A method is described for manufacturing a U-shaped support unit for use in footwear. A shaft mandrel has a longitudinal axis and a cross-section with at least one U-shape region. An enclosed shape of composite material is formed over the shaft mandrel which includes one or more layers of resin-impregnated reinforcing fibers. One or more cuts are made through the enclosed shape to create U-shaped support units adapted for use as a weight bearing structure in footwear.
FILAMENT WOUND U-SHAPED SUPPORT UNITS FOR FOOTWEAR


TECHNICAL FIELD

[0002] The invention relates to footwear construction and more specifically, to construction of a U-shaped filament-reinforced composite unit for use in a midsole or sole of footwear.

BACKGROUND ART

[0003] Existing conventional shoe cushioning can interfere with natural biomechanics and muscle function and may compromise long-term musculoskeletal health. Typical footwearing cushioning mechanisms including foam, gel, and coil spring devices that absorb shock at initial impact (foot strike), adversely affect proprioceptive input required for healthy muscle tuning throughout the body. As such, this conventional cushioning arrangement can compromise bone health and can predispose the wearer to musculoskeletal injury.

[0004] Joint forces in the gait cycle are well-observed to be at their maximum at the moment of peak body weight force, which does not occur at foot strike but later in mid-stance. For walking, that is during loading response and at terminal stance, and for running that is during mid-stance. Typical footwear cushioning compresses at foot strike, absorbing shock at initial impact, but the cushioning does not measurably compress and release (or comply) in time with the rise and fall of the peak body weight forces when joint forces are at their peak.

[0005] There is a need for footwear that effectively reduces musculoskeletal wear and tear, especially useful for helping prevent knee and hip osteoarthritis as well as other common musculoskeletal injuries. Such footwear would include a midsole that incorporated a compliant structure able to compress and release in harmony with the rise and fall of the body weight force during weight bearing activities such as gait—without cushioning the shock at initial impact. Such footwear would compress and release only when the joint forces are at their maximum, thereby minimizing joint forces.

[0006] FIG. 1 A-C shows top, cross-sectional and bottom views of one specific example of a U-shaped support unit 101 for use in footwear which is made of a filament-reinforced composite material. As used herein, the term “U-shaped” is used broadly as a generic descriptor of any structure with a U-, V- or C-shape etc. The U-shaped support unit 101 includes an upper foot support arm 102 substantially parallel to the foot supporting surface of the footwear, and a lower ground arm 103 substantially parallel to the ground contacting surface of the footwear. The foot support arm 102 and the ground arm 103 are connected together at a medial side base 106, while the lateral ends 104 and 105 of each arm are free to displace under force towards the center axis 107. The U-shaped support unit 101 is placed inside the midsole or sole of a shoe to provide a spring-like compliant shoe interface along a definite path that flexes, i.e., compresses and releases in time with the rise and fall of the body weight force without absorbing impact shock. Such a U-shaped support unit for footwear is described more fully in U.S. Pat. No. 7,418,790, which is incorporated herein by reference.

[0007] To best support the body weight, such a U-shaped footwear unit ideally is made of filament-reinforced composite material. The typical manufacturing processes for such materials in footwear, however, are insufficient, inconsistent, and/or not cost-effective. Injection molding of filament-reinforced material provides an automated consistent product, but it requires shortened fiber lengths that in composite form do not provide the combined stiffness and durability needed to completely suspend the body during gait. Hand lay-up of filament-reinforced composite materials can offer sufficient stiffness to support the body weight, but it requires substantial human labor, is prone to consistency errors, and is not cost-effective for use in footwear manufacturing.

SUMMARY

[0008] Embodiments of the present invention are directed to a method for manufacturing a U-shaped support unit for use in footwear. A shaft mandrel has a longitudinal axis and a cross-section with at least one U-shape region. An enclosed shape of composite material is formed over the shaft mandrel which includes one or more layers of resin-impregnated reinforcing fibers. One or more cuts are made through the enclosed shape to create at least one open U-shaped section of fiber-reinforced composite material, and the U-shaped section is then separated into U-shaped support units adapted for use as a weight bearing structure in footwear.

[0009] The enclosed shape may be formed using an automatic filament winding machine to wind reinforcing fibers around the shaft mandrel, for example, by rotating the shaft mandrel about its longitudinal axis. The enclosed shape may be formed by pressing an outer molding surface over at least a portion of the composite material to form an outer surface of the enclosed shape. The enclosed shape may also be formed over a non-fiber structural member that is pre-placed onto the shaft mandrel and which is incorporated into the composite material.

[0010] The reinforcing fibers may be impregnated with resin by use of a resin impregnating system such as a resin wetting bath, spray or brush prior to being formed on the shaft mandrel, or by resin injection after being formed on the shaft mandrel. The composite material of the enclosed shape may undergo a curing period of time prior to after cutting.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 A-C shows top, cross-sectional and bottom views of a filament-reinforced composite material U-shaped support unit for use in footwear.

[0012] FIG. 2 is a perspective view of a type of a shaft mandrel for use in an embodiment of the present invention.

[0013] FIG. 3 A-C shows cross-sectional views of three different symmetry types of shaft mandrels.

[0014] FIG. 4 A-B shows cross-sectional views of two U-shaped shaft mandrels with a non-fiber structural member placed onto the shaft mandrel that becomes included into the composite material of the final cured U-shaped support unit.

[0015] FIG. 5 A-B shows cross-sectional views of two embodiments of compression molds that are placed over the composite material and shaft mandrel after the filament winding process.

DETAILED DESCRIPTION

[0016] Embodiments of the present invention include an automated filament winding process that enables consistent
and cost-effective manufacturing of a U-shaped compliant unit for use in a footwear sole or midsole that compresses and releases at the time when the body weight and joint forces are at their greatest so as to minimize the peak joint forces. The use of a filament winding process provides an automated and repeatable process for the manufacturing of reinforced composite materials. Fibers are wound around the shaft mandrel which rotates along its longitudinal axis.

**[0017]** FIG. 2 is a perspective view of a shaft mandrel 201 according to one specific embodiment of the present invention. The shaft mandrel 201 has a longitudinal axis and a U-shape cross-section as seen in FIG. 3A over which an enclosed shape of composite material is formed from one or more layers of resin-impregnated reinforcing fibers. Support rods 202 along the longitudinal axis of the shaft mandrel 201 can be inserted into receiver collars of a filament winding machine which rotates the shaft mandrel 201 along its longitudinal axis. As the shaft mandrel 201 rotates, filament material is wound around it to form multiple layers of composite material. One or more tows of fiber of any thickness may be wound over the mandrel at a given time. The positioning, orientations and thickness of the tows are the same as for procedures already known in the art and their selection does not form part of the present invention.

**[0018]** In one embodiment, the filament can be drawn through a resin impregnating system to impregnate it with resin before being wound around the shaft mandrel 201. In other embodiments, the filament may be pre-impregnated with resin or resin may be injected into dry filament after winding. There may be a period of time for curing of the resin at any convenient point in the process to cure the composite material according to known operable methods appropriate to the particular resin fiber composite. For example, the assembly may be heated in a standard or platens press oven. A variety of reinforcing fiber types, either natural or synthetic, or a combination thereof may be used. Similarly, a variety of resin type materials may be used such as epoxy, polyurethane, polyester or vinyl ester. The resin may be thermosetting or thermoplastic and may include additional fillers or substrates that provide improved physical qualities to the resultant composite unit.

**[0019]** After the enclosed shape of composite material is formed over the outer surface of the shaft mandrel 201, it is cut into multiple final U-shaped elements for incorporation into footwear. In one embodiment, the composite material is cut directly into the final U-shaped support units while still on the mandrel 201. For example, the composite material can be cut off the mandrel 201 using a device such as a water jet saw that cuts through the composite material but not the mandrel 201. Or cutting blades can be incorporated into a female mold such that when the female mold is compressed on the mandrel 201 the blades cut through the composite material. Alternatively, the enclosed shape can be cut along the axial length on cut line 301 so as to create two symmetric U-shaped section lengths of fiber-reinforced composite material. This cutting creates one or more long open U-shaped section elements which can be removed from the mandrel 201 and then cut into multiple final U-shape elements for incorporation into footwear. Or, the composite material may be pulled off an end of the mandrel 201 in whole and then cut into the final U-shape support units. The final U-shape support units are placed in the midsole or sole of a shoe such that one of the arms of the unit lays parallel to the foot support surface and the other arm lays parallel to the ground contact surface.

**[0020]** Filament winding is typically used for manufacturing filament-reinforced structures with axial symmetry and closed cross-sectional shapes such as pipes, high pressure containers and rocket motors. But embodiments of the present invention may include a filament winding process which uses a shaft mandrel that is not symmetric along its axis. FIG. 3B illustrates an embodiment of a shaft mandrel 201 having an asymmetric cross-section that results in two asymmetric U-shaped sections after cutting of the composite material. FIG. 3C shows an example of a shaft mandrel 201 suitable for producing a single U-shaped section after cutting along cut line 301. All the embodiments shown have a consistent cross-section along their longitudinal lengths, but that is not necessarily required in all embodiments.

**[0021]** FIG. 4 A-B shows cross-sectional views of two embodiments of U-shaped mandrels 201 that have been altered in shape at the end vertices to accommodate a non-fiber structural member 401 that is pre-placed onto the mandrel 201 prior to filament winding. The additional structural member 401 becomes integrally incorporated into the filament wound composite material such that the final U-shape support unit includes both the composite material and the additional structure. In another embodiment, a material such as fabric or a semi-rigid or rigid structure can be placed over the outer surface of the entire mandrel or a portion thereof prior to filament winding to form a base layer of the final U-shape support unit.

**[0022]** FIG. 5 A-B illustrates two embodiments of the present invention wherein a compacting molding surface 501 is placed over a portion (FIG. 5A) or the entire surface (FIG. 5B) of the enclosed shape of filament-reinforced composite material 502 during the curing process. In the embodiment shown in FIG. 5A, a clamping device such as a vise or a press compresses opposing plates that form the molding surface 501 on either side of the outer surface of the composite material 502. In another embodiment, a material such as cello shrink tape can be applied to compress the composite material 502 against the mandrel 201 and this tape can either be left on or removed after the curing process. The molding surface 501 can be removed sometime during or after full curing of the resin.

**[0023]** Although various exemplary embodiments of the invention have been disclosed, it should be apparent to those skilled in the art that various changes and modifications can be made which will achieve some of the advantages of the invention without departing from the true scope of the invention.

What is claimed is:

1. A method for manufacturing a U-shaped support unit for use in footwear, the method comprising: providing a shaft mandrel having a longitudinal axis and a cross-section with at least one U-shape region; forming an enclosed shape of composite material over the shaft mandrel, the composite material including one or more layers of resin-impregnated reinforcing fibers; cutting through the enclosed shape of composite material to create U-shaped support units adapted for use as a weight bearing structure in footwear.

2. A method according to claim 1, wherein forming the enclosed shape includes using an automatic filament winding machine to wind reinforcing fibers around the shaft mandrel.
3. A method according to claim 2, wherein winding the reinforcing fibers includes rotating the shaft mandrel about its longitudinal axis.

4. A method according to claim 1, further comprising: incorporating the U-shaped support units into footwear as compliant weight bearing structures.

5. A method according to claim 1, wherein the reinforcing fibers are impregnated with resin by use of a resin impregnating system prior to being formed on the shaft mandrel.

6. A method according to claim 1, wherein the reinforcing fibers are impregnated with resin by resin injection after being formed on the shaft mandrel.

7. A method according to claim 1, wherein forming the enclosed shape includes pressing an outer molding surface over at least a portion of the composite material to form an outer surface of the enclosed shape.

8. A method according to claim 1, wherein forming the enclosed shape includes curing the composite material of the enclosed shape for a period of time prior to cutting.

9. A method according to claim 1, wherein the composite material is cured for a period of time after cutting.

10. A method according to claim 1, wherein forming the enclosed shape includes placing a non-fiber structural member onto the shaft mandrel which becomes incorporated into the composite material.

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