A method of fabricating a structural member by arranging a length of formable material in overlying relation to one or more recesses defined by a mandrel or mandrels. One or more rams are utilized to urge the formable material into such recess to place the formable material under tension. Various configurations of mandrels and rams are utilized to form structural members of various configurations. The method may also include the step of pivoting certain of the mandrels to bring them into contiguity with the ram or rams to thereby form structural members of still different configurations. The mandrels can be removed from the structural member, or made of lightweight material and left in place for insulation, structural stiffening, and the like.

The formable material is preferably in the form of a continuous loop or band arranged about the mandrel or mandrels so that urging of the material into the recess or recesses places the loop under tension, conforming it to the shape of the mandrel and the recess. Many variations of the concept are disclosed.

11 Claims, 19 Drawing Figures
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METHOD OF FABRICATING STRUCTURAL MEMBERS

BACKGROUND OF THE INVENTION

1. Field of the Invention
The present invention relates to a method of fabricating a structural member.

2. Description of the Prior Art
Certain structures and decorative items have heretofore been difficult or impossible to produce in certain shapes and from certain materials. For example, one of the most difficult fabrication tasks in the reinforced plastics industry is making long beams with cross-sections other than circular or uniformly convexly curved. Circular beams or tubes can presently be made by production techniques which include filament winding, tape winding, template wrapping and the like. Square tubes are roughly analogous and can also be made in the same fashion, although their manufacture is complicated by the necessity of using forming mandrels having flat faces. However, it is not possible to make a beam with a hexagonal cell wall diagonal array without utilizing expensive and time-consuming hand lay-up procedures, which involves individually wrapping mandrels and subsequently nesting them together into the required configuration.

In the paper and cardboard field it has heretofore been possible to fold such material into various configurations not possible in the reinforced plastics industry. However, very long paper or cardboard structures require equipment with long creating capacity, which is expensive and not always readily available.

The prior art systems for fabricating metal beams and pipes, such as heating ducts, are also quite limited with respect to the configurations which can be formed by known metal rolling and folding techniques.

In summary, there are many relatively complex cross-sections which cannot be economically provided in elongated members such as beams, or which cannot be provided at all.

SUMMARY

According to the present invention, there is provided a method of fabricating a structural member which comprises the steps of arranging a length of material adjacent a mandrel or mandrels with a portion of the length being made formable and located in overlying relation to a recess defined by or between the mandrel or mandrels, as the case may be. The method includes the step of urging the deformable portion of the material into the recess until the length of formable material is placed under tension. With this technique it is possible to make beams of complex, truss-like cross-section quickly and easily. For example, a pair of triangular mandrels may be spaced apart, a loop or band of formable material loosely disposed about the mandrels, and a triangular shaped ram urged against the exterior of the formable band to deform the beam into the space or recess between the two mandrels, whereby the beam is placed under tension so that it conforms to the triangular shapes of the mandrels and the ram. If the two rams are then pivoted toward one another and against the adjacent ram, a truss-like configuration is formed. If the band is made of a non- resilient metal, for example, the structural member will retain its deformed state, and a number of such elements can be nested and fastened together to form a composite beam characterized by internal cell walls, providing a high strength-to-weight ratio. If the band is made of reinforced plastics material, such material can be polymerized or cured, so that the band retains its deformed state.

The method of the present invention makes possible economical fabrication of relatively long beams and structures such as lightweight power and telephone poles which can be made of reinforced plastics material for air drooping in remote, treeless areas. Heretofore, it was economically feasible in the reinforced plastics industry to produce only a tapered cylinder, and the labor and the heavy walls of such a cylinder made its use as a pole prohibitive. In contrast, the present invention provides a method which enables reduction of both the weight of the resulting structure and also the labor and tooling costs, and also frequently is the only feasible method for fabricating the structure.

Recent development of boron and graphite high modulus fibers, and epoxy composites using these fibers, has made possible the production of primary structures which are stiff, strong, and light in weight. The present invention provides a method which can be automated to fabricate long beams of such materials and characterized by relatively complex cross-sections or flat sides, a structure heretofore impossible without use of expensive hand lay-up procedures.

The present method also makes possible inexpensive fabrication of cylinders, tubes, ducts, and other cylindrical objects out of reinforced plastics, and without resort to the hand labor common in the prior art for ironing or otherwise making the reinforced plastics material lie tightly against the forming mandrel prior to curing. According to the present invention, a band of formable material is placed under sufficient tension during formation of the structural member that the material is tightly fitted against the associated forming mandrels without any necessity for hand fitting and ironing.

Other objects and features of the invention will become apparent from a consideration of the following detailed description when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of apparatus for practicing the present method and including an internal mandrel having a cavity or recess, a loop or band of formable material disposed about the mandrel, and a single ram thrusting a portion of the loop into the mandrel recess;

FIG. 2 is an end elevational view of the apparatus of FIG. 1, on a reduced scale, and schematically showing the disposition of the components prior to movement of the ram into the mandrel recess;

FIG. 3 is a view similar to FIG. 2, but illustrating the disposition of the components after movement of the ram into the mandrel recess;

FIG. 4 is an end elevational view of apparatus for forming a structural member of I-shape;

FIG. 5 is an end elevational view of an apparatus in which a structural member of square cross-section is formed, the embodiment being noteworthy in that the ram is located interiorly of the band of formable material, the mandrel being located exteriorly of the band;

FIG. 6 is a view similar to FIG. 5 but illustrating the ram in its extended position;

FIG. 7 is yet another embodiment of apparatus utilizing the present invention, this embodiment being characterized by a mandrel adapted to press a band of formable material within a dovetail recess in the mandrel;

FIGS. 8, 9 and 10 are end elevational views illustrating steps in the formation of a structural member characterized by a truss-like cross-section, and utilizing triangularly shaped mandrels and a triangularly shaped ram;

FIG. 11 is another apparatus for practicing the method of the present invention, the apparatus in this case utilizing mandrels effective to provide a structural member of circular cross-section;

FIG. 12 is an end elevational view of the structural member formed by the apparatus of FIG. 11;

FIG. 13 is another apparatus for practicing the present invention, utilizing a pair of triangular mandrels and a relatively thin ram member which remains as part of the formed structural member;

FIG. 14 is an end elevational view of the structural member formed by the apparatus of FIG. 13;

FIG. 15 is an end elevational view of an apparatus utilizing three mandrels and one ram to form a structural member having a cross-section characterized by four triangular cells;
FIG. 16 is an end elevational view of a structural member formed by the apparatus of FIG. 15; FIG. 17 is another apparatus for practicing the present invention, and utilizing two circular mandrels and a circular ram; FIG. 18 is an end elevational view of a structural member formed by the apparatus of FIG. 17; and FIG. 19 is a perspective view, partially cut away, and illustrating a composite structure formed by utilizing a plurality of the elements of FIG. 10 to form a structural sandwich.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings, and particularly to FIGS. 1 through 3, there is illustrated an apparatus for practicing the present method of fabricating a structural member, the structural member in this case being generally indicated at 10 in FIGS. 1 and 3. The structural member in this case comprises a sheath, sleeve, band, or loop 12 which is disposed about and completely encompasses a mandrel means or composite mandrel 14.

The term "loop" is intended to comprehend a variety of configurations ranging from a thin wire to a ribbon to a belt or a tube. So long as, so that the fabricated structural members may range from discs to long beams, for example. Moreover, the term "mandrel" is also intended to comprehend more than a solid piece of tooling, including for example a telescopic or collapsible member, a foam material solid member, or decorative insert left in place as part of the fabricated structural member, a truss similarly left in place, a previously fabricated part which is to receive another ply of material, or such a fabricated part which is to become part of a larger assembly.

In the present embodiment, the loop 12 is made of reinforced plastics material such as glass fiber fabric impregnated with a suitable resin adapted to be polymerized, as is well known to those skilled in the art.

The particular mandrel 14 of the apparatus of FIG. 1 is a composite or two part mandrel maintained in its extended state by the introduction of fluid under pressure therein through a manifold 16. The mandrel 14 is retracted or collapsed by venting the pressurized fluid from between the relatively movable parts of the mandrel whereby the mandrel 14 can be separated from the loop 12 once the loop has been cured to form the structural member 10.

The structurally continuous loop 12 is arranged adjacent the mandrel 14 with a portion thereof located in overlying location to a space or recess 18 located in the upper, exterior surface of the mandrel 14.

A ram means, in this case a single ram 20 having an exterior surface shaped to complementally fit within the recess 18, is disposed above the recess 18 and is moved by any suitable means (not shown) against the portion of the loop 12 located over the recess 18. Downward pressure is exerted upon the ram 20 until the loop portion is forced within the recess 18, as best viewed in FIG. 3, to place the loop under tension. This causes the inside periphery of the loop 12 to closely fit against the outside periphery of the mandrel 14, the loop 12 being made of such a dimension that it is placed under tension just prior to or at the point of final deformation to the shape of the recess 18. The dimensions of the band will necessarily depend upon the materials being used, the shape to be imparted to it, and other factors evident to those skilled in the art.

This method lends itself to automation in that the loop 12 is adapted to be loosely positioned about the mandrel 14 and yet the continuous nature of the loop 12 enables tension to be developed in it by the ram 20 to an extent sufficient that the loop 12 closely hugs the contour of the mandrel 14 without any necessity for hand fitting or auxiliary rams. However, the present method is not limited to the use of continuous loop 12. For example, a material different from the material of the parent loop 12 can be disposed between the points A—A and B—B, which are diagrammatically indicated in FIG. 2, and stitched or otherwise secured to the parent loop. Whatever the material used to couple the points A—A and B—B of the modified loop 12, it can be made detachable for re-use as part of the tooling for the next part.

An extension of this concept, which is also within the scope of the present invention, is to provide any suitable means, not shown, to secure against movement the upper ram of the loop 12 at point A—A, with similar clamping means or anchorages being provided for the lower ram of the loop 12 at the points B—B. Thus, two separate lengths of formable material can be independently clamped to provide the same result as would occur if a structurally continuous loop were used.

It will be apparent that various configurations of mandrel can be used in the practice of the present method, including mandrels of circular cross-section or cruciform cross-section. Referring now to FIG. 4, a mandrel 22 is illustrated which is I-shaped. The opposite channels 24 each constitute a separate recess and a pair of confronting rims 26 are moved toward each other to sequentially press a first loop 28 into the recesses 24, and next a loop 30 into the recesses 24 in overlying relation to the loop 28. This forms a two-ply structural member. Alternatively, both plies or loops 28 and 30 could be formed simultaneously by the rams 26. Of course, the outer loop 30 must be made slightly larger in dimension than the first loop 28 in order to provide the necessary tensioning effect as the loops achieve intimate contact with the mandrel 22, or the loop 28 as the case may be.

Structural elements, such as channels, angles, T-sections or the like are difficult to fabricate out of reinforced plastics unless resort is made to prior art hand lay-up procedures, or expensive male-female matched molds, or close-tolerance dies and punches, and the like. However, the method of the present invention greatly simplifies the fabrication of such shapes, requiring only that a multiplicity of differently configured mandrels and rams be utilized to provide the desired configuration.

More particularly, and with reference to FIGS. 5 and 6, there is illustrated an internal ram 32 having outwardly projectable ram portions 34 for urging a structurally continuous loop 36 of formable material into the corners or recesses defined by the interior surfaces of an internal cavity of an exterior mandrel 40. FIG. 6 shows the ram portions 34 urging the loop 36 into the recesses of the mandrel 40, demonstrating that the present method is not limited to an arrangement in which the mandrel is located interiorly of the band or loop 36.

FIG. 7 illustrates a structural member which would be difficult if not impossible to produce by any method of the prior art. The structural member is formed by utilizing an internal mandrel 42 having a dovetail shaped recess 44, with a continuous band or loop of formable material 46 being disposed about the mandrel 42. In this case, a ram 48 is provided having extendible fingers or ram portions 50 for urging the adjacent portions of the loops 46 into the recess 44.

Although not shown, it will be apparent that the band or loop of any of the various embodiments of this disclosure can be tapered, that is, reduced in cross-sectional dimension throughout its length, whereby it is suited for association with similarly tapered mandrels and rams to provide a structural member having a corresponding tapered shape.

A detailed description of all of the various types and shapes of mandrels and rams which can be utilized with the present method has been omitted for brevity inasmuch as such variations are well known to those skilled in the art. Although the mandrels can be left in place to provide strength, structural rigidity, insulation or the like, meltable or dissolvable mandrels may also be used to enable their easy removal. Here again, many types of removable mandrel are presently available and in the interest of brevity will be omitted from the present discussion.

The present method also contemplates the use of more than one mandrel. Referring again to FIG. 1 through 10, there is illustrated a structural member 52 which is truss-like in cross-sectional configuration. The member 52 is fabricated by utilizing a pair of triangularly shaped mandrels 54 disposed within a structurally continuous loop or band 56 of formable material.
such as resin reinforced glass fiber material. A triangularly shaped ram 58 is disposed, in FIG. 8, above a space, opening or recess 60 which is defined by the spaced apart mandrels 54, which rest upon a work table 61. Although the ram 58 is termed a "Ram", it will be apparent that it functions in a manner similar to the mandrels once the loop 56 is deformed.

FIG. 9 illustrates depression of the ram 58 into the space 60 to deform the loop 56, and also illustrates the upward and inward pivotable movement of the mandrels 54 toward one another and in contiguity with the sloping adjacent surfaces of the ram 58. The ram 58 is now performing a function like that of the mandrels 54, as will be apparent.

The new arrangement of the mandrels and ram-mandrel produces a truss-like configuration of the structural member 52 illustrated in FIG. 10. Once the material of the loop 56 is cured and hardened, the loop 56 normally will adequately retain its deformed shape, but adhesive can be applied at the line of abutment indicated at 62 to insure shape retention and structural integrity.

Summarizing the steps in the method of FIGS. 8 through 10, a loop of formable material is positioned adjacent a pair of mandrels, the loop is tightened firmly to enclose the mandrels by pushing in on a portion of the loop with a ram, and the internal mandrels are pivoted around hinge points created in the loop to form a cross-section of cellular configuration. The mandrels may then be removed or left in place, as desired.

Other shapes of mandrels can be used, as seen in FIGS. 11 and 12, a pair of mandrels 64 being illustrated which are characterized by a curvilinear exterior surface. The ram 66 utilized is also similarly configured. For convenience, the mandrels 64 rest within complementary depressions formed in the work table 68, and a structurally continuous band or loop 70 is disposed about the pair of mandrels 64, a portion of the loop 70 lies within a central depression or recess 72 formed in the work table 68. After the ram 66 is brought down upon the loop 70 to deform it into the recess 72, the ram 66 is left in place and an insert 74 is placed in overlying relation to the insert ram 66. Next, the mandrels 64 are pivoted toward one another and into abutment with the insert 74 to form the structural member 76 shown in FIG. 12. If desired, the mandrels 64 and rams 66 can be made of lightweight foam material, for example, and left in place in the final structural member 76. This enables use of the assembly as a packing container for an elongated fragile member (not shown) disposed within the hollow central portion of the structural member 76. FIGS. 13 and 14 also illustrate this feature, the ram in this case being a pair of glass 78, or the like, sandwiched between the mandrel material mandrels 80 which are pivoted towards one another from the positions of FIG. 13 to those of FIG. 14. This orients the continuous loop 82 into a generally square cross-section, with the fragile glass pane 78 cushioned by the mandrels 80.

FIG. 15 illustrates another apparatus using the present method, and comprising three mandrels 84 and a single ram 86, all of triangular shape. The lowermost mandrel 84 fits within a triangular trough provided in the work table 88, and the continuous band or loop 90 is disposed around all three mandrels 84, as illustrated, with pivotal movement of the outermost mandrels 84 producing the structural member 92 illustrated in FIG. 16.

Referring now to FIGS. 17 and 18, and apparatus is illustrated which utilizes a pair of spaced apart mandrels 94 of circular cross-section. A continuous band or loop 96 or formable material is disposed about the mandrels 94, and is made of resin reinforced glass fiber or the like so that it becomes rigid upon curing. However, the formable material can be flexible, non-rigid material such as corrugated packing board or the like so that the structural member 94 illustrated in FIG. 18 is then useful as a carrier for transporting fragile items. In such a case the mandrels 94 and the ram 100 would constitute the fragile items to be shipped. A tie member 102 is adhesively bonded to the pivoted-together components to maintain them in their assembled relation, as will be apparent.

The foregoing illustrates the considerable variety of shapes and configurations which can be provided for the mandrels and rams to produce structural members of various configurations. In addition, a plurality of such structural members can be joined together to form still more complex structures. Thus, in FIG. 19 a plurality of the structural members 52 of FIG. 10 are arranged in nested, side-by-side, parallel relation. Facing skins 104 are bonded or otherwise attached to the structural members 52 to form a strong, lightweight, structural sandwich characterized by a truss-like cross-section defined by the assembled members 52. A variety of structural or decorative end uses for this and similarly fabricated structures will immediately suggest themselves to those skilled in the art. Many of these complex shapes and structures could not readily be fabricated in the prior art, being producible only by utilization of the method of the present invention.

The work table support for the mandrels of the various embodiments is largely schematic. In actual practice the mandrels would most likely be supported at their ends so as to permit the lengths or loop of formable material to move relative to the mandrels during the tensioning operation. Such relative movement will also be facilitated by providing lubrication, vibration, or the like of the mandrels and the rams.

The loop of formable material may also take the form of a vacuum tight bag to completely enclose a part, such as the I-beam, of FIG. 4. Utilizing the present method to tension the bag on the I-beam would facilitate a desirable intimate contact between the bag and the part, which is valuable for autoclave curing of certain reinforced plastic parts.

Various modifications and changes may be made with regard to the foregoing detailed description without departing from the spirit of the invention.

I claim:

1. The method of fabricating a structural member comprising the steps of:
   arranging structurally continuous loop means about the exterior surfaces of a mandrel means comprising at least a pair of mandrels spaced apart to define a recess, with a portion of said loop means being formable and located in overlying relation to said recess;
   moving said means against said pair of said loop means and into said recess to urge said pair into said recess and place said loop means under tension; and
   pivoting said pair of mandrels toward one another and upon said mandrel means in said recess.

2. The method of fabricating a structural member comprising the steps of:
   arranging structurally continuous loop means adjacent a mandrel means having a forming surface including a recess, at least a portion of said loop means being formable and located in adjacent relation to said recess, said loop means having a peripheral dimension less than the peripheral dimension of said forming surface; and
   moving said means against said portion of said loop means to urge said portion into said recess and place said loop means under sufficient tension throughout the length thereof that the remainder of said loop means is tightly urged against the periphery of said mandrel means.

3. The method according to claim 2 wherein said loop means are arranged about the exterior surfaces of said mandrel means and said exterior surfaces comprise said forming surface.

4. The method according to claim 3 wherein said mandrel means are left in place as an integral part of the structural member.

5. The method according to claim 3 including the additional step of removing said mandrel means to render the structural member hollow.

6. The method according to claim 3 wherein said mandrel means is l-shaped and the opposite channels thereof each constitute a separate said recess; wherein said ram means comprise a pair of confronting rams; and moving said rams toward each other to form said loop means against said mandrel means into a tensioned I-shape structural member.
7. The method according to claim 2 wherein said loop means are arranged adjacent interior surfaces of said mandrel means and said recess is defined by said interior surfaces.

8. The method according to claim 1 wherein said pair of mandrels and said ram means are each triangular in cross-section whereby said structural member is truss-like in construction.

9. The method according to claim 1 wherein said pair of mandrels and said ram means are each characterized by a curved exterior surface whereby said structural member may be formed circular in cross section.

10. The method according to claim 1 wherein said pair of mandrels and said ram means are each characterized by a circular cross section whereby they may be transported using said structural member as a carrier.

11. The method according to claim 8 and including the additional steps of arranging a plurality of said structural members in nested, side-by-side and parallel relation; and affixing facing skins to said structural members to form a structural sandwich.