In some other aspects, all the each groove type may have different shape and dimension, for example, the longitudinal grooves may have a rectangular shape while the lateral grooves have a triangle shape and the helical grooves have a circular shape. Moreover, the same types of groove can have different shapes. For example, some longitudinal grooves may have a T shape while others have a rectangle shape. A large variety of mixing and matching of groove cross-section shape and dimension is possible with the present invention.

The exterior working surface of the segments of the present invention may be made from nearly any suitable material that can have a network of intersecting grooves formed therein. In some aspects, such materials may be rigid. In other aspects, such materials may be soft. Examples of rigid materials include without limitation, metals, ceramics, cured polymeric materials, composites, alloys, and mixtures thereof. Examples of metals and metalloids include without limitation, stainless steel, aluminum, tungeston, titanium, iron, magnesium, nickel, chromium, manganese, boron, silicon, and mixtures and alloys thereof. Examples of ceramic or other superhard materials include without limitation, diamond, diamond-like carbon, silicon carbide, tungsten carbide, silicon nitride, aluminum oxide, boron nitride, cubic boron nitride (cBN), titanium carbide, as well as combinations thereof. Examples of cured polymers include without limitation acrylic and acrylate polymers, silicone polymers, epoxies, urethanes and polyurethanes, and rubber based polymers, among others, including combinations and mixtures thereof. Examples of composites include without limitation, fiber-resin composites, carbon fiber composites, particulate-polymer composites, etc.

In some aspects of the present invention, all of the segments, or exterior working surfaces of the segments, may be made from the same materials (i.e. all are stainless steel, etc.). However, in other aspects, one or more segments may be made of a different material. In addition, when made of rigid materials, the segments may be reusable or multi-use segments. When made of softer materials, including softer materials or composites, the segments can be of limited time use, or of single use. Such segments are thought to be disposable and in some aspects can be sacrificed or destroyed as part of the collapsing process.

In order to facilitate release of the formed article from the mandrel grooves, the working surface, including the grooves, or in some aspects, only the grooves can be provided with a lubricant. Such a lubricant can be temporarily applied prior to insertion of the fiber-based composite material into the grooves and/or onto the working surface (e.g. such as an oil, petroleum product, silicone lubricant, etc.), or such lubricant property can be more permanently affixed to the working surface (e.g. coating with a friction reducing polymer such as polytetrafluroethylene, etc.). In some aspects, the entire working surface may be coated. In other aspects, substantially all of the grooves of the working surface may be coated.

Referring again to Fig. 1 is shown a cross-sectional view of the removable core assembly 30. The core assembly occupies the interior volume of the enclosure formed by the segments 15, and couples the segments together to form the enclosure. One example of a coupling mechanism that can be used is by screwing the segments to the core assembly. Screw holes, 60 can be seen in Figs. 4 and 5. A variety of other mechanisms, including adhesives, clips, etc. can be used to couple the segments to the core assembly.

As shown in Fig. 1, the core assembly 30 includes solid support members 35 and solid core 40. Such support members fill substantially the entire interior volume of the enclosure. In such an embodiment, the core or one or more of the solid support members is pushed along the longitudinal axis and removed from the mandrel in order to create a hollow space of sufficient size to allow entry of one or more of the segments as part of the process of collapsing the mandrel. However, in other embodiments, support members may be used which do not substantially file the entire interior volume of the enclosure and a hollow space may exist without removal of the core or any core pieces.

In one aspect, the core assembly can consist of a single piece. In other aspects, the core assembly can include multiple integrated pieces. Such pieces can be coated with a lubricant or other friction reducing material in order to facilitate their removal from the mandrel. In other aspects, such pieces may be capable of manipulation within the enclosure in order to create or expand a hollow space and allow entry of one or more segments as shown in Fig. 6.

As shown in Fig. 1, the core 40 has a specific configuration that keys the placement of specific supporting members which in turn may key the placement of the segments. Such keying can be useful in automating assembly of the segments into an enclosure with a specific working surface configuration. In alternative embodiments, the core assembly can be non-keyed and can universally couple segments to allow interchangeability of segment location so that an operator can select and place segments at his discretion in the creation of a custom made working surface.

In addition to the mandrel devices and structures disclosed herein, the present invention additionally encompasses methods of using such mandrels. In one aspect, such a method includes shaping a fiber-based composite material to be consolidated into a three dimensional structure. Such a method may include providing a mandrel as recited herein, filling the grooves with a composite material, or a composite material perform, consolidating the composite material into a three dimensional structure substantially corresponding to the geometric configuration cooperatively established by the grooves, collapsing the mandrel into pieces inside of the three dimensional consolidated structure, and removing the mandrel pieces from within the consolidated structure. One example of a mandrel collapsed inside a consolidated structure is shown in Fig. 6.

In some aspect, the filling of the grooves with a composite material to be consolidated can include winding a carbon fiber or other fibrous material into the grooves of the mandrel and adding a curable resin to the fibrous material. Furthermore, the consolidation of the composite material can include covering the working surface of the mandrel with a wrap of a flexible resilient material, such as a silicone layer, and pressing and heating the assembled mandrel and materials using a suitable pressurized heating device. Examples of such devices and methods are more fully disclosed in the applicants' related applications previously mentioned and incorporated by reference.

Furthermore, the present invention encompasses a shaped fiber-based composite material assembly. Such an assembly may include a mandrel, or collapsible mandrel as disclosed herein and a fiber-based composite material perform filling the groves of the interconnected lattice on the working surface thereof. As previously mentioned, such a composite material perform can be applied to the mandrel by winding, filling, pasting, etc.

Of course, it is to be understood that the above-described arrangements are only illustrative of the application of the principles of the present invention. Numerous modifications and alternative arrangements may be devised by those skilled in the art without departing from the spirit and scope of the present invention and the appended claims are intended to cover such modifications and arrangements. Thus, while the present invention has been described above with particularity and detail in connection with what is presently deemed to be the most practical and preferred embodiments of the invention, it will be apparent to those of ordinary skill in the art that numerous modifications, including, but not limited to, variations in size, materials, shape, form, function and manner of operation, assembly and use may be made without departing from the principles and concepts set forth herein.

CLAIMS

What is claimed is:

1. A collapsible mandrel comprising:

a plurality of discrete segments coupled about a longitudinal axis and collectively forming an enclosure with a substantially continuous exterior working surface, said working surface having a network of intersecting grooves formed therein, said grooves cooperatively establishing a substantially continuous interconnected lattice corresponding to a three dimensional geometric configuration to be imparted to a composite article formed using the mandrel; and

a removable core assembly occupying an interior volume of the enclosure and coupling the segments together to form the enclosure, said interior volume having a size sufficient to permit entry of a segment into a hollow portion thereof in order to collapse the mandrel.

2. The collapsible mandrel of claim 1, wherein the exterior working surface of the enclosure has a predetermined shape that matches a shape intended for the composite article.

3. The collapsible mandrel of claim 2, wherein the shape includes a cross-section perpendicular to the longitudinal axis with a geometric form selected from the group consisting of: a circle, an oval, an ellipse, a crescent, a triangle, a square, a rectangle, a pentagon, a hexagon, a heptagon, an octagon, a polygon, a star, and combinations thereof.

4. The collapsible mandrel of claim 3, wherein the geometric form of the perpendicular cross-section extends for the entire length of the mandrel.

5. The collapsible mandrel of claim 3, wherein the geometric form of the perpendicular cross-section extends for less than the entire length of the mandrel.

6. The collapsible mandrel of claim 2, wherein the shape is a member selected from the group consisting of: a cylinder, a cone, a pyramid, a triangular prism, a rectangular prism, a pentagonal prism, a hexagonal prism, a heptagonal prism, and an octagonal prism.

7. The collapsible mandrel of claim 1, wherein the shape is a cylinder.

8. The collapsible mandrel of claim 1, wherein the network of intersecting grooves includes intersection of longitudinal grooves with lateral grooves.

9. The collapsible mandrel of claim 1, wherein the network of intersecting grooves includes intersection of longitudinal grooves with helical grooves.

10. The collapsible mandrel of claim 1, wherein the network of intersecting grooves includes intersection of lateral grooves with helical grooves.

11. The collapsible mandrel of claim 1, wherein the network of intersecting grooves includes intersection of longitudinal, lateral, and helical grooves at a single intersection.

12. The collapsible mandrel of claim 1, wherein the grooves each have a predetermined cross-section shape corresponding to a cross-section shape intended for individual supports contained in the composite article.

13. The collapsible mandrel of claim 12, wherein the cross-section shape is substantially identical for each groove.

14. The collapsible mandrel of claim 12, wherein the cross-section shape is substantially different for longitudinal, lateral, and helical grooves.

15. The collapsible mandrel of claim 12, wherein the cross-section shape is widest at a top portion of the groove and a narrowest at a bottom portion of the groove.

16. The collapsible mandrel of claim 15, wherein the cross-section shape has no acute angle smaller than about 20 degrees.

17. The collapsible mandrel of claim 15, wherein the cross-section shape has a plurality of obtuse angles at the bottom portion of the groove.

18. The collapsible mandrel of claim 15, wherein the bottom portion of the groove is rounded.

19. The collapsible mandrel of claim 15, wherein the groove shape is a member selected from the group consisting of: a T shape with a flange at the top portion of the groove, a rectangle, a square, a triangle with a single vertex at the bottom portion of the groove, a half circle, a trapezoid with two obtuse angles at the bottom portion of the groove, a half pentagon with two obtuse angles at the bottom portion of the groove, a half hexagon with two obtuse angles at the bottom portion of the groove, and a half octagon with three obtuse angles at the bottom portion of the groove.

20. The collapsible mandrel of claim 19, wherein the angles of the shapes at the bottom of the grooves are rounded rather than having a sharp vertex.

21. The collapsible mandrel of claim 1, wherein the interconnected lattice of grooves is an unbroken lattice extending substantially around the entire enclosure.

22. The collapsible mandrel of claim 1, wherein the interconnected lattice of grooves is a broken lattice extending around only a portion of the enclosure.

23. The collapsible mandrel of claim 22, wherein the portion of the enclosure is a majority of the enclosure.

24. The collapsible mandrel of claim 22, wherein the portion of the enclosure is at least half of the enclosure.

25. The collapsible mandrel of claim 22, wherein the portion of the enclosure is at least two thirds of the enclosure.

26. The collapsible mandrel of claim 22, wherein the portion of the enclosure is at least three quarters of the enclosure.

27. The collapsible mandrel of claim 1, wherein the exterior working surface of the segments is a rigid material selected from the group consisting of: metals, ceramics, cured polymeric materials, composites, alloys, and mixtures thereof.

28. The collapsible mandrel of claim 27, wherein the material is a metal.

29. The collapsible mandrel of claim 1, wherein the exterior working surfaces of the segments are all made of the same material.

30. The collapsible mandrel of claim 1, wherein the exterior working surfaces of the segments are made of different materials.

31. The collapsible mandrel of claim 1, further comprising a lubricant coating coated over at least a portion of the working surface.

32. The collapsible mandrel of claim 1, wherein the lubricant coating is coated in substantially all the grooves of the working surface.

33. The collapsible mandrel of claim 1, wherein the removable core assembly is a single piece.

34. The collapsible mandrel of claim 1, wherein the removable core assembly comprises a multiple integrated pieces.

35. The collapsible mandrel of claim 1, wherein the removable core assembly occupies less than the entire interior volume of the enclosure.

36. The collapsible mandrel of claim 1, wherein the removable core assembly occupies substantially the entire interior volume of the enclosure and the hollow portion of the interior volume is created by removal of at least a portion of the core assembly.

37. The collapsible mandrel of claim 1, wherein the removable core assembly has a configuration which keys the placement of specific segments at specific locations in the enclosure.

38. The collapsible mandrel of claim 1, wherein the removable core assembly has a configuration which universally couples segments to allow segment location in the enclosure to be interchangeable.

39. A method of shaping a fiber-based composite material to be consolidated into a three dimensional structure, comprising:

providing a mandrel as recited in claim 1;

filling the grooves with a composite perform material;

consolidating the composite perform material into a three dimensional structure substantially corresponding to the geometric configuration cooperatively established by the grooves;

collapsing the mandrel into pieces inside of the three dimensional consolidated structure; and

removing the mandrel pieces from within the consolidated structure.

40. A shaped fiber-based composite material assembly comprising:

a collapsible mandrel as recited in claim 1; and

a fiber-based composite material preform filling the grooves of the interconnected lattice.

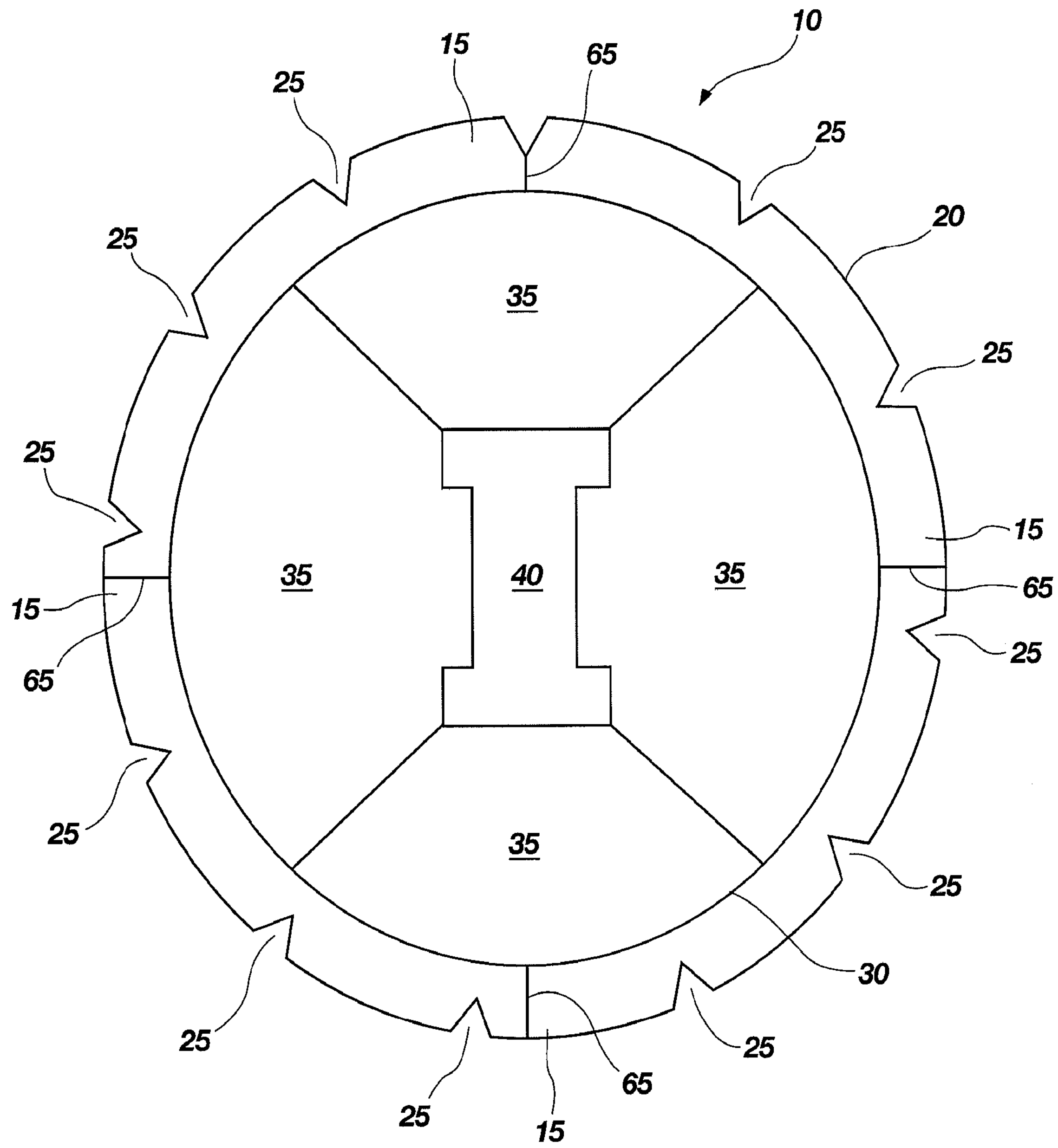
10
15
65
25
25
20
25
25
25
15
65
15
65
25
35
35
35
35
40
25
25
25
30
25
25
65
15

FIG. 1

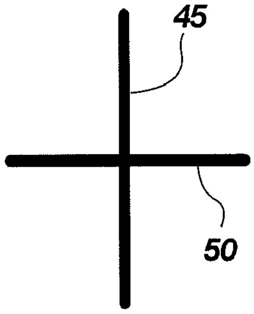

FIG. 2A

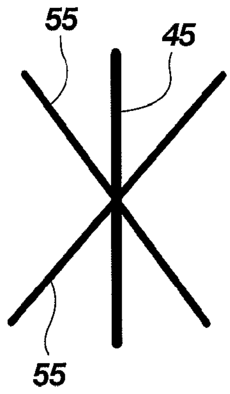

FIG. 2B

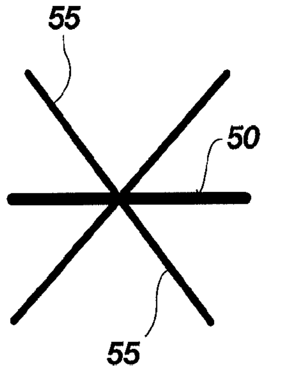

FIG. 2C

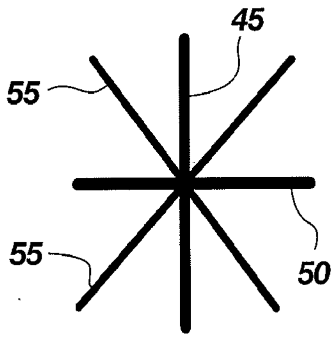

FIG. 2D

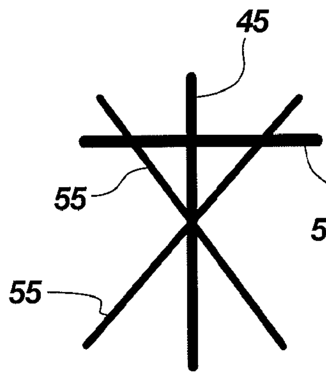

FIG. 2E

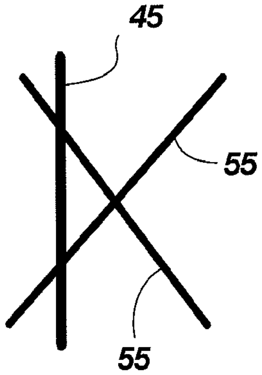

FIG. 2F

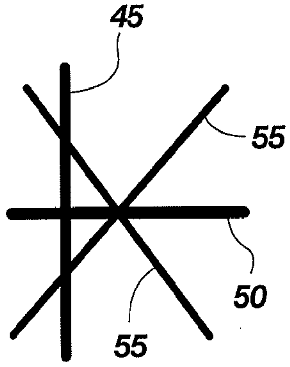

FIG. 2G

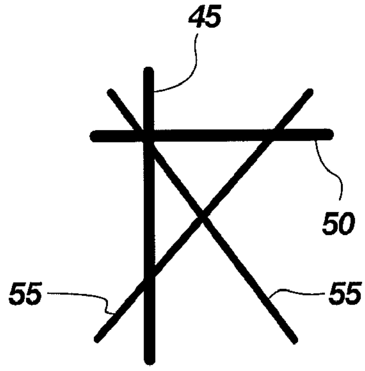

FIG. 2H

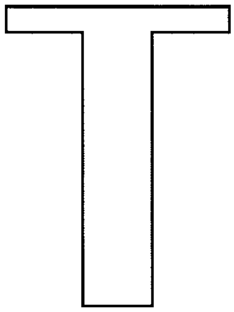

FIG. 3A

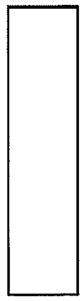

FIG. 3B

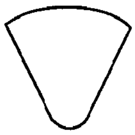

FIG. 3C

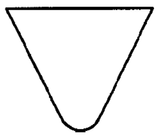

FIG. 3D

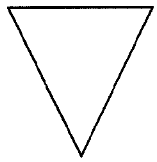

FIG. 3E

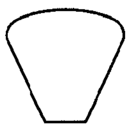

FIG. 3F

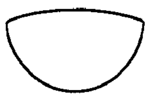

FIG. 3G

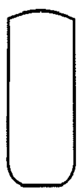

FIG. 3H

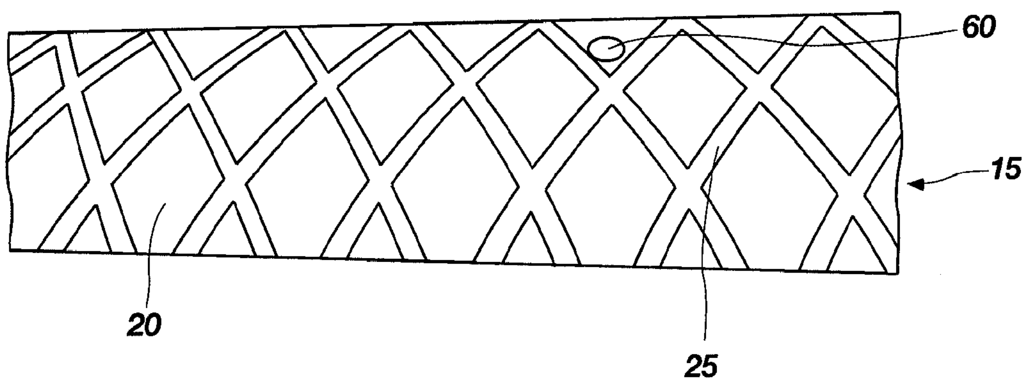

FIG. 4

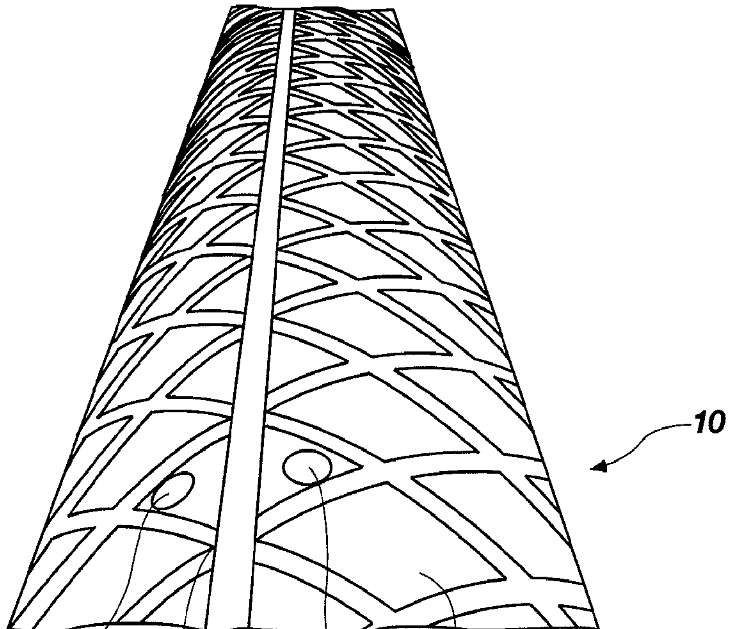

FIG. 5

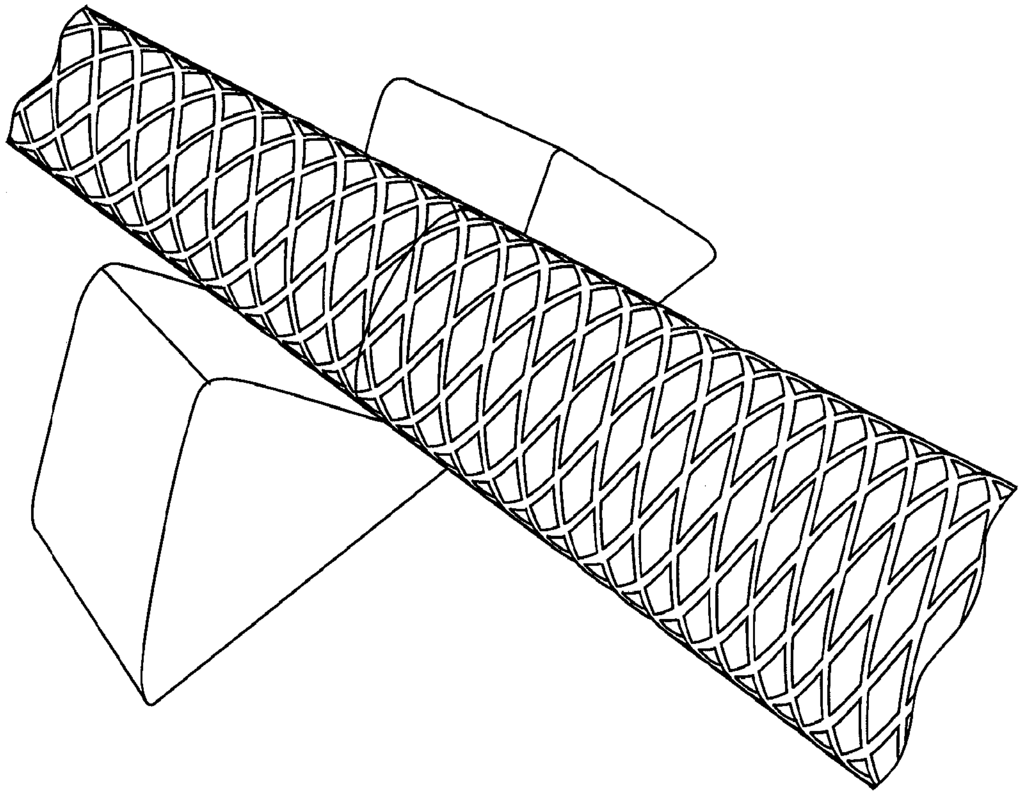

FIG. 6