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(54) **GOLF SHAFTS HAVING A VARYING OUTER DIAMETER, INNER DIAMETER, AND/OR WALL THICKNESS AND METHODS FOR MANUFACTURING GOLF SHAFTS USING ADDITIVE MANUFACTURING**

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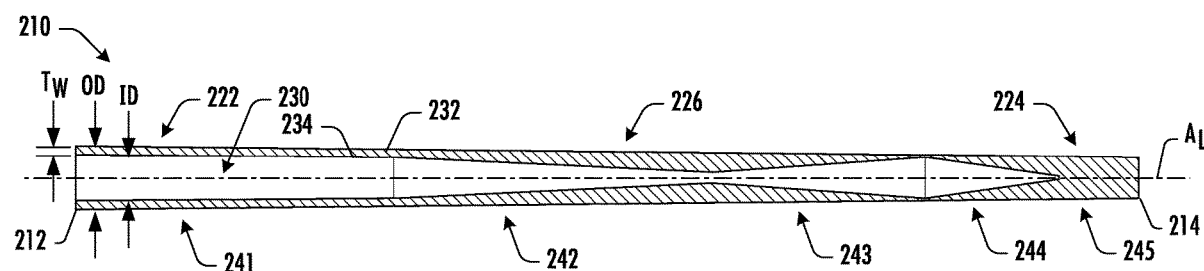
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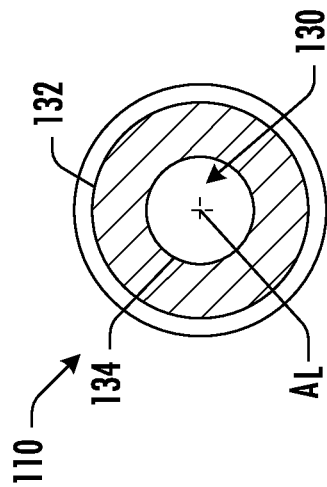
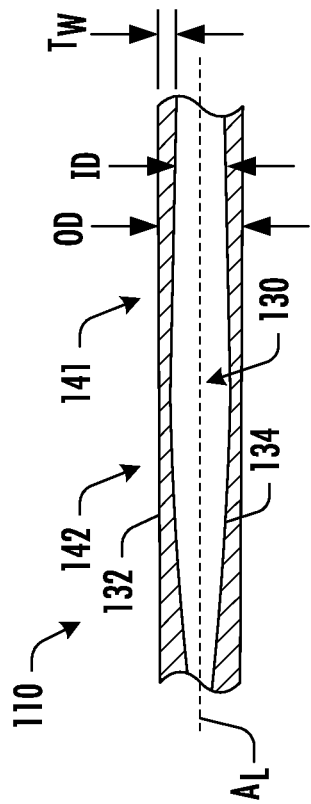
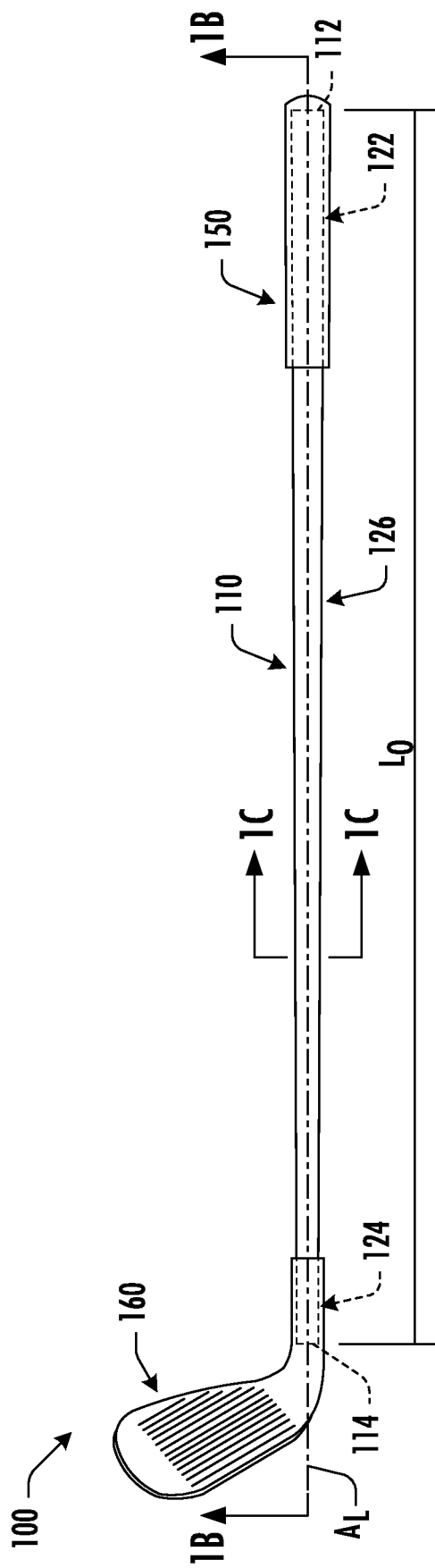
Related U.S. Application Data

(60) Provisional application No. 63/253,730, filed on Oct. 8, 2021.

(57) **ABSTRACT**

A method for manufacturing a golf shaft may include receiving a CAD model corresponding to the golf shaft, and forming, based at least in part on the CAD model, the golf shaft using one or more additive manufacturing techniques. The golf shaft may include a first end and a second end disposed opposite one another along a longitudinal axis of the golf shaft, and the golf shaft may define one or more internal cavities extending along the longitudinal axis. The golf shaft may have an overall length from the first end to the second end, an outer diameter, an inner diameter, and a wall thickness, and at least one of the outer diameter, the inner diameter, and the wall thickness may vary along the overall length.





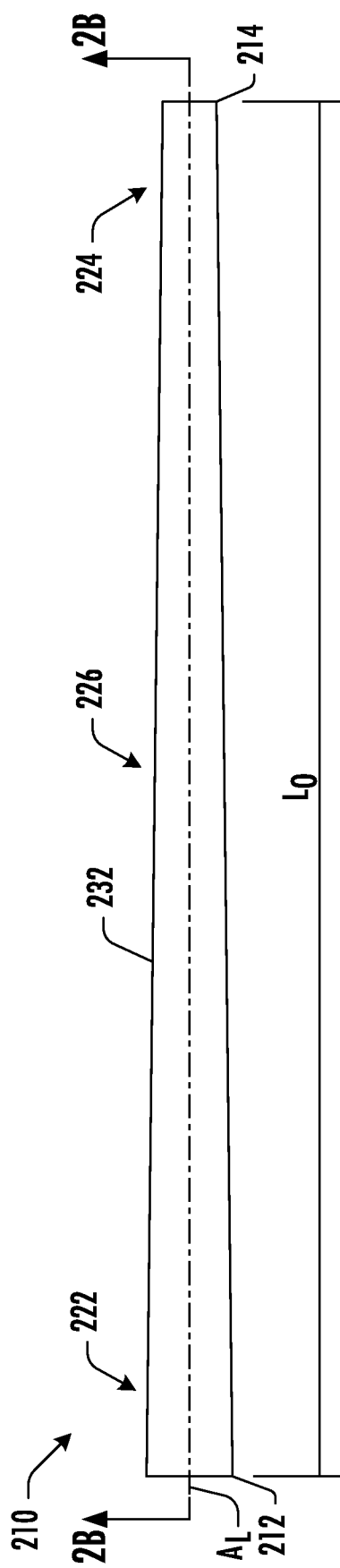


FIG. 2A

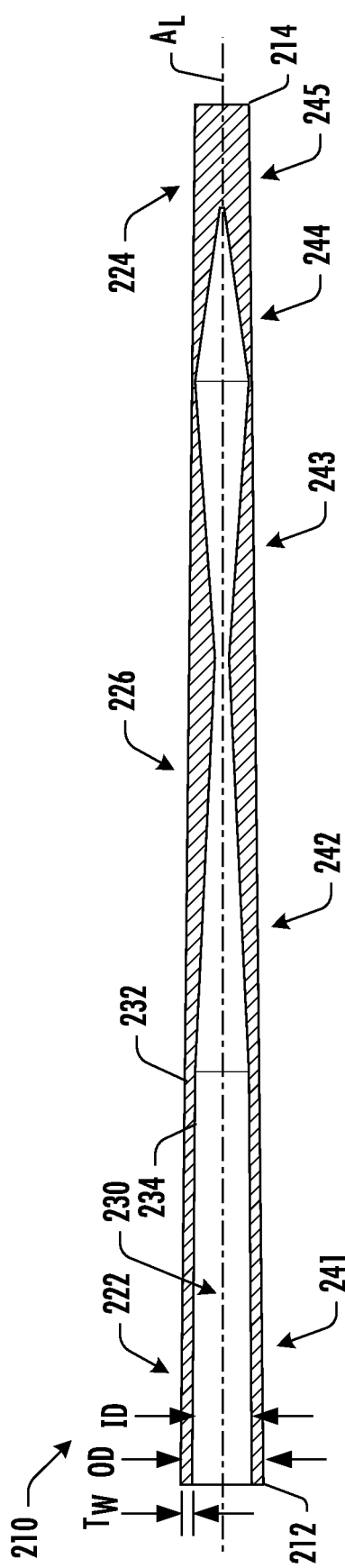
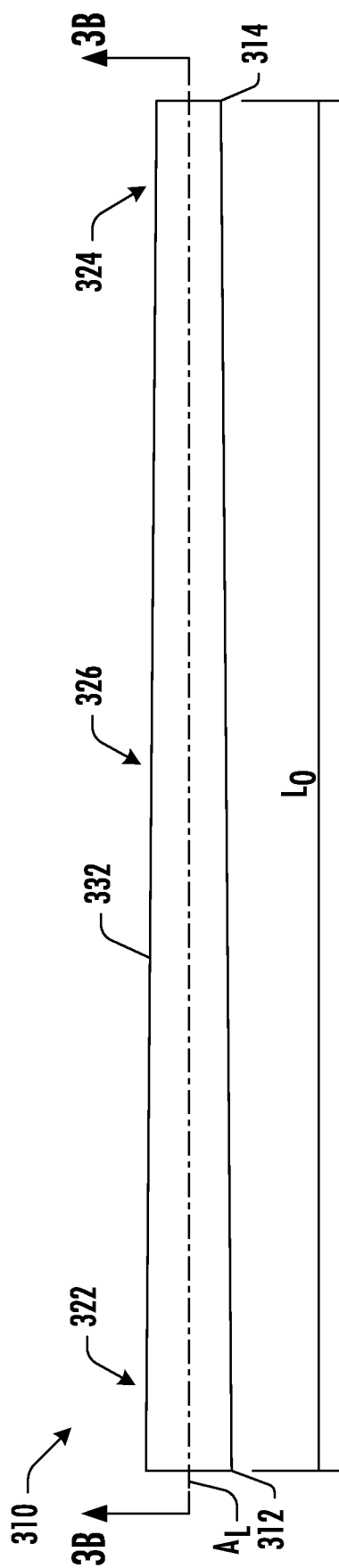
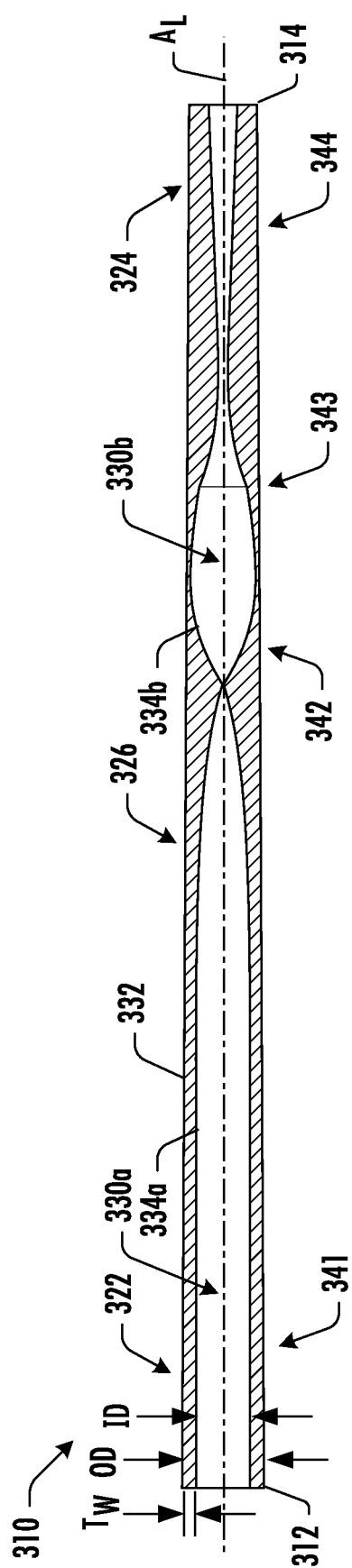


FIG. 2B



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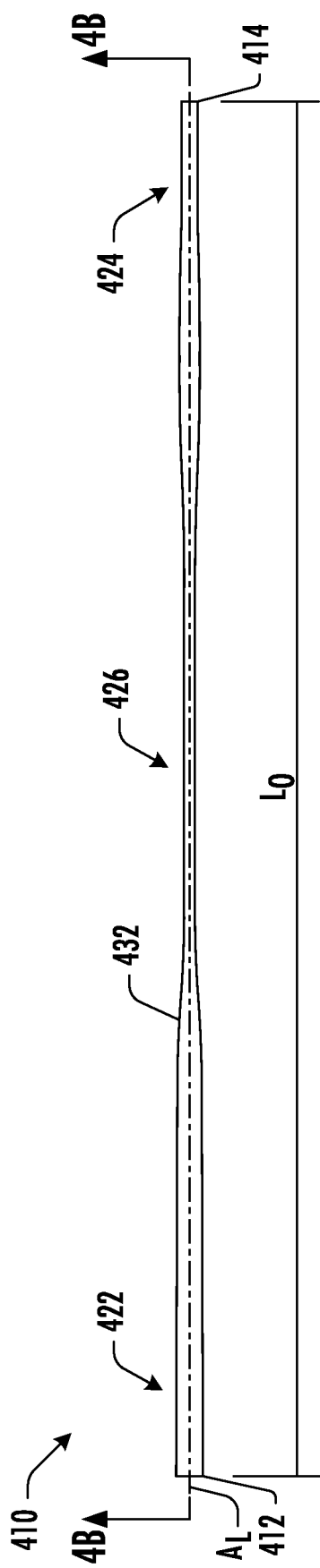


FIG. 4A

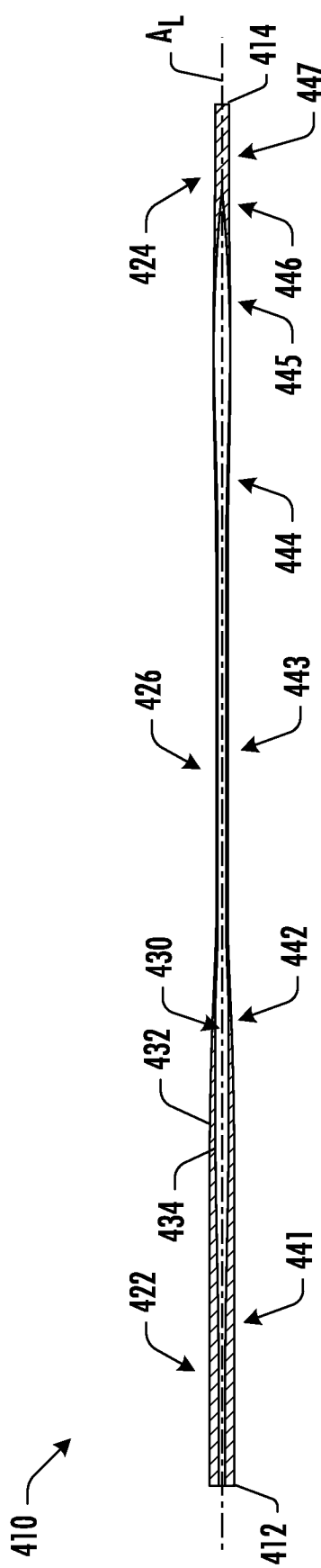
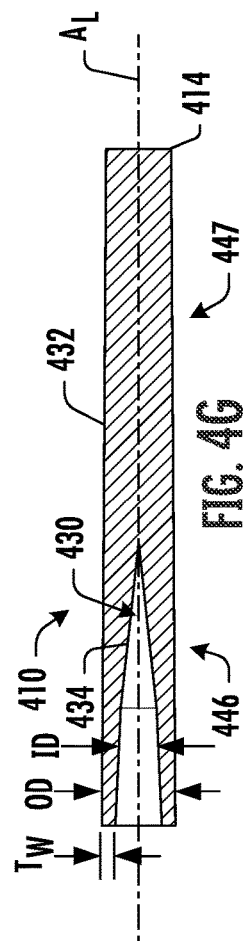
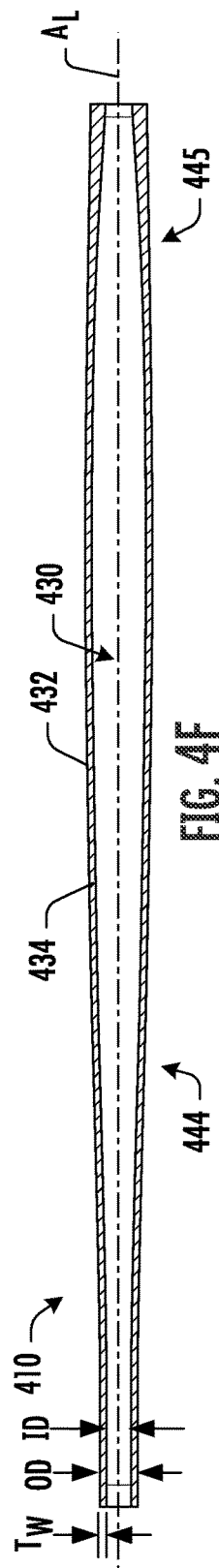
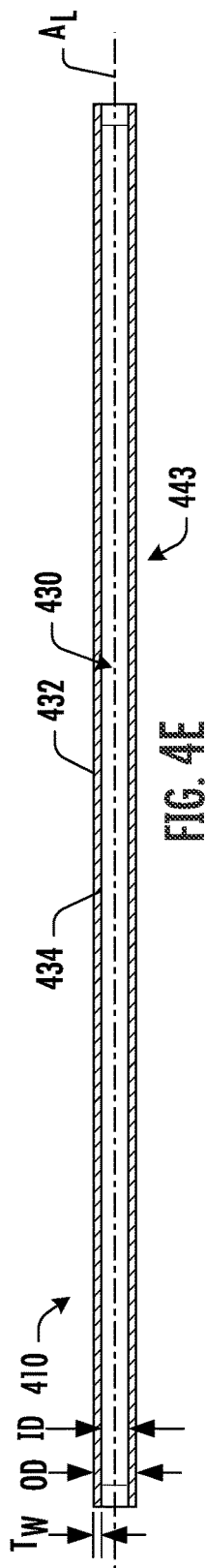
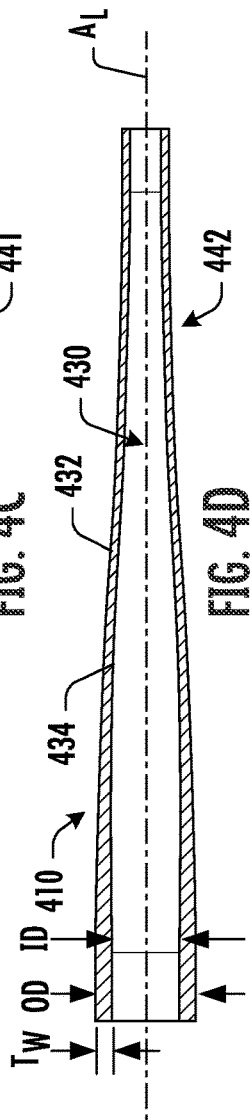
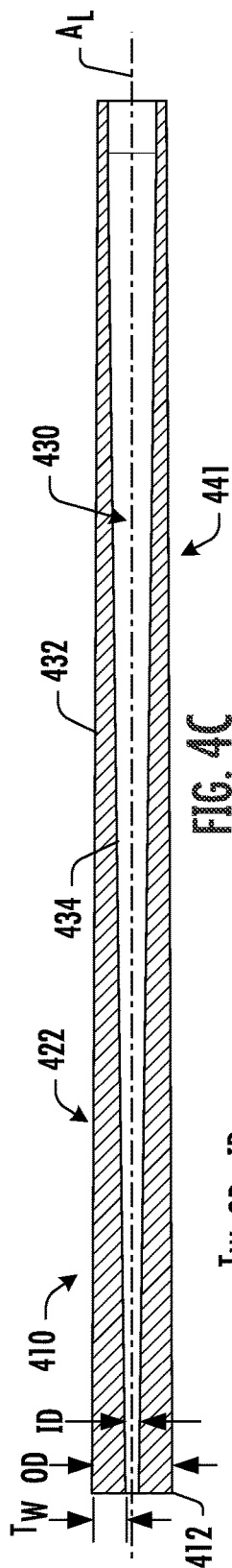


FIG. 4B



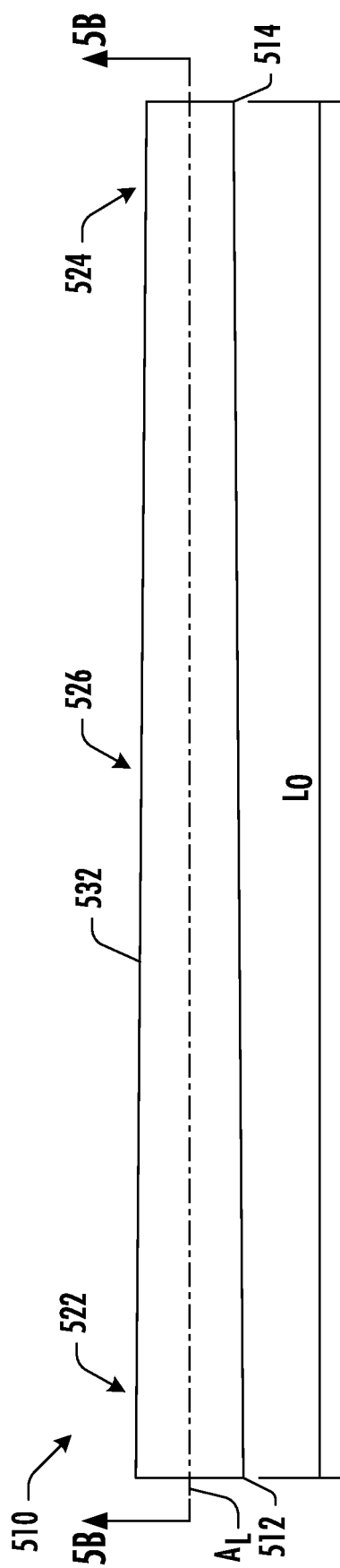


FIG. 5A

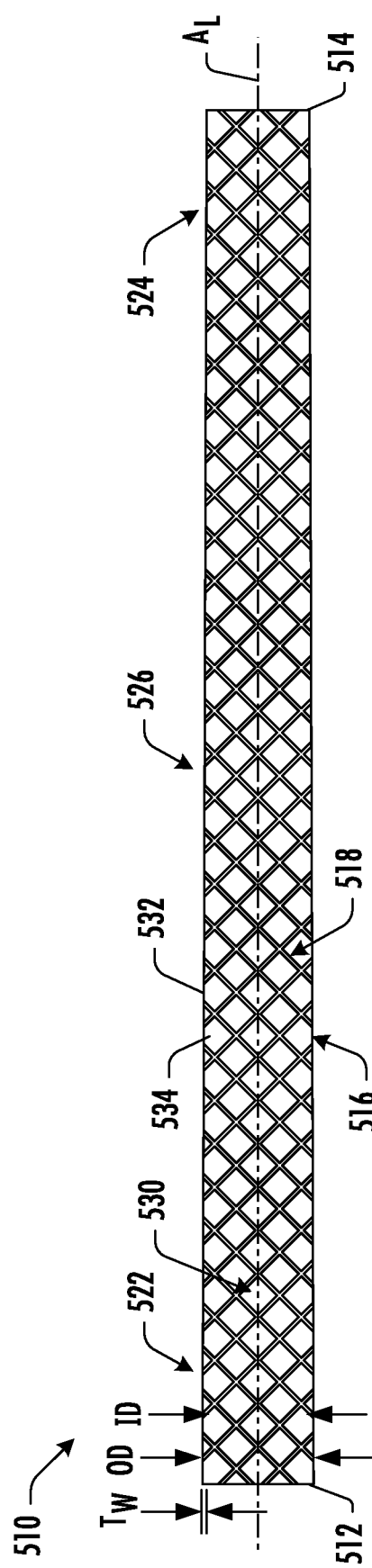


FIG. 5B

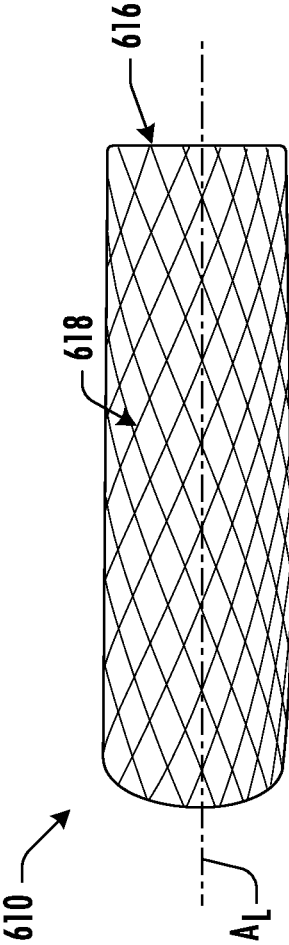


FIG. 6

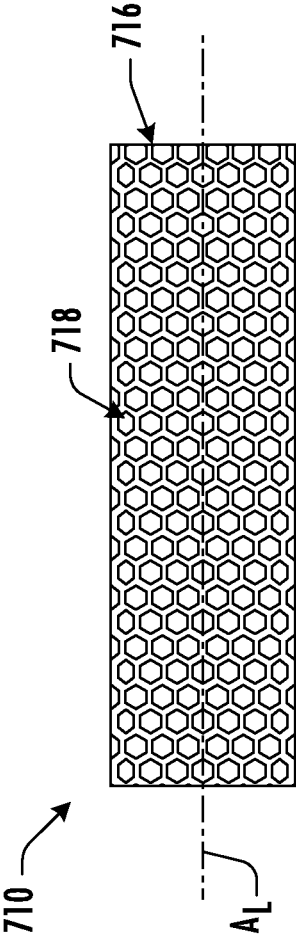


FIG. 7

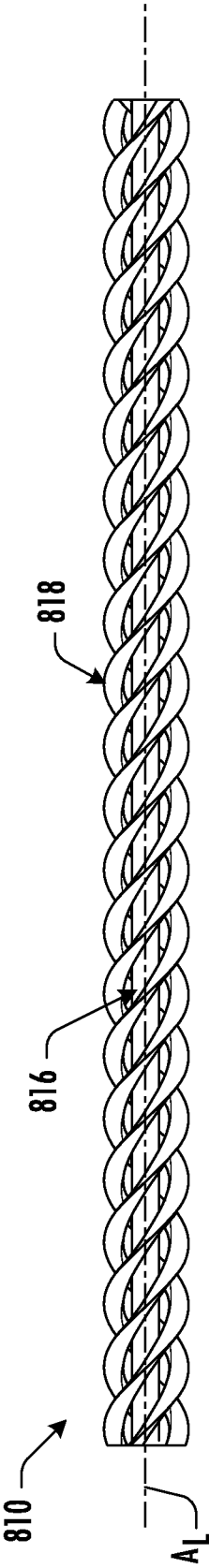


FIG. 8

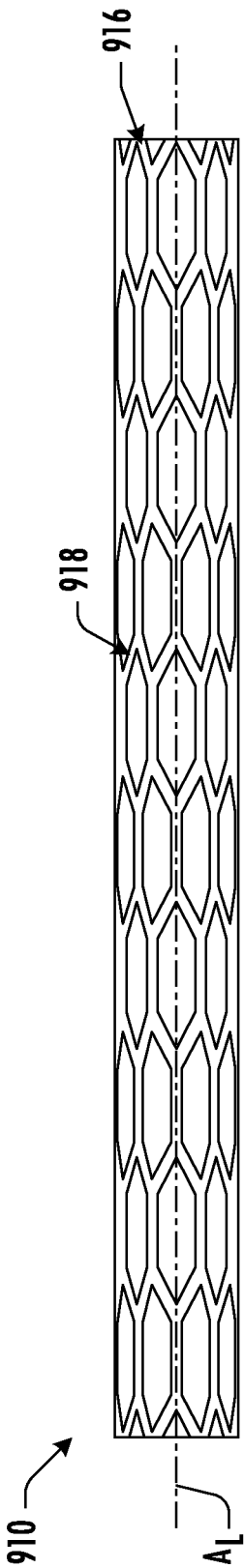


FIG. 9

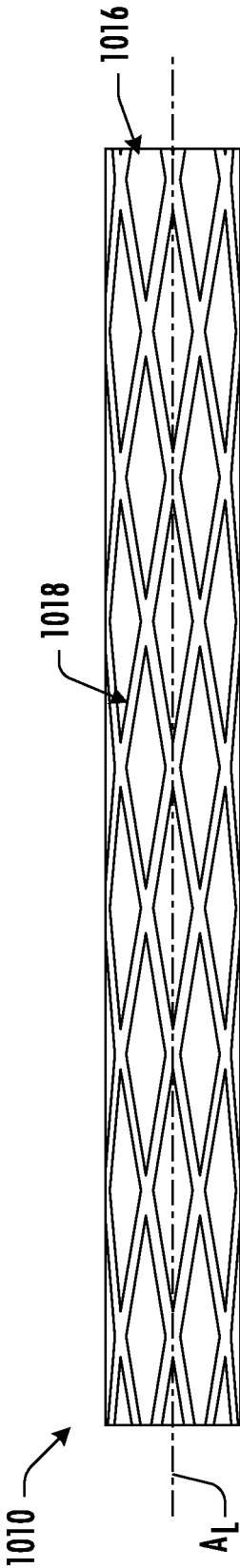


FIG. 10

GOLF SHAFTS HAVING A VARYING OUTER DIAMETER, INNER DIAMETER, AND/OR WALL THICKNESS AND METHODS FOR MANUFACTURING GOLF SHAFTS USING ADDITIVE MANUFACTURING

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of, and priority to, U.S. Provisional Patent Application No. 63/253,730, filed on Oct. 8, 2021, and titled “Golf Shafts Having a Varying Outer Diameter, Inner Diameter, and/or Wall Thickness and Methods for Manufacturing Golf Shafts Using Additive Manufacturing,” the disclosure of which is expressly incorporated herein by reference in its entirety.

FIELD OF THE DISCLOSURE

[0002] The present disclosure relates generally to golf clubs and more particularly to golf shafts having a varying outer diameter, inner diameter, and/or wall thickness and related methods for manufacturing golf shafts having a varying outer diameter, inner diameter, and/or wall thickness using additive manufacturing.

BACKGROUND OF THE DISCLOSURE

[0003] Golf clubs generally include three components: a shaft, a grip, and a clubhead. Of these components, the shaft typically is considered the most influential in determining the overall performance of a golf club and thus often may be referred to as the “engine” of the club. Each golf shaft has a stiffness profile that dictates how the shaft flexes when swung by a user during a golf swing. The weight of a golf shaft and how it flexes generally are the key factors in controlling swing speed and output ball flight dynamics, such as launch angle, launch direction, and spin rate. These dynamics ultimately may determine the distance and accuracy of a golf shot.

[0004] Steel golf shafts traditionally may be manufactured by first drawing a thick-walled tube down into a thin-walled tube. Then, individual sections of the thin-walled tube may be squeezed to reduce the diameters of the respective sections and create “steps” in the golf shaft. Notably, this manufacturing technique typically requires large assembly lines and expensive machinery that can be used to economically make golf shafts of only a few different stiffnesses. Moreover, this technique generally is not capable of varying the stiffness profile continuously along the length of a golf shaft, thereby limiting the design capabilities of the process. Consequently, current golf shaft providers typically lump golfers into a select number of shaft stiffness “bins” based on a golfer’s swing speed, with each bin covering a relatively large range of swing speeds. For example, certain providers may use five different shaft stiffness bins in recommending a golf shaft for a particular golfer: an “Extra-Flexible” bin for those with a swing speed of 62 mph or less, a “Flexible” bin for those with a swing speed of 63 mph to 76 mph, a “Regular” bin for those with a swing speed of 77 mph to 92 mph, a “Stiff” bin for those with a swing speed of 93 mph to 107 mph, and an “Extra Stiff” bin for those with a swing speed of 108 mph or greater. This approach may result in two different golfers having significantly different swing speeds being lumped into the same bin. For example, a golfer with a swing speed of 78 mph and another golfer with

a swing speed of 91 mph both would be fit into a Regular golf shaft even though their swing speeds are 13 mph apart and will result in different shaft loading patterns. Ultimately, the traditional bin approach often may result in a particular golfer using a shaft that is not ideal for his/her golf swing, thereby resulting in a loss of shot distance and/or decreased accuracy.

[0005] A need therefore exists for improved golf shafts and related methods for manufacturing golf shafts, which may overcome one or more of the above-mentioned limitations associated with traditional golf shafts and techniques for manufacturing such golf shafts.

SUMMARY OF THE DISCLOSURE

[0006] The present disclosure provides golf shafts, golf clubs, and related methods for manufacturing golf shafts. In one aspect, a method for manufacturing a golf shaft is provided. In one embodiment, the method may include receiving a CAD model corresponding to the golf shaft, and forming, based at least in part on the CAD model, the golf shaft using one or more additive manufacturing techniques. The golf shaft may include a first end and a second end disposed opposite one another along a longitudinal axis of the golf shaft, and the golf shaft may define one or more internal cavities extending along the longitudinal axis. The golf shaft may have an overall length from the first end to the second end, an outer diameter, an inner diameter, and a wall thickness, and at least one of the outer diameter, the inner diameter, and the wall thickness may vary along the overall length.

[0007] In some embodiments, forming the golf shaft using one or more additive manufacturing techniques may include forming the golf shaft of one or more metals or metal alloys using one or more metal additive manufacturing techniques. In some embodiments, forming the golf shaft using one or more additive manufacturing techniques may include forming the golf shaft using one or more powder bed fusion techniques. In some embodiments, forming the golf shaft using one or more additive manufacturing techniques may include forming the golf shaft as a single component using the one or more additive manufacturing techniques. In some embodiments, the method also may include determining user data corresponding to a swing pattern of a predetermined user of the golf shaft, and generating the CAD model based at least in part on the user data. In some embodiments, the method also may include determining a stiffness profile of the golf shaft based at least in part on the user data, and generating the CAD model based at least in part on the user data may include generating the CAD model based at least in part on the stiffness profile. In some embodiments, the golf shaft further also may include an external geometric structure disposed along an outer surface of the golf shaft, and wherein the external geometric structure has a pattern of geometric shapes. In some embodiments, at least a portion of the golf shaft may be devoid of any cylindrical thin-walled segments.

[0008] In another aspect, a method for manufacturing a golf shaft is provided. In one embodiment, the method may include receiving a CAD model corresponding to the golf shaft, and forming, based at least in part on the CAD model, the golf shaft using one or more additive manufacturing techniques. The golf shaft may include a first end and a second end disposed opposite one another along a longitudinal axis of the golf shaft, and the golf shaft may define one

or more internal cavities extending along the longitudinal axis. The golf shaft may have an overall length from the first end to the second end, an outer diameter, an inner diameter, and a wall thickness, and the wall thickness may vary along the overall length. A variation of the wall thickness between any two cross-sections of the golf shaft taken perpendicular to the longitudinal axis is equal to or greater than 0.001 inches.

[0009] In some embodiments, at least one of the inner diameter or the outer diameter may vary in a non-linear manner along at least a portion of the golf shaft. In some embodiments, at least one of the inner diameter or the outer diameter may vary along at least a portion of the golf shaft such that a taper rate of the at least one of the inner diameter or the outer diameter changes more than once along the at least a portion of the golf shaft. In some embodiments, forming the golf shaft using one or more additive manufacturing techniques may include forming the golf shaft of one or more metals or metal alloys using one or more metal additive manufacturing techniques. In some embodiments, forming the golf shaft using one or more additive manufacturing techniques may include forming the golf shaft as a single component using the one or more additive manufacturing techniques. In some embodiments, the method also may include determining user data corresponding to a swing pattern of a predetermined user of the golf shaft, and generating the CAD model based at least in part on the user data. In some embodiments, the method also may include determining a stiffness profile of the golf shaft based at least in part on the user data, and generating the CAD model based at least in part on the stiffness profile. In some embodiments, the golf shaft also may include an internal lattice structure disposed within at least one of the one or more internal cavities. In some embodiments, the golf shaft also may include an external geometric structure disposed along an outer surface of the golf shaft, and the external geometric structure may have a pattern of geometric shapes.

[0010] In still another aspect, a method for manufacturing a golf shaft is provided. In one embodiment, the method may include receiving a CAD model corresponding to the golf shaft, and forming, based at least in part on the CAD model, the golf shaft using one or more additive manufacturing techniques. The golf shaft may include a first end, a second end disposed opposite the first end along a longitudinal axis of the golf shaft, with the golf shaft having an overall length from the first end to the second end, a shaft body extending from the first end to the second end and having an outer surface, with the shaft body defining an internal cavity extending along the longitudinal axis, and an external geometric structure disposed along the outer surface, with the external geometric structure having a pattern of geometric shapes.

[0011] In some embodiments, the pattern of geometric shapes may be a repeating pattern. In some embodiments, the pattern of geometric shapes may be a non-repeating pattern.

[0012] In one aspect, a method for manufacturing a golf shaft is provided. In one embodiment, the method may include receiving a CAD model corresponding to the golf shaft, and forming, based at least in part on the CAD model, the golf shaft using one or more additive manufacturing techniques. The golf shaft may include a first end and a

second end disposed opposite one another along a longitudinal axis of the golf shaft, and the golf shaft may define one or more internal cavities extending along the longitudinal axis. The golf shaft may have an overall length from the first end to the second end, an outer diameter, an inner diameter, and a wall thickness, and at least one of the outer diameter, the inner diameter, and the wall thickness may vary along the overall length.

[0013] In some embodiments, forming the golf shaft using one or more additive manufacturing techniques may include forming the golf shaft of one or more metals or metal alloys using one or more metal additive manufacturing techniques. In some embodiments, the one or more metals or metal alloys may include at least one of: steel, a steel alloy, titanium, a titanium alloy, aluminum, or an aluminum alloy. In some embodiments, forming the golf shaft using one or more additive manufacturing techniques may include forming the golf shaft using one or more powder bed fusion techniques. In some embodiments, the one or more powder bed fusion techniques may include at least one of: direct metal laser sintering, selective laser melting, or electron beam melting. In some embodiments, forming the golf shaft using one or more additive manufacturing techniques may include forming the golf shaft using one or more metal binder jetting techniques. In some embodiments, the one or more metal binder jetting techniques may include 3D printing. In some embodiments, forming the golf shaft using one or more additive manufacturing techniques may include forming the golf shaft using one or more direct energy deposition techniques. In some embodiments, the one or more direct energy deposition techniques may include at least one of: laser engineered net shaping, direct metal deposition, or laser metal deposition. In some embodiments, forming the golf shaft using one or more additive manufacturing techniques may include forming the golf shaft using metal material extrusion. In some embodiments, forming the golf shaft using one or more additive manufacturing techniques may include forming the golf shaft using one or more material jetting techniques. In some embodiments, the one or more material jetting techniques may include liquid metal additive manufacturing. In some embodiments, forming the golf shaft using one or more additive manufacturing techniques may include forming the golf shaft using at least one of: joule printing, digital light projection metal printing, or cold spray metal printing. In some embodiments, forming the golf shaft using one or more additive manufacturing techniques may include forming the golf shaft as a single component using the one or more additive manufacturing techniques. In some embodiments, forming the golf shaft using one or more additive manufacturing techniques may include separately forming two or more segments of the golf shaft using the one or more additive manufacturing techniques, and the method also may include fixedly coupling the two or more segments of the golf shaft to one another. In some embodiments, fixedly coupling the two or more segments of the golf shaft to one another may include welding the two or more segments of the golf shaft to one another. In some embodiments, the method also may include determining user data corresponding to a swing pattern of a predetermined user of the golf shaft, and generating the CAD model based at least in part on the user data. In some embodiments, the method also may include determining a stiffness profile of the golf shaft based at least in part on the user data, and generating the CAD model based at least in

part on the user data may include generating the CAD model based at least in part on the stiffness profile. In some embodiments, the outer diameter may vary along the overall length. In some embodiments, the inner diameter may vary along the overall length. In some embodiments, the wall thickness may vary along the overall length. In some embodiments, the outer diameter and the inner diameter each may vary along the overall length. In some embodiments, the outer diameter and the wall thickness each may vary along the overall length. In some embodiments, the inner diameter and the wall thickness each may vary along the overall length. In some embodiments, the outer diameter, the inner diameter, and the wall thickness each may vary along the overall length.

[0014] In another aspect, a golf shaft is provided. In one embodiment, the golf shaft may include a first end and a second end disposed opposite one another along a longitudinal axis of the golf shaft. The golf shaft may define one or more internal cavities extending along the longitudinal axis. The golf shaft may have an overall length from the first end to the second end, an outer diameter, an inner diameter, and a wall thickness. At least one of the outer diameter, the inner diameter, and the wall thickness may vary along the overall length.

[0015] In some embodiments, the outer diameter may vary along the overall length. In some embodiments, the inner diameter may vary along the overall length. In some embodiments, the wall thickness may vary along the overall length. In some embodiments, the outer diameter and the inner diameter each may vary along the overall length. In some embodiments, the outer diameter and the wall thickness each may vary along the overall length. In some embodiments, the inner diameter and the wall thickness each may vary along the overall length. In some embodiments, the outer diameter, the inner diameter, and the wall thickness each may vary along the overall length.

[0016] In some embodiments, the golf shaft may include a first shaft portion and a second shaft portion each disposed between the first end and the second end, the outer diameter may decrease along the first shaft portion in a direction from the first end toward the second end, and the outer diameter may increase along the second shaft portion in the direction from the first end toward the second end. In some embodiments, the golf shaft may include a first shaft portion and a second shaft portion each disposed between the first end and the second end, the inner diameter may decrease along the first shaft portion in a direction from the first end toward the second end, and the inner diameter may increase along the second shaft portion in the direction from the first end toward the second end. In some embodiments, the golf shaft may include a first shaft portion and a second shaft portion each disposed between the first end and the second end, the wall thickness may decrease along the first shaft portion in a direction from the first end toward the second end, and the wall thickness may increase along the second shaft portion in the direction from the first end toward the second end. In some embodiments, the golf shaft may be formed of one or more metals or metal alloys. In some embodiments, the one or more metals or metal alloys may include at least one of: steel, a steel alloy, titanium, a titanium alloy, aluminum, or an aluminum alloy.

[0017] In still another aspect, a golf club is provided. In one embodiment, the golf club may include a golf shaft, a grip, and a clubhead. The golf shaft may include a first end

and a second end disposed opposite one another along a longitudinal axis of the golf shaft, a grip section extending from the first end toward the second end, and a clubhead section extending from the second end toward the first end. The golf shaft may define one or more internal cavities extending along the longitudinal axis. The golf shaft may have an overall length from the first end to the second end, an outer diameter, an inner diameter, and a wall thickness. At least one of the outer diameter, the inner diameter, and the wall thickness may vary along the overall length. The grip may be coupled to the grip section, and the clubhead may be coupled to the clubhead section.

[0018] In one aspect, a method for manufacturing a golf shaft is provided. In one embodiment, the method may include receiving a CAD model corresponding to the golf shaft, and forming, based at least in part on the CAD model, the golf shaft using one or more additive manufacturing techniques. The golf shaft may include a first end and a second end disposed opposite one another along a longitudinal axis of the golf shaft, and the golf shaft may define one or more internal cavities extending along the longitudinal axis. The golf shaft may have an overall length from the first end to the second end, and a wall thickness of the golf shaft may continuously vary along at least 5% of the overall length.

[0019] In another aspect, a golf shaft is provided. In one embodiment, the golf shaft may include a first end, and a second end disposed opposite the first end along a longitudinal axis of the golf shaft. The golf shaft may be formed of one or more metals or metal alloys. The golf shaft may define one or more internal cavities extending along the longitudinal axis. The golf shaft may have an overall length from the first end to the second end. A wall thickness of the golf shaft may continuously vary along at least 5% of the overall length.

[0020] In some embodiments, the wall thickness may continuously vary along at least 10% of the overall length. In some embodiments, the wall thickness may continuously vary along at least 20% of the overall length. In some embodiments, the wall thickness may continuously vary along at least 30% of the overall length. In some embodiments, the wall thickness may continuously vary along at least 40% of the overall length. In some embodiments, the wall thickness may continuously vary along at least 50% of the overall length. In some embodiments, the wall thickness may continuously vary along at least 60% of the overall length. In some embodiments, the wall thickness may continuously vary along at least 70% of the overall length. In some embodiments, the wall thickness may continuously vary along at least 80% of the overall length. In some embodiments, the wall thickness may continuously vary along at least 90% of the overall length. In some embodiments, the wall thickness may continuously vary along an entirety of the overall length. In some embodiments, the wall thickness may be constant along a minority of the overall length.

[0021] In some embodiments, the golf shaft also may include a shaft portion disposed between the first end and the second end, and the wall thickness may continuously decrease along the shaft portion in a direction from the first end toward the second end. In some embodiments, an outer diameter of the golf shaft may continuously decrease along the shaft portion in the direction from the first end toward the second end. In some embodiments, the outer diameter of the

golf shaft may continuously decrease in a linear manner along the shaft portion in the direction from the first end toward the second end. In some embodiments, the outer diameter of the golf shaft may continuously decrease in a non-linear manner along the shaft portion in the direction from the first end toward the second end. In some embodiments, the outer diameter of the golf shaft may continuously decrease at an increasing rate along at least part of the shaft portion in the direction from the first end toward the second end. In some embodiments, the outer diameter of the golf shaft may continuously decrease at a decreasing rate along at least part of the shaft portion in the direction from the first end toward the second end. In some embodiments, an inner diameter of the golf shaft may continuously increase along the shaft portion in the direction from the first end toward the second end. In some embodiments, the inner diameter of the golf shaft may continuously increase in a linear manner along the shaft portion in the direction from the first end toward the second end. In some embodiments, the inner diameter of the golf shaft may continuously increase in a non-linear manner along the shaft portion in the direction from the first end toward the second end. In some embodiments, the inner diameter of the golf shaft may continuously increase at an increasing rate along at least part of the shaft portion in the direction from the first end toward the second end. In some embodiments, the inner diameter of the golf shaft may continuously increase at a decreasing rate along at least part of the shaft portion in the direction from the first end toward the second end. In some embodiments, an inner diameter of the golf shaft may continuously decrease along the shaft portion in the direction from the first end toward the second end. In some embodiments, an inner diameter of the golf shaft may be constant along the shaft portion. In some embodiments, an inner diameter of the golf shaft may continuously increase along the shaft portion in the direction from the first end toward the second end. In some embodiments, the inner diameter of the golf shaft may continuously increase in a linear manner along the shaft portion in the direction from the first end toward the second end. In some embodiments, the inner diameter of the golf shaft may continuously increase in a non-linear manner along the shaft portion in the direction from the first end toward the second end. In some embodiments, the inner diameter of the golf shaft may continuously increase at an increasing rate along at least part of the shaft portion in the direction from the first end toward the second end. In some embodiments, the inner diameter of the golf shaft may continuously increase at a decreasing rate along at least part of the shaft portion in the direction from the first end toward the second end. In some embodiments, an outer diameter of the golf shaft may continuously increase along the shaft portion in the direction from the first end toward the second end. In some embodiments, an outer diameter of the golf shaft may be constant along the shaft portion. In some embodiments, the shaft portion may extend from the first end and may be spaced apart from the second end. In some embodiments, the shaft portion may be spaced apart from the first end and may extend to the second end. In some embodiments, the shaft portion may be spaced apart from each of the first end and the second end.

[0022] In some embodiments, the golf shaft also may include a shaft portion disposed between the first end and the second end, and the wall thickness may continuously increase along the shaft portion in a direction from the first

[illegible]

[0023] In some embodiments, the golf shaft also may include a first shaft portion disposed between the first end and the second end, and a second shaft portion disposed between the first end and the second end. The wall thickness may continuously decrease along the first shaft portion in a direction from the first end toward the second end, and the wall thickness may continuously increase along the second shaft portion in the direction from the first end toward the second end. In some embodiments, the first shaft portion may be disposed between the first end and the second shaft portion. In some embodiments, the first shaft portion may be disposed between the second end and the second shaft portion. In some embodiments, the first shaft portion and the second shaft portion may be disposed adjacent one another. In some embodiments, the first shaft portion and the second shaft portion may be spaced apart from one another. In some embodiments, the golf shaft also may include a third shaft portion disposed between the first end and the second end, and the wall thickness may continuously decrease along the third shaft portion in the direction from the first end toward the second end. In some embodiments, the golf shaft also may include a fourth shaft portion disposed between the first end and the second end, the wall thickness may continuously increase along the third shaft portion in the direction from the first end toward the second end. In some embodiments, the golf shaft also may include a third shaft portion disposed between the first end and the second end, and the wall thickness may continuously increase along the third shaft portion in the direction from the first end toward the second end. In some embodiments, an outer diameter of the golf shaft may continuously decrease along at least a majority of the overall length in a direction from the first end toward the second end. In some embodiments, an outer diameter of the golf shaft continuously may decrease from the first end to the second end.

[0024] In some embodiments, the golf shaft also may include a grip section extending from the first end toward the second end, and a clubhead section extending from the second end toward the first end. The grip section may be configured to receive a grip thereon, and the clubhead section may be configured to receive a clubhead thereon. In some embodiments, the wall thickness may continuously vary along the grip section in a direction from the first end toward the second end. In some embodiments, the wall thickness may continuously decrease along the grip section in the direction from the first end toward the second end. In some embodiments, the wall thickness may continuously increase along the grip section in the direction from the first end toward the second end. In some embodiments, the wall thickness may be constant along the grip section. In some embodiments, the wall thickness may continuously vary along the clubhead section in a direction from the first end toward the second end. In some embodiments, the wall thickness may continuously decrease along the clubhead section in the direction from the first end toward the second end. In some embodiments, the wall thickness may continuously increase along the clubhead section in the direction from the first end toward the second end. In some embodiments, the wall thickness may be constant along the clubhead section.

[0025] In some embodiments, the one or more internal cavities may include an internal cavity that extends from the first end to the second end. In some embodiments, the one or more internal cavities may include an internal cavity that

extends from the first end toward the second end and is spaced apart from the second end. In some embodiments, the golf shaft also may include a shaft portion disposed between the internal cavity and the second end, and the shaft portion may be devoid of any internal cavities. In some embodiments, the shaft portion may extend to the second end. In some embodiments, the one or more internal cavities may include an internal cavity that extends from the second end toward the first end and is spaced apart from the first end. In some embodiments, the golf shaft also may include a shaft portion disposed between the internal cavity and the first end, and the shaft portion may be devoid of any internal cavities. In some embodiments, the shaft portion may extend to the first end. In some embodiments, the one or more internal cavities may include an internal cavity that is spaced apart from each of the first end and the second end. In some embodiments, the golf shaft also may include a first shaft portion disposed between the internal cavity and the first end, and a second shaft portion disposed between the internal cavity and the second end. The first shaft portion may be devoid of any internal cavities, and the second shaft portion may be devoid of any internal cavities. In some embodiments, the first shaft portion may extend to the first end, and the second shaft portion may extend to the second end. In some embodiments, the one or more internal cavities may include a first internal cavity and a second internal cavity that are not in communication with one another. In some embodiments, the first internal cavity and the second internal cavity may be spaced apart from one another by a shaft portion that is devoid of any internal cavities. In some embodiments, the first internal cavity may extend from the first end toward the second end, and the second internal cavity may extend from the second end toward the first end. In some embodiments, the golf shaft may be formed of steel or a steel alloy. In some embodiments, the golf shaft may be formed of titanium or a titanium alloy. In some embodiments, the golf shaft may be formed of aluminum or an aluminum alloy.

[0026] In still another aspect, a golf club is provided. In one embodiment, the golf club may include a golf shaft, a grip, and a clubhead. The golf shaft may include a first end, a second end disposed opposite the first end along a longitudinal axis of the golf shaft, a grip section extending from the first end toward the second end, and a clubhead section extending from the second end toward the first end. The golf shaft may be formed of one or more metals or metal alloys. The golf shaft may define one or more internal cavities extending along the longitudinal axis. The golf shaft may have an overall length from the first end to the second end. A wall thickness of the golf shaft may continuously vary along at least 5% of the overall length. The grip may be coupled to the grip section, and the clubhead may be coupled to the clubhead section.

[0027] In one aspect, a method for manufacturing a golf shaft is provided. In one embodiment, the method may include receiving a CAD model corresponding to the golf shaft, and forming, based at least in part on the CAD model, the golf shaft using one or more additive manufacturing techniques. The golf shaft may include a first end, and a second end disposed opposite the first end along a longitudinal axis of the golf shaft. The golf shaft may define one or more internal cavities extending along the longitudinal axis. The golf shaft may have an overall length from the first end

to the second end, and an outer diameter of the golf shaft may continuously decrease from the first end to the second end.

[0028] In another aspect, a golf shaft is provided. In one embodiment, the golf shaft may include a first end and a second end disposed opposite the first end along a longitudinal axis of the golf shaft. The golf shaft may be formed of one or more metals or metal alloys, and the golf shaft may define one or more internal cavities extending along the longitudinal axis. The golf shaft may have an overall length from the first end to the second end, and an outer diameter of the golf shaft may continuously decrease from the first end to the second end.

[0029] In some embodiments, the outer diameter of the golf shaft may continuously decrease in a linear manner from the first end to the second end. In some embodiments, the outer diameter of the golf shaft may continuously decrease in a non-linear manner from the first end to the second end. In some embodiments, the golf shaft may include a first shaft portion disposed between the first end and the second end, and a second shaft portion disposed between the first end and the second end. The outer diameter of the golf shaft may continuously decrease at an increasing rate along the first shaft portion in a direction from the first end toward the second end, and the outer diameter of the golf shaft may continuously decrease at a decreasing rate along the second shaft portion in the direction from the first end toward the second end. In some embodiments, an inner diameter of the golf shaft may continuously increase along the first shaft portion in the direction from the first end toward the second end, and the inner diameter of the golf shaft may continuously decrease along the second shaft portion in the direction from the first end toward the second end. In some embodiments, the inner diameter of the golf shaft may continuously increase in a linear manner along the first shaft portion in the direction from the first end toward the second end. In some embodiments, the inner diameter of the golf shaft may continuously increase in a non-linear manner along the first shaft portion in the direction from the first end toward the second end. In some embodiments, the inner diameter of the golf shaft may continuously decrease in a linear manner along the second shaft portion in the direction from the first end toward the second end. In some embodiments, the inner diameter of the golf shaft may continuously decrease in a non-linear manner along the second shaft portion in the direction from the first end toward the second end. In some embodiments, the golf shaft also may include a third shaft portion disposed between the first end and the second end, and the inner diameter of the golf shaft may be constant along the third shaft portion. In some embodiments, a wall thickness of the golf shaft may continuously vary along at least a majority of the overall length. In some embodiments, the wall thickness of the golf shaft may continuously vary along an entirety of the overall length. In some embodiments, the wall thickness of the golf shaft may be constant along a minority of the overall length. In some embodiments, the one or more metals or metal alloys may include at least one of: steel, a steel alloy, titanium, a titanium alloy, aluminum, or an aluminum alloy.

[0030] In still another aspect, a golf club is provided. In one embodiment, the golf club may include a golf shaft, a grip, and a clubhead. The golf shaft may include a first end, a second end disposed opposite the first end along a longitudinal axis of the golf shaft, a grip section extending from

the first end toward the second end, and a clubhead section extending from the second end toward the first end. The golf shaft may be formed of one or more metals or metal alloys, and the golf shaft may define one or more internal cavities extending along the longitudinal axis. The golf shaft may have an overall length from the first end to the second end, and an outer diameter of the golf shaft may continuously decrease from the first end to the second end. The grip may be coupled to the grip section, and the clubhead may be coupled to the clubhead section.

[0031] In one aspect, a method for manufacturing a golf shaft is provided. In one embodiment, the method may include receiving a CAD model corresponding to the golf shaft, and forming, based at least in part on the CAD model, the golf shaft using one or more additive manufacturing techniques. The golf shaft may include a first end, a second end disposed opposite the first end along a longitudinal axis of the golf shaft, and one or more shaft portions disposed between the first end and the second end. The golf shaft may define one or more internal cavities extending along the longitudinal axis. The golf shaft may have an overall length from the first end to the second end, and an outer diameter of the golf shaft may continuously vary in a non-linear manner along each of the one or more shaft portions.

[0032] In another aspect, a golf shaft is provided. In one embodiment, the golf shaft may include a first end, a second end disposed opposite the first end along a longitudinal axis of the golf shaft, and one or more shaft portions disposed between the first end and the second end. The golf shaft may define one or more internal cavities extending along the longitudinal axis. The golf shaft may have an overall length from the first end to the second end, and an outer diameter of the golf shaft may continuously vary in a non-linear manner along each of the one or more shaft portions.

[0033] In some embodiments, the outer diameter of the golf shaft may continuously decrease in a non-linear manner along each of the one or more shaft portions in a direction from the first end toward the second end. In some embodiments, the outer diameter of the golf shaft may continuously decrease at an increasing rate along each of the one or more shaft portions in the direction from the first end toward the second end. In some embodiments, the outer diameter of the golf shaft may continuously decrease at a decreasing rate along each of the one or more shaft portions in the direction from the first end toward the second end. In some embodiments, the outer diameter of the golf shaft may continuously increase in a non-linear manner along each of the one or more shaft portions in a direction from the first end toward the second end. In some embodiments, the outer diameter of the golf shaft may continuously increase at an increasing rate along each of the one or more shaft portions in the direction from the first end toward the second end. In some embodiments, the outer diameter of the golf shaft may continuously increase at a decreasing rate along each of the one or more shaft portions in the direction from the first end toward the second end. In some embodiments, the one or more shaft portions may include a first shaft portion disposed between the first end and the second end, and a second shaft portion disposed between the first end and the second end. The outer diameter of the golf shaft may continuously decrease in a non-linear manner along the first shaft portion in a direction from the first end toward the second end, and the outer diameter of the golf shaft may continuously increase in a non-linear manner along the second shaft

portion in the direction from the first end toward the second end. In some embodiments, an inner diameter of the golf shaft may continuously vary in a non-linear manner along each of the one or more shaft portions. In some embodiments, the golf shaft may be formed of one or more metals or metal alloys. In some embodiments, the one or more metals or metal alloys may include at least one of: steel, a steel alloy, titanium, a titanium alloy, aluminum, or an aluminum alloy.

[0034] In still another aspect, a golf club is provided. In one embodiment, the golf club may include a golf shaft, a grip, and a clubhead. The golf shaft may include a first end, a second end disposed opposite the first end along a longitudinal axis of the golf shaft, one or more shaft portions disposed between the first end and the second end, a grip section extending from the first end toward the second end, and a clubhead section extending from the second end toward the first end. The golf shaft may define one or more internal cavities extending along the longitudinal axis. The golf shaft may have an overall length from the first end to the second end, and an outer diameter of the golf shaft may continuously vary in a non-linear manner along each of the one or more shaft portions. The grip may be coupled to the grip section, and the clubhead may be coupled to the clubhead section.

[0035] In one aspect, a method for manufacturing a golf shaft is provided. In one embodiment, the method may include receiving a CAD model corresponding to the golf shaft, and forming, based at least in part on the CAD model, the golf shaft using one or more additive manufacturing techniques. The golf shaft may include a first end, a second end disposed opposite the first end along a longitudinal axis of the golf shaft, and one or more shaft portions disposed between the first end and the second end. The golf shaft may define one or more internal cavities extending along the longitudinal axis. The golf shaft may have an overall length from the first end to the second end, and an inner diameter of the golf shaft may continuously vary in a non-linear manner along each of the one or more shaft portions.

[0036] In another aspect, a golf shaft is provided. In one embodiment, the golf shaft may include a first end, a second end disposed opposite the first end along a longitudinal axis of the golf shaft, and one or more shaft portions disposed between the first end and the second end. The golf shaft may define one or more internal cavities extending along the longitudinal axis. The golf shaft may have an overall length from the first end to the second end, and an inner diameter of the golf shaft may continuously vary in a non-linear manner along each of the one or more shaft portions.

[0037] In some embodiments, the inner diameter of the golf shaft may continuously decrease in a non-linear manner along each of the one or more shaft portions in a direction from the first end toward the second end. In some embodiments, the inner diameter of the golf shaft may continuously decrease at an increasing rate along each of the one or more shaft portions in the direction from the first end toward the second end. In some embodiments, the inner diameter of the golf shaft may continuously decrease at a decreasing rate along each of the one or more shaft portions in the direction from the first end toward the second end. In some embodiments, the inner diameter of the golf shaft may continuously increase in a non-linear manner along each of the one or more shaft portions in a direction from the first end toward the second end. In some embodiments, the inner diameter of

the golf shaft may continuously increase at an increasing rate along each of the one or more shaft portions in the direction from the first end toward the second end. In some embodiments, the inner diameter of the golf shaft may continuously increase at a decreasing rate along each of the one or more shaft portions in the direction from the first end toward the second end. In some embodiments, the one or more shaft portions may include a first shaft portion disposed between the first end and the second end, and a second shaft portion disposed between the first end and the second end. The inner diameter of the golf shaft may continuously decrease in a non-linear manner along the first shaft portion in a direction from the first end toward the second end, and the inner diameter of the golf shaft may continuously increase in a non-linear manner along the second shaft portion in the direction from the first end toward the second end. In some embodiments, an outer diameter of the golf shaft may continuously vary in a non-linear manner along each of the one or more shaft portions. In some embodiments, the golf shaft may be formed of one or more metals or metal alloys. In some embodiments, the one or more metals or metal alloys may include at least one of: steel, a steel alloy, titanium, a titanium alloy, aluminum, or an aluminum alloy.

[0038] In still another aspect, a golf club is provided. In one embodiment, the golf club may include a golf shaft, a grip, and a clubhead. The golf shaft may include a first end, a second end disposed opposite the first end along a longitudinal axis of the golf shaft, one or more shaft portions disposed between the first end and the second end, a grip section extending from the first end toward the second end, and a clubhead section extending from the second end toward the first end. The golf shaft may define one or more internal cavities extending along the longitudinal axis. The golf shaft may have an overall length from the first end to the second end, and an inner diameter of the golf shaft may continuously vary in a non-linear manner along each of the one or more shaft portions. The grip may be coupled to the grip section, and the clubhead may be coupled to the clubhead section.

[0039] In one aspect, a method for manufacturing a golf shaft is provided. In one embodiment, the method may include receiving a CAD model corresponding to the golf shaft, and forming, based at least in part on the CAD model, the golf shaft using one or more additive manufacturing techniques. The golf shaft may include a first end, a second end disposed opposite the first end along a longitudinal axis of the golf shaft, a shaft body extending from the first end to the second end, and an internal lattice structure. The golf shaft may have an overall length from the first end to the second end. The shaft body may define an internal cavity extending along the longitudinal axis. The internal lattice structure may be disposed within the internal cavity.

[0040] In another aspect, a golf shaft is provided. In one embodiment, the golf shaft may include a first end, a second end disposed opposite the first end along a longitudinal axis of the golf shaft, a shaft body extending from the first end to the second end, and an internal lattice structure. The golf shaft may have an overall length from the first end to the second end. The shaft body may define an internal cavity extending along the longitudinal axis. The internal lattice structure may be disposed within the internal cavity. The golf shaft may be formed of one or more metals or metal alloys.

[0041] In some embodiments, the internal lattice structure may define a plurality of openings each having a polygonal shape. In some embodiments, the internal lattice structure may extend along at least part of a length of the internal cavity. In some embodiments, the internal lattice structure may extend along an entirety of a length of the internal cavity. In some embodiments, the internal cavity may extend from the first end to the second end, and the internal lattice structure may extend from the first end to the second end. In some embodiments, the internal cavity may extend from the first end toward the second end and be spaced apart from the second end, and the internal lattice structure may extend from the first end toward the second end and be spaced apart from the second end. In some embodiments, the internal cavity may extend from the second end toward the first end and be spaced apart from the first end, and the internal lattice structure may extend from the second end toward the first end and be spaced apart from the first end. In some embodiments, the internal cavity may be spaced apart from each of the first end and the second end, and the internal lattice structure may extend along an entirety of a length of the internal cavity. In some embodiments, the shaft body and the internal lattice structure may be integrally formed with one another. In some embodiments, a wall thickness of the shaft body may vary along the overall length. In some embodiments, a wall thickness of the shaft body may continuously vary along at least a majority of the overall length. In some embodiments, an outer diameter of the shaft body may vary along the overall length. In some embodiments, an outer diameter of the shaft body may continuously vary along at least a majority of the overall length. In some embodiments, an inner diameter of the shaft body may vary along the overall length. In some embodiments, an outer diameter of the shaft body may continuously vary along at least a majority of the overall length. In some embodiments, the one or more metals or metal alloys may include at least one of: steel, a steel alloy, titanium, a titanium alloy, aluminum, or an aluminum alloy.

[0042] In still another aspect, a golf club is provided. In one embodiment, the golf club may include a golf shaft, a grip, and a clubhead. The golf shaft may include a first end, a second end disposed opposite the first end along a longitudinal axis of the golf shaft, a shaft body extending from the first end to the second end, and an internal lattice structure. The golf shaft may have an overall length from the first end to the second end. The shaft body may define an internal cavity extending along the longitudinal axis. The shaft body may include a grip section extending from the first end toward the second end, and a clubhead section extending from the second end toward the first end. The internal lattice structure may be disposed within the internal cavity. The golf shaft may be formed of one or more metals or metal alloys. The grip may be coupled to the grip section, and the clubhead may be coupled to the clubhead section.

[0043] In one aspect, a method for manufacturing a golf shaft is provided. In one embodiment, the method may include receiving a CAD model corresponding to the golf shaft, and forming, based at least in part on the CAD model, the golf shaft using one or more additive manufacturing techniques. The golf shaft may include a first end, a second end disposed opposite the first end along a longitudinal axis of the golf shaft, a shaft body extending from the first end to the second end and having an outer surface, and an external geometric structure disposed along the outer sur-

face. The golf shaft may have an overall length from the first end to the second end. The shaft body may define an internal cavity extending along the longitudinal axis. The external geometric structure may have a pattern of geometric shapes.

[0044] In another aspect, a golf shaft is provided. In one embodiment, the golf shaft may include a first end, a second end disposed opposite the first end along a longitudinal axis of the golf shaft, a shaft body extending from the first end to the second end and having an outer surface, and an external geometric structure disposed along the outer surface. The golf shaft may have an overall length from the first end to the second end. The shaft body may define an internal cavity extending along the longitudinal axis. The external geometric structure may have a pattern of geometric shapes. The golf shaft may be formed of one or more metals or metal alloys.

[0045] In some embodiments, the pattern of geometric shapes may be a repeating pattern. In some embodiments, the pattern of geometric shapes may be a non-repeating pattern. In some embodiments, the external geometric structure may have a repeating pattern of polygonal shapes. In some embodiments, the external geometric structure may include one or more helixes centered on the longitudinal axis. In some embodiments, the shaft body may include a grip section extending from the first end toward the second end and configured to receive a grip thereon, a clubhead section extending from the second end toward the first end and configured to receive a clubhead thereon, and an intermediate section extending from the grip section to the clubhead section. In some embodiments, the external geometric structure may extend along at least part of a length of the intermediate section. In some embodiments, the external geometric structure may extend along at least a majority of the length of the intermediate section. In some embodiments, the external geometric structure may extend along an entirety of the length of the intermediate section. In some embodiments, the internal cavity may extend from the first end to the second end. In some embodiments, the internal cavity may extend from the first end toward the second end and be spaced apart from the second end. In some embodiments, the internal cavity may extend from the second end toward the first end and be spaced apart from the first end. In some embodiments, the internal cavity may be spaced apart from each of the first end and the second end. In some embodiments, the shaft body and the external geometric structure may be integrally formed with one another. In some embodiments, a wall thickness of the shaft body may vary along the overall length. In some embodiments, a wall thickness of the shaft body may continuously vary along at least a majority of the overall length. In some embodiments, an outer diameter of the shaft body may vary along the overall length. In some embodiments, an outer diameter of the shaft body may continuously vary along at least a majority of the overall length. In some embodiments, an inner diameter of the shaft body may vary along the overall length. In some embodiments, an outer diameter of the shaft body may continuously vary along at least a majority of the overall length. In some embodiments, the one or more metals or metal alloys may include at least one of: steel, a steel alloy, titanium, a titanium alloy, aluminum, or an aluminum alloy.

[0046] In still another aspect, a golf club is provided. In one embodiment, the golf club may include a golf shaft, a grip, and a clubhead. The golf shaft may include a first end,

a second end disposed opposite the first end along a longitudinal axis of the golf shaft, a shaft body extending from the first end to the second end and having an outer surface, and an external geometric structure disposed along the outer surface. The golf shaft may have an overall length from the first end to the second end. The shaft body may define an internal cavity extending along the longitudinal axis. The shaft body may include a grip section extending from the first end toward the second end, a clubhead section extending from the second end toward the first end, and an intermediate section extending from the grip section to the clubhead section. The external geometric structure may be disposed along the intermediate section, and the external geometric structure may have a pattern of geometric shapes. The golf shaft may be formed of one or more metals or metal alloys. The grip may be coupled to the grip section, and the clubhead may be coupled to the clubhead section.

[0047] In one aspect, a method for manufacturing a golf shaft is provided. In one embodiment, the method may include receiving a CAD model corresponding to the golf shaft, and forming, based at least in part on the CAD model, the golf shaft using one or more additive manufacturing techniques. The golf shaft may include a first end, a second end disposed opposite the first end along a longitudinal axis of the golf shaft, and an external geometric structure extending along the longitudinal axis. The golf shaft may have an overall length from the first end to the second end. The external geometric structure may have a pattern of geometric shapes, and the golf shaft may be devoid of any thin-walled cylindrical segments.

[0048] In another aspect, a golf shaft is provided. In one embodiment, the golf shaft may include a first end, a second end disposed opposite the first end along a longitudinal axis of the golf shaft, and an external geometric structure extending along the longitudinal axis. The golf shaft may have an overall length from the first end to the second end. The shaft body may define an internal cavity extending along the longitudinal axis. The external geometric structure may have a pattern of geometric shapes. The golf shaft may be formed of one or more metals or metal alloys, and at least a portion of the golf shaft may be devoid of any thin-walled cylindrical segments.

[0049] In some embodiments, the pattern of geometric shapes may be a repeating pattern. In some embodiments, the pattern of geometric shapes may be a non-repeating pattern. In some embodiments, the external geometric structure may have a repeating pattern of polygonal shapes. In some embodiments, the external geometric structure may include one or more helixes centered on the longitudinal axis. In some embodiments, the shaft body may include a grip section extending from the first end toward the second end and configured to receive a grip thereon, a clubhead section extending from the second end toward the first end and configured to receive a clubhead thereon, and an intermediate section extending from the grip section to the clubhead section. In some embodiments, the external geometric structure may extend along at least part of a length of the intermediate section. In some embodiments, the external geometric structure may extend along at least a majority of the length of the intermediate section. In some embodiments, the external geometric structure may extend along an entirety of the length of the intermediate section. In some embodiments, the one or more metals or metal alloys may

include at least one of: steel, a steel alloy, titanium, a titanium alloy, aluminum, or an aluminum alloy.

[0050] In still another aspect, a golf club is provided. In one embodiment, the golf club may include a golf shaft, a grip, and a clubhead. The golf shaft may include a first end, a second end disposed opposite the first end along a longitudinal axis of the golf shaft, a grip section extending from the first end toward the second end, a clubhead section extending from the second end toward the first end, an intermediate section extending from the grip section to the clubhead section, and an external geometric structure extending along the longitudinal axis. The golf shaft may have an overall length from the first end to the second end. The external geometric structure may have a pattern of geometric shapes. The golf shaft may be formed of one or more metals or metal alloys, and the golf shaft may be devoid of any thin-walled cylindrical segments. The grip may be coupled to the grip section, and the clubhead may be coupled to the clubhead section.

[0051] These and other aspects and improvements of the present disclosure will become apparent to one of ordinary skill in the art upon review of the following detailed description when taken in conjunction with the several drawings and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0052] FIG. 1A is a plan view of an example golf club in accordance with one or more embodiments of the disclosure, the golf club including a golf shaft, a grip, and a clubhead.

[0053] FIG. 1B is a detailed cross-sectional plan view of a region of the golf shaft of the golf club of FIG. 1A, with the cross-section taken along plane 1B-1B of FIG. 1A, showing an internal cavity and varying wall thickness of the golf shaft.

[0054] FIG. 1C is a detailed cross-sectional end view of a region of the golf shaft of the golf club of FIG. 1A, with the cross-section taken along plane 1C-1C of FIG. 1A.

[0055] FIG. 2A is a plan view of an example golf shaft as may be used as a part of the golf club of FIG. 1 in accordance with one or more embodiments of the disclosure.

[0056] FIG. 2B is a cross-sectional plan view of the golf shaft of FIG. 2A, with the cross-section taken along plane 2B-2B of FIG. 2A, showing an internal cavity and varying wall thickness of the golf shaft.

[0057] FIG. 3A is a plan view of an example golf shaft as may be used as a part of the golf club of FIG. 1 in accordance with one or more embodiments of the disclosure.

[0058] FIG. 3B is a cross-sectional plan view of the golf shaft of FIG. 3A, with the cross-section taken along plane 3B-3B of FIG. 3A, showing an internal cavity and varying wall thickness of the golf shaft.

[0059] FIG. 4A is a plan view of an example golf shaft as may be used as a part of the golf club of FIG. 1 in accordance with one or more embodiments of the disclosure.

[0060] FIG. 4B is a cross-sectional plan view of the golf shaft of FIG. 4A, with the cross-section taken along plane 4B-4B of FIG. 4A, showing an internal cavity of the golf shaft.

[0061] FIG. 4C is a detailed cross-sectional plan view of a first region of the golf shaft of FIG. 4A, similar to the cross-section of FIG. 4B, showing varying wall thickness of the golf shaft along the first region.

[0062] FIG. 4D is a detailed cross-sectional plan view of a second region of the golf shaft of FIG. 4A, similar to the

cross-section of FIG. 4B, showing varying wall thickness of the golf shaft along the second region.

[0063] FIG. 4E is a detailed cross-sectional plan view of a third region of the golf shaft of FIG. 4A, similar to the cross-section of FIG. 4B, showing varying wall thickness of the golf shaft along the third region.

[0064] FIG. 4F is a detailed cross-sectional plan view of a fourth region of the golf shaft of FIG. 4A, similar to the cross-section of FIG. 4B, showing varying wall thickness of the golf shaft along the fourth region.

[0065] FIG. 4G is a detailed cross-sectional plan view of a fifth region of the golf shaft of FIG. 4A, similar to the cross-section of FIG. 4B, showing varying wall thickness of the golf shaft along the fifth region.

[0066] FIG. 5A is a plan view of an example golf shaft as may be used as a part of the golf club of FIG. 1 in accordance with one or more embodiments of the disclosure.

[0067] FIG. 5B is a cross-sectional plan view of the golf shaft of FIG. 5A, with the cross-section taken along plane 5B-5B of FIG. 5A, showing an internal cavity and an internal lattice structure of the golf shaft.

[0068] FIG. 6 is a plan view of a portion of an example golf shaft as may be used as a part of the golf club of FIG. 1 in accordance with one or more embodiments of the disclosure, showing an external geometric structure of the golf shaft.

[0069] FIG. 7 is a plan view of a portion of an example golf shaft as may be used as a part of the golf club of FIG. 1 in accordance with one or more embodiments of the disclosure, showing an external geometric structure of the golf shaft.

[0070] FIG. 8 is a plan view of a portion of an example golf shaft as may be used as a part of the golf club of FIG. 1 in accordance with one or more embodiments of the disclosure, showing an external geometric structure of the golf shaft.

[0071] FIG. 9 is a plan view of a portion of an example golf shaft as may be used as a part of the golf club of FIG. 1 in accordance with one or more embodiments of the disclosure, showing an external geometric structure of the golf shaft.

[0072] FIG. 10 is a plan view of a portion of an example golf shaft as may be used as a part of the golf club of FIG. 1 in accordance with one or more embodiments of the disclosure, showing an external geometric structure of the golf shaft.

[0073] The detailed description is set forth with reference to the accompanying drawings. The drawings are provided for purposes of illustration only and merely depict example embodiments of the disclosure. The drawings are provided to facilitate understanding of the disclosure and shall not be deemed to limit the breadth, scope, or applicability of the disclosure. The use of the same reference numerals indicates similar, but not necessarily the same or identical components. Different reference numerals may be used to identify similar components. Various embodiments may utilize elements or components other than those illustrated in the drawings, and some elements and/or components may not be present in various embodiments. The use of singular terminology to describe a component or element may, depending on the context, encompass a plural number of such components or elements and vice versa.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0074] In the following description, specific details are set forth describing some embodiments consistent with the present disclosure. Numerous specific details are set forth in order to provide a thorough understanding of the embodiments. It will be apparent, however, to one skilled in the art that some embodiments may be practiced without some or all of these specific details. The specific embodiments disclosed herein are meant to be illustrative but not limiting. One skilled in the art may realize other elements that, although not specifically described here, are within the scope and the spirit of this disclosure. In addition, to avoid unnecessary repetition, one or more features shown and described in association with one embodiment may be incorporated into other embodiments unless specifically described otherwise or if the one or more features would make an embodiment non-functional. In some instances, well known methods, procedures, and/or components have not been described in detail so as not to unnecessarily obscure aspects of the embodiments.

[0075] Overview

[0076] Embodiments of golf shafts having a varying outer diameter, inner diameter, and/or wall thickness and related methods for manufacturing golf shafts having a varying outer diameter, inner diameter, and/or wall thickness using additive manufacturing are provided herein. According to the techniques described herein, a golf shaft may be customized for a particular user by varying the shaft's outer diameter, inner diameter, and/or wall thickness along the length of the shaft in a manner that provides an optimal stiffness profile for the user. Additionally, golf shafts having a varying outer diameter, inner diameter, and/or wall thickness according to the present disclosure may be mass produced and provided in a wide variety of shaft stiffness bins, such as bins for each 1 mph increment of swing speed. Although the disclosed golf shafts may be manufactured by various methods, the use of additive manufacturing techniques may be particularly advantageous for fabricating the shafts, as described below.

[0077] The golf shafts provided herein may include a first end and a second end disposed opposite one another along a longitudinal axis of the shaft and defining an overall length of the shaft. The golf shaft may define one or more internal cavities extending along the longitudinal axis. As described herein, an outer diameter, an inner diameter, and/or a wall thickness of the golf shaft may continuously vary along one or more portions of the overall length. According to various embodiments, the wall thickness may continuously vary along at least 5%, at least 10%, at least 20%, at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, or at least 90% of the overall length. In some embodiments, the wall thickness may continuously vary along at least a majority of the overall length. In some embodiments, the wall thickness may continuously vary along an entirety of the overall length. In some embodiments, the wall thickness may continuously vary along a continuous portion of the shaft having a length that is greater than 50% of the overall length. In some embodiments, the wall thickness may be constant along a minority of the overall length. As described herein, the wall thickness may continuously decrease along one or more portions of the shaft in a direction from the first end toward the second end and/or the wall thickness may continuously increase along one or more

portions of the shaft in the direction from the first end toward the second end. In some embodiments, the wall thickness may continuously increase or continuously decrease in a linear manner along one or more portions of the shaft. In some embodiments, the wall thickness may continuously increase or continuously decrease in a non-linear manner along one or more portions of the shaft. In this manner, the wall thickness may continuously decrease or continuously increase at a varying rate. According to various embodiments, the wall thickness may be continuously varied over a particular portion of the shaft by continuously varying an outer diameter of the shaft, an inner diameter of the shaft, or both the outer diameter and the inner diameter along the shaft portion. Various combinations of one or more shaft portions having a continuously-decreasing wall thickness, one or more shaft portions having a continuously-increasing wall thickness, and one or more shaft portions having a constant wall thickness may be used to provide a desired stiffness profile of the shaft. Ultimately, a particular configuration of varying wall thickness of a golf shaft may be selected to provide an optimal stiffness profile for a particular user or for a particular subset of users having closely-similar swing speeds.

[0078] The use of additive manufacturing to fabricate golf shafts advantageously may provide the ability to continuously alter the stiffness profile along the length of a shaft instead of in stepped increments according to traditional manufacturing techniques. Although various types of additive manufacturing techniques may be used to produce the golf shafts described herein, selective laser melting (SLM) and direct metal laser sintering (DMLS) are two techniques that may be particularly well suited for manufacturing the shafts. By utilizing one or more additive manufacturing techniques, such as SLM or DMLS, the stiffness profile of a golf shaft may be controlled by varying the outer diameter, the inner diameter, and/or the wall thickness along the shaft. Meanwhile, the outer dimensions of end portions of the golf shaft may be selected to correspond to the outer dimensions of conventional golf shafts, thereby allowing the golf shaft to suitably interface with common grips and clubheads. By using additive manufacturing, the stiffness profile of a golf shaft may be optimized for each user's different swing speed and tempo, resulting in increased distance and improved accuracy for each user. For users who do not want to pay for a custom fitting, golf shafts may be mass produced in a wide variety of bins for different swing speeds. For example, different golf shafts may be provided in shaft stiffness bins having 1 mph increments instead of the significantly larger increments used in the conventional bin approach. In contrast to traditional methods for manufacturing golf shafts, additive manufacturing techniques do not require tooling and thus allow for each shaft in a build to be unique. Therefore, by using additive manufacturing, the cost to build 100 shafts for a single swing speed and the cost to build 100 shafts for 100 different swing speeds would be the same. As described herein, additive manufacturing also may enable fabrication of golf shafts having other complex features that would be challenging or impossible to form using conventional manufacturing methods. For example, a golf shaft may include an internal lattice structure disposed within a cavity of the shaft, the configuration and extent of which may be selected to vary the stiffness profile of the shaft. As another example, an external geometric structure having a pattern of geometric shapes may be provided along an outer

surface of a golf shaft, which may provide aesthetic appeal and/or may be configured to increase performance characteristics of the shaft. Such an external geometric structure may include a pattern of polygonal shapes, a honeycomb structure, one or more helixes, or other complex geometric forms. The pattern of geometric shapes may be repeating or non-repeating in different embodiments. Further, other types of external structures having irregular or non-geometric forms also may be provided along an outer surface of a golf shaft for aesthetic appeal and/or increased performance characteristics. The formation of such external structures, which may not be feasible or practical using traditional manufacturing techniques, may be readily achieved using additive manufacturing techniques.

[0079] Still other benefits and advantages of the golf shafts and methods for manufacturing golf shafts provided herein over existing technology will be appreciated by those of ordinary skill in the art from the following description and the appended drawings.

[0080] Example Embodiments of Golf Clubs and Golf Shafts

[0081] Referring now to FIGS. 1A-1C, an example golf club **100** (which also may be referred to as simply a "club") is depicted. In some embodiments, as shown, the golf club **100** may be an iron, although other configurations of the club **100** as a wedge, a hybrid, a driver, a wood, or a putter may be used in other embodiments. The golf club **100** may include a golf shaft **110** (which also may be referred to as simply a "shaft"), a grip **150**, and a clubhead **160**. In some embodiments, the grip **150** and the clubhead **160** each may have a conventional configuration and may be coupled to the shaft **110** in a conventional manner. It will be appreciated that various configurations of the clubhead **160** may be used, depending on whether the golf club **100** is provided as an iron, a wedge, a hybrid, a driver, a wood, or a putter.

[0082] As shown, the golf shaft **110** may be formed as an elongated structure having a longitudinal axis A_L . The shaft **110** may have a first end **112** (which also may be referred to as a "butt end" or a "grip end") and a second end **114** (which also may be referred to as a "tip end" or a "clubhead end") disposed opposite one another along the longitudinal axis A_L of the shaft **110**. As shown, the shaft **110** may have an overall length L_O from the first end **112** to the second end **114**. The shaft **110** may include a first end section **122** (which also may be referred to as a "butt end section" or a "grip end section"), a second end section **124** (which also may be referred to as a "tip end section" or a "clubhead end section"), and an intermediate section **126** extending from the first end section **122** to the second end section **124**. As shown, the first end section **122** may be configured to receive the grip **150** thereon, and the second end section **124** may be configured to receive the clubhead **160** thereon. In this manner, upon assembly of the golf club **100**, the grip **150** may cover and be coupled to the first end section **122**, and the clubhead **160** may cover and be coupled to the second end section **124**, while the intermediate section **126** may remain exposed and not be covered by the grip **150** or the clubhead **160**.

[0083] The golf shaft **110** may define one or more internal cavities **130** (each of which also may be referred to as an "internal opening" or "opening," an "internal bore" or "bore," or simply a "cavity") extending along the longitudinal axis A_L of the shaft **110**. In this manner, the shaft **110** may have a tubular shape along at least a portion of the shaft

110. In some embodiments, the shaft **110** may define a single internal cavity **130**. In some embodiments, the cavity **130** may extend from the first end **112** to the second end **114**. In this manner, the cavity **130** may extend along the entire overall length L_O of the shaft **110**, with the first end **112** and the second end **114** being open. In some embodiments, the cavity **130** may extend from the first end **112** toward the second end **114** and be spaced apart from the second end **114**. In other words, the cavity **130** may begin at the first end **112** and terminate at a location spaced apart from the second end **114**. In this manner, the cavity **130** may extend along only a portion of the overall length L_O of the shaft **110**, with the first end **112** being open and the second end **114** being closed. In some embodiments, the cavity **130** may extend from the second end **114** toward the first end **112** and be spaced apart from the first end **112**. In other words, the cavity **130** may begin at the second end **114** and terminate at a location spaced apart from the first end **112**. In this manner, the cavity **130** may extend along only a portion of the overall length L_O of the shaft **110**, with the second end **114** being open and the first end **112** being closed. In some embodiments, the cavity **130** may be spaced apart from each of the first end **112** and the second end **114**. In other words, the cavity **130** may begin at a location spaced apart from the first end **112** and terminate at a location spaced apart from the second end **114**. In this manner, the cavity **130** may extend along only a portion of the overall length L_O of the shaft **110**, with the second end **114** being closed. In some embodiments, the golf shaft **110** may define two or more internal cavities **130** that are not in communication with one another. In other words, the shaft **110** may include a portion having a solid cross section (taken perpendicular to the longitudinal axis A_L of the shaft **110**) disposed between a consecutive pair of the cavities **130**. Various configurations of one or more internal cavities **130** may be used in different embodiments.

[0084] The golf shaft **110** may have an outer surface **132** (which also may be referred to as an “external surface”) and an inner surface **134** (which also may be referred to as an “internal surface”). As shown in FIGS. **1B** and **1C**, the inner surface **134** may define the cavity **130**. In some embodiments, as shown, each of the outer surface **132** and the inner surface **134** may have a circular cross-sectional shape (taken perpendicular to the longitudinal axis A_L of the shaft **110**). In this manner, the shaft **110** may have an outer diameter OD, an inner diameter ID, and a wall thickness T_w , as shown in FIG. **1B**.

[0085] The outer diameter OD of the shaft **110** may continuously vary along one or more portions of the overall length L_O . According to various embodiments, the outer diameter OD may continuously vary along at least 5%, at least 10%, at least 20%, at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, or at least 90% of the overall length L_O . In some embodiments, the outer diameter OD may continuously vary along at least a majority (i.e., greater than 50%) of the overall length L_O . In some embodiments, the outer diameter OD may continuously vary along only a minority (i.e., less than 50%) of the overall length L_O . In some embodiments, the outer diameter OD may continuously vary along an entirety of the overall length L_O . According to various embodiments, the outer diameter OD may continuously vary along a continuous portion of the shaft **110** having a length that is greater than 5%, greater than 10%, greater than 20%, greater than 30%,

greater than 40%, greater than 50%, greater than 60%, greater than 70%, greater than 80%, or greater than 90% of the overall length L_O . In some embodiments, the outer diameter OD may be constant along one or more portions of the overall length L_O . According to various embodiments, the outer diameter OD may be constant along at least 5%, at least 10%, at least 20%, at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, or at least 90% of the overall length L_O . In some embodiments, the outer diameter OD may be constant along at least a majority (i.e., greater than 50%) of the overall length L_O . In some embodiments, the outer diameter OD may be constant along only a minority (i.e., less than 50%) of the overall length L_O . In some embodiments, the outer diameter OD may be constant along an entirety of the overall length L_O . According to various embodiments, the outer diameter OD may be constant along a continuous portion of the shaft **110** having a length that is greater than 5%, greater than 10%, greater than 20%, greater than 30%, greater than 40%, greater than 50%, greater than 60%, greater than 70%, greater than 80%, or greater than 90% of the overall length L_O .

[0086] The outer diameter OD may continuously decrease along one or more portions of the shaft **110** in a direction from the first end **112** toward the second end **114** and/or the outer diameter OD may continuously increase along one or more portions of the shaft **110** in the direction from the first end **112** toward the second end **114**. In some embodiments, the outer diameter OD may continuously increase or continuously decrease in a linear manner along one or more portions of the shaft **110**. In some embodiments, the outer diameter OD may continuously increase or continuously decrease in a non-linear manner along one or more portions of the shaft **110**. In this manner, the outer diameter OD may continuously decrease or continuously increase at a varying rate. Various combinations of one or more shaft portions having a continuously-decreasing outer diameter OD, one or more shaft portions having a continuously-increasing outer diameter OD, and one or more shaft portions having a constant outer diameter OD may be used to provide a desired stiffness profile of the shaft **110**.

[0087] The inner diameter ID of the shaft **110** may continuously vary along one or more portions of the overall length L_O . According to various embodiments, the inner diameter ID may continuously vary along at least 5%, at least 10%, at least 20%, at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, or at least 90% of the overall length L_O . In some embodiments, the inner diameter ID may continuously vary along at least a majority (i.e., greater than 50%) of the overall length L_O . In some embodiments, the inner diameter ID may continuously vary along only a minority (i.e., less than 50%) of the overall length L_O . In some embodiments, the inner diameter ID may continuously vary along an entirety of the overall length L_O . According to various embodiments, the inner diameter ID may continuously vary along a continuous portion of the shaft **110** having a length that is greater than 5%, greater than 10%, greater than 20%, greater than 30%, greater than 40%, greater than 50%, greater than 60%, greater than 70%, greater than 80%, or greater than 90% of the overall length L_O . In some embodiments, the inner diameter ID may be constant along one or more portions of the overall length L_O . According to various embodiments, the inner diameter ID may be constant along at least 5%, at least 10%, at least 20%, at least 30%, at least 40%, at least 50%, at least 60%,

at least 70%, at least 80%, or at least 90% of the overall length L_O . In some embodiments, the inner diameter ID may be constant along at least a majority (i.e., greater than 50%) of the overall length L_O . In some embodiments, the inner diameter ID may be constant along only a minority (i.e., less than 50%) of the overall length L_O . In some embodiments, the inner diameter ID may be constant along an entirety of the overall length L_O . According to various embodiments, the inner diameter ID may be constant along a continuous portion of the shaft 110 having a length that is greater than 5%, greater than 10%, greater than 20%, greater than 30%, greater than 40%, greater than 50%, greater than 60%, greater than 70%, greater than 80%, or greater than 90% of the overall length L_O .

[0088] The inner diameter ID may continuously decrease along one or more portions of the shaft 110 in a direction from the first end 112 toward the second end 114 and/or the inner diameter ID may continuously increase along one or more portions of the shaft 110 in the direction from the first end 112 toward the second end 114. In some embodiments, the inner diameter ID may continuously increase or continuously decrease in a linear manner along one or more portions of the shaft 110. In some embodiments, the inner diameter ID may continuously increase or continuously decrease in a non-linear manner along one or more portions of the shaft 110. In this manner, the inner diameter ID may continuously decrease or continuously increase at a varying rate. Various combinations of one or more shaft portions having a continuously-decreasing inner diameter ID, one or more shaft portions having a continuously-increasing inner diameter ID, and one or more shaft portions having a constant inner diameter ID may be used to provide a desired stiffness profile of the shaft 110.

[0089] The wall thickness T_W of the shaft 110 may continuously vary along one or more portions of the overall length L_O . According to various embodiments, the wall thickness T_W may continuously vary along at least 5%, at least 10%, at least 20%, at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, or at least 90% of the overall length L_O . In some embodiments, the wall thickness T_W may continuously vary along at least a majority (i.e., greater than 50%) of the overall length L_O . In some embodiments, the wall thickness T_W may continuously vary along only a minority (i.e., less than 50%) of the overall length L_O . In some embodiments, the wall thickness T_W may continuously vary along an entirety of the overall length L_O . According to various embodiments, the wall thickness T_W may continuously vary along a continuous portion of the shaft 110 having a length that is greater than 5%, greater than 10%, greater than 20%, greater than 30%, greater than 40%, greater than 50%, greater than 60%, greater than 70%, greater than 80%, or greater than 90% of the overall length L_O . In some embodiments, the wall thickness T_W may be constant along one or more portions of the overall length L_O . According to various embodiments, the wall thickness T_W may be constant along at least 5%, at least 10%, at least 20%, at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, or at least 90% of the overall length L_O . In some embodiments, the wall thickness T_W may be constant along at least a majority (i.e., greater than 50%) of the overall length L_O . In some embodiments, the wall thickness T_W may be constant along only a minority (i.e., less than 50%) of the overall length L_O . According to various embodiments, the wall thickness T_W may be con-

stant along a continuous portion of the shaft 110 having a length that is greater than 5%, greater than 10%, greater than 20%, greater than 30%, greater than 40%, greater than 50%, greater than 60%, greater than 70%, greater than 80%, or greater than 90% of the overall length L_O .

[0090] The wall thickness T_W may continuously decrease along one or more portions of the shaft 110 in a direction from the first end 112 toward the second end 114 and/or the wall thickness T_W may continuously increase along one or more portions of the shaft 110 in the direction from the first end 112 toward the second end 114. In some embodiments, the wall thickness T_W may continuously increase or continuously decrease in a linear manner along one or more portions of the shaft 110. In some embodiments, the wall thickness T_W may continuously increase or continuously decrease in a non-linear manner along one or more portions of the shaft 110. In this manner, the wall thickness T_W may continuously decrease or continuously increase at a varying rate. In various embodiments, the wall thickness T_W may be continuously varied over a particular portion of the shaft 110 by continuously varying the outer diameter OD, the inner diameter ID, or both the outer diameter OD and the inner diameter ID along the shaft portion. Various combinations of one or more shaft portions having a continuously-decreasing wall thickness T_W , one or more shaft portions having a continuously-increasing wall thickness T_W , and one or more shaft portions having a constant wall thickness T_W may be used to provide a desired stiffness profile of the shaft 110.

[0091] As shown in FIG. 1B, the golf shaft 110 may include a first shaft portion 141 along which the wall thickness T_W continuously varies, and a second shaft portion 142 along which the wall thickness T_W continuously varies in a manner different from the first shaft portion 141. According to various embodiments, the shaft 110 may include any number of different shaft portions along which the wall thickness T_W continuously varies in different manners. As shown, the wall thickness T_W may continuously decrease along the first shaft portion 141 in the direction from the first end 112 toward the second end 114, and the wall thickness T_W may continuously increase along the second shaft portion 142 in the direction from the first end 112 toward the second end 114. In some embodiments, as shown, the outer diameter OD may continuously decrease along each of the first shaft portion 141 and the second shaft portion 142. In some embodiments, as shown, the outer diameter OD may continuously decrease in a linear manner along each of the first shaft portion 141 and the second shaft portion 142. In some embodiments, as shown, the outer diameter OD may continuously decrease in a linear manner along the entire intermediate section 126. In some embodiments, as shown, the outer diameter OD may continuously decrease in a linear manner from the first end 112 to the second end 114. In some embodiments, as shown, the inner diameter ID may continuously increase along the first shaft portion 141 and may continuously decrease along the second shaft portion 142. In some embodiments, as shown, the inner diameter ID may continuously increase in a linear manner along the first shaft portion 141 and may continuously decrease in a non-linear manner along the second shaft portion 142. It will be appreciated that various configurations of different portions of the shaft 110 having a continuously-varying wall thickness T_W may be achieved by varying one or both of the outer diameter OD and the inner diameter ID along the respective portions of the shaft 110, as discussed

above. Further, as discussed above, one or more other portions of the shaft **110** may be provided with a constant wall thickness T_w , which may be achieved by having the outer diameter OD and the inner diameter ID constant along the respective portions of the shaft **110** or by varying the outer diameter OD and the inner diameter ID in the same manner along the respective portions of the shaft **110**.

[0092] FIGS. 2A and 2B depict another example golf shaft **210** as may be used as a part of the golf club **100** of FIG. 1A instead of the shaft **110**. Certain similarities and differences between the shaft **210** and the shaft **110** described above will be appreciated from the drawings and the following description. Corresponding reference numbers are used for corresponding features, which generally may be configured in a manner similar to the features described above unless indicated otherwise.

[0093] As shown, the golf shaft **210** may be formed as an elongated structure having a longitudinal axis A_L . The shaft **210** may have a first end **212** and a second end **214** disposed opposite one another along the longitudinal axis A_L of the shaft **210**. As shown, the shaft **210** may have an overall length L_O from the first end **212** to the second end **214**. The shaft **210** may include a first end section **222**, a second end section **224**, and an intermediate section **226** extending from the first end section **222** to the second end section **224**. The first end section **222** may be configured to receive the grip **150** thereon, and the second end section **224** may be configured to receive the clubhead **160** thereon. In this manner, upon assembly of the golf club **100**, the grip **150** may cover and be coupled to the first end section **222**, and the clubhead **160** may cover and be coupled to the second end section **224**, while the intermediate section **226** may remain exposed and not be covered by the grip **150** or the clubhead **160**.

[0094] The golf shaft **210** may define an internal cavity **230** extending along the longitudinal axis A_L of the shaft **210**. In this manner, the shaft **210** may have a tubular shape along at least a portion of the shaft **210**. As shown, the cavity **230** may extend from the first end **212** toward the second end **214** and be spaced apart from the second end **214**. In other words, the cavity **230** may begin at the first end **212** and terminate at a location spaced apart from the second end **214**. In this manner, the cavity **230** may extend along only a portion of the overall length L_O of the shaft **210**, with the first end **212** being open and the second end **214** being closed. As shown, a portion of the shaft **210** disposed between the cavity **230** and the second end **214** may have a solid cross section (taken perpendicular to the longitudinal axis A_L of the shaft **210**). As discussed above, various configurations of one or more internal cavities may be used in different embodiments.

[0095] The golf shaft **210** may have an outer surface **232** and an inner surface **234**. As shown in FIG. 2B, the inner surface **234** may define the cavity **230**. In some embodiments, as shown, each of the outer surface **232** and the inner surface **234** may have a circular cross-sectional shape (taken perpendicular to the longitudinal axis A_L of the shaft **210**). In this manner, the shaft **210** may have an outer diameter OD, an inner diameter ID, and a wall thickness T_w , as shown in FIG. 2B. The wall thickness T_w of the shaft **210** may continuously vary along one or more portions of the overall length L_O . In some embodiments, as shown, the wall thickness T_w may continuously vary along at least a majority of the overall length L_O . According to various embodiments,

the wall thickness T_w may continuously vary along at least 5%, at least 10%, at least 20%, at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, or at least 90% of the overall length L_O . In some embodiments, the wall thickness T_w may continuously vary along an entirety of the overall length L_O . According to various embodiments, the wall thickness T_w may continuously vary along a continuous portion of the shaft **210** having a length that is greater than 5%, greater than 10%, greater than 20%, greater than 30%, greater than 40%, greater than 50%, greater than 60%, greater than 70%, greater than 80%, or greater than 90% of the overall length L_O . In some embodiments, the wall thickness T_w may be constant along a minority of the overall length L_O .

[0096] The wall thickness T_w may continuously decrease along one or more portions of the shaft **210** in a direction from the first end **212** toward the second end **214** and/or the wall thickness T_w may continuously increase along one or more portions of the shaft **210** in the direction from the first end **212** toward the second end **214**. In some embodiments, the wall thickness T_w may continuously increase or continuously decrease in a linear manner along one or more portions of the shaft **210**. In some embodiments, the wall thickness T_w may continuously increase or continuously decrease in a non-linear manner along one or more portions of the shaft **210**. In this manner, the wall thickness T_w may continuously decrease or continuously increase at a varying rate. In various embodiments, the wall thickness T_w may be continuously varied over a particular portion of the shaft **210** by continuously varying the outer diameter OD, the inner diameter ID, or both the outer diameter OD and the inner diameter ID along the shaft portion. Various combinations of one or more shaft portions having a continuously-decreasing wall thickness T_w , one or more shaft portions having a continuously-increasing wall thickness T_w , and one or more shaft portions having a constant wall thickness T_w may be used to provide a desired stiffness profile of the shaft **210**.

[0097] As shown in FIG. 2B, the golf shaft **210** may include a first shaft portion **241** along which the wall thickness T_w continuously varies, a second shaft portion **242** along which the wall thickness T_w continuously varies in a manner different from the first shaft portion **241**, a third shaft portion **243** along which the wall thickness T_w continuously varies in a manner different from each of the first shaft portion **241** and the second shaft portion **242**, and a fourth shaft portion **244** along which the wall thickness T_w continuously varies in a manner different from each of the first shaft portion **241**, the second shaft portion **242**, and the third shaft portion **243**. As shown, the shaft **210** also may include a fifth shaft portion **245** that is disposed between the fourth shaft portion **244** and the second end **214** and is solid because the cavity **230** does not extend along the fifth shaft portion **245**. According to various embodiments, the shaft **210** may include any number of different shaft portions along which the wall thickness T_w continuously varies in different manners. As shown, the wall thickness T_w may continuously decrease along the first shaft portion **241** in the direction from the first end **212** toward the second end **214**, the wall thickness T_w may continuously increase along the second shaft portion **242** in the direction from the first end **212** toward the second end **214**, the wall thickness T_w may continuously decrease along the third shaft portion **243** in the direction from the first end **212** toward the second end **214**, and the wall thickness T_w may continuously increase

along the fourth shaft portion **243** in the direction from the first end **212** toward the second end **214**. In some embodiments, as shown, the outer diameter OD may continuously decrease along each of the first shaft portion **241**, the second shaft portion **242**, the third shaft portion **243**, and the fourth shaft portion **244**. In some embodiments, as shown, the outer diameter OD may continuously decrease in a linear manner along each of the first shaft portion **241**, the second shaft portion **242**, the third shaft portion **243**, and the fourth shaft portion **244**. In some embodiments, as shown, the outer diameter OD may continuously decrease in a linear manner along the entire intermediate section **226**. In some embodiments, as shown, the outer diameter OD may continuously decrease in a linear manner from the first end **212** to the second end **214**. In some embodiments, as shown, the inner diameter ID may be constant along the first shaft portion **241**, may continuously decrease along the second shaft portion **242**, may continuously increase along the third shaft portion **243**, and may continuously decrease along the fourth shaft portion **244**. In some embodiments, as shown, the inner diameter ID may continuously decrease in a linear manner along the second shaft portion **242**, may continuously increase in a linear manner along the third shaft portion **243**, and may continuously decrease in a linear manner along the fourth shaft portion **244**. It will be appreciated that various configurations of different portions of the shaft **210** having a continuously-varying wall thickness T_w may be achieved by varying one or both of the outer diameter OD and the inner diameter ID along the respective portions of the shaft **210**, as discussed above.

[0098] FIGS. 3A and 3B depict another example golf shaft **310** as may be used as a part of the golf club **100** of FIG. 1A instead of the shaft **110**. Certain similarities and differences between the shaft **310** and the shafts **110**, **210** described above will be appreciated from the drawings and the following description. Corresponding reference numbers are used for corresponding features, which generally may be configured in a manner similar to the features described above unless indicated otherwise.

[0099] As shown, the golf shaft **310** may be formed as an elongated structure having a longitudinal axis A_L . The shaft **310** may have a first end **312** and a second end **314** disposed opposite one another along the longitudinal axis A_L of the shaft **310**. As shown, the shaft **310** may have an overall length L_O from the first end **312** to the second end **314**. The shaft **310** may include a first end section **322**, a second end section **324**, and an intermediate section **326** extending from the first end section **322** to the second end section **324**. The first end section **322** may be configured to receive the grip **150** thereon, and the second end section **324** may be configured to receive the clubhead **160** thereon. In this manner, upon assembly of the golf club **100**, the grip **150** may cover and be coupled to the first end section **322**, and the clubhead **160** may cover and be coupled to the second end section **324**, while the intermediate section **326** may remain exposed and not be covered by the grip **150** or the clubhead **160**.

[0100] The golf shaft **210** may define a plurality of internal cavities **330** extending along the longitudinal axis A_L of the shaft **310**. In this manner, the shaft **310** may have a tubular shape along at least a portion of the shaft **310**. As shown, the shaft **310** may define a first cavity **330a** and a second cavity **330b** that are not in communication with one another. The first cavity **330a** may extend from the first end **312** toward

the second end **314** and be spaced apart from the second end **314**, and the second cavity **330b** may extend from the second end **314** toward the first end **312** and be spaced apart from the first end **312**. In other words, the first cavity **330a** may begin at the first end **312** and terminate at a location spaced apart from the second end **314**, and the second cavity **330b** may begin at the second end **314** and terminate at a location spaced apart from the first end **312**. In this manner, each of the cavities **330a**, **330b** may extend along only a portion of the overall length L_O of the shaft **310**, with each of the first end **312** and the second end **314** being open. As shown, a portion of the shaft **310** disposed between the cavities **330a**, **330b** may have a solid cross section (taken perpendicular to the longitudinal axis A_L of the shaft **310**). As discussed above, various configurations of one or more internal cavities may be used in different embodiments.

[0101] The golf shaft **310** may have an outer surface **332** and a plurality of inner surfaces **334**. As shown in FIG. 3B, a first inner surface **334a** may define the first cavity **330a**, and a second inner surface **334b** may define the second cavity **330b**. In some embodiments, as shown, each of the outer surface **332**, the first inner surface **334a**, and the second inner surface **334b** may have a circular cross-sectional shape (taken perpendicular to the longitudinal axis A_L of the shaft **310**). In this manner, the shaft **310** may have an outer diameter OD, an inner diameter ID, and a wall thickness T_w , as shown in FIG. 3B. The wall thickness T_w of the shaft **310** may continuously vary along one or more portions of the overall length L_O . In some embodiments, as shown, the wall thickness T_w may continuously vary along at least a majority of the overall length L_O . According to various embodiments, the wall thickness T_w may continuously vary along at least 5%, at least 10%, at least 20%, at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, or at least 90% of the overall length L_O . In some embodiments, as shown, the wall thickness T_w may continuously vary along an entirety of the overall length L_O . According to various embodiments, the wall thickness T_w may continuously vary along a continuous portion of the shaft **310** having a length that is greater than 5%, greater than 10%, greater than 20%, greater than 30%, greater than 40%, greater than 50%, greater than 60%, greater than 70%, greater than 80%, or greater than 90% of the overall length L_O . In some embodiments, the wall thickness T_w may be constant along a minority of the overall length L_O .

[0102] The wall thickness T_w may continuously decrease along one or more portions of the shaft **310** in a direction from the first end **312** toward the second end **314** and/or the wall thickness T_w may continuously increase along one or more portions of the shaft **310** in the direction from the first end **312** toward the second end **314**. In some embodiments, the wall thickness T_w may continuously increase or continuously decrease in a linear manner along one or more portions of the shaft **310**. In some embodiments, the wall thickness T_w may continuously increase or continuously decrease in a non-linear manner along one or more portions of the shaft **310**. In this manner, the wall thickness T_w may continuously decrease or continuously increase at a varying rate. In various embodiments, the wall thickness T_w may be continuously varied over a particular portion of the shaft **310** by continuously varying the outer diameter OD, the inner diameter ID, or both the outer diameter OD and the inner diameter ID along the shaft portion. Various combinations of one or more shaft portions having a continuously-decreasing

wall thickness T_w , one or more shaft portions having a continuously-increasing wall thickness T_w , and one or more shaft portions having a constant wall thickness T_w may be used to provide a desired stiffness profile of the shaft 310.

[0103] As shown in FIG. 3B, the golf shaft 310 may include a first shaft portion 341 along which the wall thickness T_w continuously varies, a second shaft portion 342 along which the wall thickness T_w continuously varies in a manner different from the first shaft portion 341, a third shaft portion 343 along which the wall thickness T_w continuously varies in a manner different from each of the first shaft portion 341 and the second shaft portion 342, and a fourth shaft portion 344 along which the wall thickness T_w continuously varies in a manner different from each of the first shaft portion 341, the second shaft portion 342, and the third shaft portion 343. According to various embodiments, the shaft 310 may include any number of different shaft portions along which the wall thickness T_w continuously varies in different manners. As shown, the wall thickness T_w may continuously increase along the first shaft portion 341 in the direction from the first end 312 toward the second end 314, the wall thickness T_w may continuously decrease along the second shaft portion 342 in the direction from the first end 312 toward the second end 314, the wall thickness T_w may continuously increase along the third shaft portion 343 in the direction from the first end 312 toward the second end 314, and the wall thickness T_w may continuously decrease along the fourth shaft portion 344 in the direction from the first end 312 toward the second end 314. In some embodiments, as shown, the outer diameter OD may continuously decrease along each of the first shaft portion 341, the second shaft portion 342, the third shaft portion 343, and the fourth shaft portion 344. In some embodiments, as shown, the outer diameter OD may continuously decrease in a linear manner along each of the first shaft portion 341, the second shaft portion 342, the third shaft portion 343, and the fourth shaft portion 344. In some embodiments, as shown, the outer diameter OD may continuously decrease in a linear manner along the entire intermediate section 326. In some embodiments, as shown, the outer diameter OD may continuously decrease in a linear manner from the first end 312 to the second end 314. In some embodiments, as shown, the inner diameter ID may continuously decrease along the first shaft portion 341, may continuously increase along the second shaft portion 342, may continuously decrease along the third shaft portion 343, and may continuously increase along the fourth shaft portion 344. In some embodiments, as shown, the inner diameter ID may continuously decrease in a non-linear manner along the first shaft portion 341, may continuously increase in a non-linear manner along the second shaft portion 342, may continuously decrease in a non-linear manner along the third shaft portion 343, and may continuously increase in a non-linear manner along the fourth shaft portion 344. It will be appreciated that various configurations of different portions of the shaft 310 having a continuously-varying wall thickness T_w may be achieved by varying one or both of the outer diameter OD and the inner diameter ID along the respective portions of the shaft 310, as discussed above.

[0104] FIGS. 4A-4G depict another example golf shaft 410 as may be used as a part of the golf club 100 of FIG. 1A instead of the shaft 110. Certain similarities and differences between the shaft 410 and the shafts 110, 210, 310 described above will be appreciated from the drawings and the fol-

lowing description. Corresponding reference numbers are used for corresponding features, which generally may be configured in a manner similar to the features described above unless indicated otherwise.

[0105] As shown, the golf shaft 410 may be formed as an elongated structure having a longitudinal axis A_L . The shaft 410 may have a first end 412 and a second end 414 disposed opposite one another along the longitudinal axis A_L of the shaft 410. As shown, the shaft 410 may have an overall length L_O from the first end 412 to the second end 414. The shaft 410 may include a first end section 422, a second end section 424, and an intermediate section 426 extending from the first end section 422 to the second end section 424. The first end section 422 may be configured to receive the grip 150 thereon, and the second end section 424 may be configured to receive the clubhead 160 thereon. In this manner, upon assembly of the golf club 100, the grip 150 may cover and be coupled to the first end section 422, and the clubhead 160 may cover and be coupled to the second end section 424, while the intermediate section 426 may remain exposed and not be covered by the grip 150 or the clubhead 160.

[0106] The golf shaft 410 may define an internal cavity 430 extending along the longitudinal axis A_L of the shaft 410. In this manner, the shaft 410 may have a tubular shape along at least a portion of the shaft 410. As shown, the cavity 430 may extend from the first end 412 toward the second end 414 and be spaced apart from the second end 414. In other words, the cavity 430 may begin at the first end 412 and terminate at a location spaced apart from the second end 414. In this manner, the cavity 430 may extend along only a portion of the overall length L_O of the shaft 410, with the first end 412 being open and the second end 414 being closed. As shown, a portion of the shaft 410 disposed between the cavity 430 and the second end 414 may have a solid cross section (taken perpendicular to the longitudinal axis A_L of the shaft 410). As discussed above, various configurations of one or more internal cavities may be used in different embodiments.

[0107] The golf shaft 410 may have an outer surface 432 and an inner surface 434. As shown in FIGS. 4B-4G, the inner surface 434 may define the cavity 430. In some embodiments, as shown, each of the outer surface 432 and the inner surface 434 may have a circular cross-sectional shape (taken perpendicular to the longitudinal axis A_L of the shaft 410). In this manner, the shaft 410 may have an outer diameter OD, an inner diameter ID, and a wall thickness T_w , as shown in FIGS. 4C-4G. The wall thickness T_w of the shaft 410 may continuously vary along one or more portions of the overall length L_O . In some embodiments, as shown, the wall thickness T_w may continuously vary along at least a majority of the overall length L_O . According to various embodiments, the wall thickness T_w may continuously vary along at least 5%, at least 10%, at least 20%, at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, or at least 90% of the overall length L_O . In some embodiments, the wall thickness T_w may continuously vary along an entirety of the overall length L_O . According to various embodiments, the wall thickness T_w may continuously vary along a continuous portion of the shaft 410 having a length that is greater than 5%, greater than 10%, greater than 20%, greater than 30%, greater than 40%, greater than 50%, greater than 60%, greater than 70%, greater than 80%, or greater than 90% of the overall length

L_O . In some embodiments, as shown, the wall thickness T_W may be constant along a minority of the overall length L_O .

[0108] The wall thickness T_W may continuously decrease along one or more portions of the shaft **410** in a direction from the first end **412** toward the second end **414** and/or the wall thickness T_W may continuously increase along one or more portions of the shaft **410** in the direction from the first end **412** toward the second end **414**. In some embodiments, the wall thickness T_W may continuously increase or continuously decrease in a linear manner along one or more portions of the shaft **410**. In some embodiments, the wall thickness T_W may continuously increase or continuously decrease in a non-linear manner along one or more portions of the shaft **410**. In this manner, the wall thickness T_W may continuously decrease or continuously increase at a varying rate. In various embodiments, the wall thickness T_W may be continuously varied over a particular portion of the shaft **410** by continuously varying the outer diameter OD, the inner diameter ID, or both the outer diameter OD and the inner diameter ID along the shaft portion. Various combinations of one or more shaft portions having a continuously-decreasing wall thickness T_W , one or more shaft portions having a continuously-increasing wall thickness T_W , and one or more shaft portions having a constant wall thickness T_W may be used to provide a desired stiffness profile of the shaft **410**.

[0109] As shown in FIGS. 4B-4G, the golf shaft **410** may include a first shaft portion **441** along which the wall thickness T_W continuously varies, a second shaft portion **442** along which the wall thickness T_W continuously varies in a manner different from the first shaft portion **441**, a third shaft portion **443** along which the wall thickness T_W is constant, a fourth shaft portion **444** along with the wall thickness T_W continuously varies in a manner different from each of the first shaft portion **441** and the second shaft portion **442**, a fifth shaft portion **445** along which the wall thickness T_W continuously varies in a manner different from each of the first shaft portion **441**, the second shaft portion **442**, and the fourth shaft portion **444**, and a sixth shaft portion **446** along which the wall thickness T_W continuously varies in a manner different from each of the first shaft portion **441**, the second shaft portion **442**, the fourth shaft portion **444**, and the fifth shaft portion **445**. As shown, the shaft **410** also may include a seventh shaft portion **447** that is disposed between the sixth shaft portion **446** and the second end **414** and is solid because the cavity **430** does not extend along the seventh shaft portion **447**. According to various embodiments, the shaft **410** may include any number of different shaft portions along which the wall thickness T_W continuously varies in different manners. As shown, the wall thickness T_W may continuously decrease along the first shaft portion **441** in the direction from the first end **412** toward the second end **414**, the wall thickness T_W may continuously decrease along the second shaft portion **442** in the direction from the first end **412** toward the second end **414**, the wall thickness T_W may be constant along the third shaft portion **443**, the wall thickness T_W may continuously increase along the fourth shaft portion **444** in the direction from the first end **412** toward the second end **414**, the wall thickness T_W may continuously increase along the fifth shaft portion **445** in the direction from the first end **412** toward the second end **414**, and the wall thickness T_W may continuously increase along the sixth shaft portion **446** in the direction from the first end **412** toward the second end **414**. In some embodiments, as shown, the outer diameter OD may continuously decrease

along the first shaft portion **441**, may continuously decrease along the second shaft portion **442**, may be constant along the third shaft portion **443**, may continuously increase along the fourth shaft portion **444**, may continuously decrease along the fifth shaft portion **445**, may continuously decrease along the sixth shaft portion **446**, and may continuously decrease along the seventh shaft portion **447**. In some embodiments, as shown, the outer diameter OD may continuously decrease in a linear manner along the first shaft portion **441**, may continuously decrease in a non-linear manner along the second shaft portion **442**, may continuously increase in a non-linear manner along the fourth shaft portion **444**, may continuously decrease in a non-linear manner along the fifth shaft portion **445**, may continuously decrease in a linear manner along the sixth shaft portion **446**, and may continuously decrease in a linear manner along the seventh shaft portion **447**. In some embodiments, as shown, the inner diameter ID may continuously increase along the first shaft portion **441**, may continuously decrease along the second shaft portion **442**, may be constant along the third shaft portion **443**, may continuously increase along the fourth shaft portion **444**, may continuously decrease along the fifth shaft portion **445**, and may continuously decrease along the sixth shaft portion **446**. In some embodiments, as shown, the inner diameter ID may continuously increase in a linear manner along the first shaft portion **441**, may continuously decrease in a non-linear manner along the second shaft portion **442**, may continuously increase in a non-linear manner along the fourth shaft portion **444**, may continuously decrease in a non-linear manner along the fifth shaft portion **445**, and may continuously decrease in a linear manner along the sixth shaft portion **446**. It will be appreciated that various configurations of different portions of the shaft **410** having a continuously-varying wall thickness T_W may be achieved by varying one or both of the outer diameter OD and the inner diameter ID along the respective portions of the shaft **410**, as discussed above.

[0110] As discussed above, in certain embodiments, a golf shaft may include an internal lattice structure disposed within a cavity of the shaft, the configuration and extent of which may be selected to vary the stiffness profile of the shaft. FIGS. 5A and 5B depict an example golf shaft **510** that includes a shaft body and an internal lattice structure. In some embodiments, the golf shaft **510** may be used as a part of the golf club **100** of FIG. 1A instead of the shaft **110**. In various embodiments, any one of the shafts **110**, **210**, **310**, **410** described above may include an internal lattice structure similar to that described with respect to shaft **510**, implemented in a similar manner. In such embodiments, the structure of the shafts **110**, **210**, **310**, **410** described above and depicted in the corresponding figures may be considered to constitute the “shaft body” that in combination with the internal lattice structure may form the overall shaft.

[0111] As shown, the golf shaft **510** may be formed as an elongated structure having a longitudinal axis A_L . The shaft **510** may have a first end **512** and a second end **514** disposed opposite one another along the longitudinal axis A_L of the shaft **510**. As shown, the shaft **510** may have an overall length L_O from the first end **512** to the second end **514**. The shaft **510** may include a first end section **522**, a second end section **524**, and an intermediate section **526** extending from the first end section **522** to the second end section **524**. The first end section **522** may be configured to receive the grip **150** thereon, and the second end section **524** may be

configured to receive the clubhead **160** thereon. In this manner, upon assembly of the golf club **100**, the grip **150** may cover and be coupled to the first end section **522**, and the clubhead **160** may cover and be coupled to the second end section **524**, while the intermediate section **526** may remain exposed and not be covered by the grip **150** or the clubhead **160**.

[0112] As shown, the golf shaft **510** may include a shaft body **516** (which also may be referred to as simply a “body”) and an internal lattice structure **518** (which also may be referred to as simply a “lattice structure”) integrally formed with the shaft body **516**. The shaft body **516** may extend from the first end **512** to the second end **514**. The shaft body **516** may define an internal cavity **530** extending along the longitudinal axis A_L of the shaft **510**. In this manner, the shaft body **516** may have a tubular shape along at least a portion of the shaft body **516**. As shown, the cavity **530** may extend from the first end **512** to the second end **514**. As discussed above, various configurations of one or more internal cavities may be used in different embodiments. As shown, the lattice structure **518** may be disposed within the cavity **530**. The lattice structure **518** may extend along at least part of the length of the cavity **530**. In some embodiments, as shown, the lattice structure **518** may extend along the entire length of the cavity **530**. In some embodiments, as shown, the lattice structure **518** may extend from the first end **512** to the second end **514**. In some embodiments, as shown, the lattice structure **518** may define a plurality of openings each having a polygonal shape, although other shapes of the openings may be used in other embodiments. Various configurations and arrangements of the lattice structure **518** may be used to provide a desired stiffness profile of the shaft **510**.

[0113] The shaft body **516** may have an outer surface **532** and an inner surface **534**. As shown in FIG. 5B, the inner surface **534** may define the cavity **530**. In some embodiments, as shown, each of the outer surface **532** and the inner surface **534** may have a circular cross-sectional shape (taken perpendicular to the longitudinal axis A_L of the shaft **510**). In this manner, the shaft body **516** may have an outer diameter OD, an inner diameter ID, and a wall thickness T_W , as shown in FIG. 5B. The wall thickness T_W of the shaft body **516** may continuously vary along one or more portions of the overall length L_O . In some embodiments, as shown, the wall thickness T_W may continuously vary along at least a majority of the overall length L_O . According to various embodiments, the wall thickness T_W may continuously vary along at least 5%, at least 10%, at least 20%, at least 30%, at least 40%, at least 50%, at least 60%, at least 70%, at least 80%, or at least 90% of the overall length L_O . In some embodiments, as shown, the wall thickness T_W may continuously vary along an entirety of the overall length L_O . According to various embodiments, the wall thickness T_W may continuously vary along a continuous portion of the shaft body **516** having a length that is greater than 5%, greater than 10%, greater than 20%, greater than 30%, greater than 40%, greater than 50%, greater than 60%, greater than 70%, greater than 80%, or greater than 90% of the overall length L_O . In some embodiments, the wall thickness T_W may be constant along a minority of the overall length L_O .

[0114] The wall thickness T_W may continuously decrease along one or more portions of the shaft body **516** in a direction from the first end **512** toward the second end **514**

and/or the wall thickness T_W may continuously increase along one or more portions of the shaft body **516** in the direction from the first end **512** toward the second end **514**. In some embodiments, the wall thickness T_W may continuously increase or continuously decrease in a linear manner along one or more portions of the shaft body **516**. In some embodiments, the wall thickness T_W may continuously increase or continuously decrease in a non-linear manner along one or more portions of the shaft body **516**. In this manner, the wall thickness T_W may continuously decrease or continuously increase at a varying rate. In various embodiments, the wall thickness T_W may be continuously varied over a particular portion of the shaft body **516** by continuously varying the outer diameter OD, the inner diameter ID, or both the outer diameter OD and the inner diameter ID along the shaft portion. Various combinations of one or more shaft portions having a continuously-decreasing wall thickness T_W , one or more shaft portions having a continuously-increasing wall thickness T_W , and one or more shaft portions having a constant wall thickness T_W may be used to provide a desired stiffness profile of the shaft **510**.

[0115] As shown in FIG. 5B, the wall thickness T_W of the shaft body **516** may continuously vary along the entirety of the overall length L_O . Specifically, the wall thickness T_W of the shaft body **516** may continuously decrease along the entirety of the overall length L_O in the direction from the first end **512** toward the second end **514**. In some embodiments, as shown, the outer diameter OD may continuously decrease from the first end **512** to the second end **514**, and the inner diameter ID may be constant from the first end **512** to the second end **514**. In some embodiments, as shown, the outer diameter OD may continuously decrease in a linear manner from the first end **512** to the second end **514**. It will be appreciated that various configurations of different portions of the shaft body **516** having a continuously-varying wall thickness T_W may be achieved by varying one or both of the outer diameter OD and the inner diameter ID along the respective portions of the shaft body **516**, as discussed above.

[0116] As discussed above, in certain embodiments, a golf shaft may include an external geometric structure disposed along an outer surface of the shaft, the configuration and extent of which may be selected to provide an aesthetic appeal and/or to increase performance characteristics of the shaft. FIGS. 6-10 depict example golf shafts **610**, **710**, **810**, **910**, **1010** that each include a shaft body and an external geometric structure. In some embodiments, the golf shafts **610**, **710**, **810**, **910**, **1010** may be used as a part of the golf club **100** of FIG. 1A instead of the shaft **110**. In various embodiments, any one of the shafts **110**, **210**, **310**, **410** described above may include an external geometric structure similar to that described with respect to shafts **610**, **710**, **810**, **910**, **1010** implemented in a similar manner. In such embodiments, the structure of the shafts **110**, **210**, **310**, **410** described above and depicted in the corresponding figures may be considered to constitute the “shaft body” that in combination with the external geometric structure may form the overall shaft. In some embodiments, an external geometric structure may itself constitute a golf shaft. In other words, such a golf shaft may not include a shaft body as described herein but rather may be formed solely by an external geometric structure as described herein. In this manner, for such embodiments, the golf shaft may be devoid of any thin-walled cylindrical segments.

[0117] As shown in FIG. 6, a golf shaft **610** may include a shaft body **616** and an external geometric structure **618** disposed along an outer surface of the shaft body **616**. In some embodiments, the external geometric structure **618** may have a pattern of geometric shapes, such as polygonal shapes. As shown, the external geometric structure **618** may have a pattern of triangles. Patterns of other polygonal shapes or non-polygonal shapes may be used in other embodiments. In some embodiments, as shown, the pattern of geometric shapes may be a repeating pattern. In other embodiments, the pattern of geometric shapes may be a non-repeating pattern. Further, in other embodiments, the external geometric structure **618** may include various irregular or non-geometric forms. As noted above, in some embodiments, the shaft body **616** may be omitted, such that the external geometric structure **618** itself constitutes the golf shaft **610**, and the golf shaft **610** may be devoid of any thin-walled cylindrical segments.

[0118] As shown in FIG. 7, a golf shaft **710** may include a shaft body **716** and an external geometric structure **718** disposed along an outer surface of the shaft body **716**. In some embodiments, the external geometric structure **718** may have a pattern of geometric shapes, such as polygonal shapes. As shown, the external geometric structure **718** may have a pattern of hexagons. In some embodiments, as shown, the pattern may form a honeycomb structure. Patterns of other polygonal shapes or non-polygonal shapes may be used in other embodiments. In some embodiments, as shown, the pattern of geometric shapes may be a repeating pattern. In other embodiments, the pattern of geometric shapes may be a non-repeating pattern. Further, in other embodiments, the external geometric structure **718** may include various irregular or non-geometric forms. As noted above, in some embodiments, the shaft body **716** may be omitted, such that the external geometric structure **718** itself constitutes the golf shaft **710**, and the golf shaft **710** may be devoid of any thin-walled cylindrical segments.

[0119] As shown in FIG. 8, a golf shaft **810** may include a shaft body **816** and an external geometric structure **818** disposed along an outer surface of the shaft body **816**. In some embodiments, the external geometric structure **818** may include one of more helixes centered on the longitudinal axis A_L of the shaft **810**. In some embodiments, as shown, the one of more helixes may be radially spaced apart from the shaft body **816**. As noted above, in some embodiments, the shaft body **816** may be omitted, such that the external geometric structure **818** itself constitutes the golf shaft **810**, and the golf shaft **810** may be devoid of any thin-walled cylindrical segments.

[0120] As shown in FIG. 9, a golf shaft **910** may include a shaft body **916** and an external geometric structure **918** disposed along an outer surface of the shaft body **916**. In some embodiments, the external geometric structure **918** may have a pattern of geometric shapes, such as polygonal shapes. As shown, the external geometric structure **918** may have a pattern of irregular hexagons, although regular hexagons may be used in other embodiments. Patterns of other polygonal shapes or non-polygonal shapes may be used in other embodiments. In some embodiments, as shown, the pattern of geometric shapes may be a repeating pattern. In other embodiments, the pattern of geometric shapes may be a non-repeating pattern. Further, in other embodiments, the external geometric structure **918** may include various irregular or non-geometric forms. As noted above, in some

embodiments, the shaft body **916** may be omitted, such that the external geometric structure **918** itself constitutes the golf shaft **910**, and the golf shaft **910** may be devoid of any thin-walled cylindrical segments.

[0121] As shown in FIG. 10, a golf shaft **1010** may include a shaft body **1016** and an external geometric structure **1018** disposed along an outer surface of the shaft body **1016**. In some embodiments, the external geometric structure **1018** may have a pattern of geometric shapes, such as polygonal shapes. As shown, the external geometric structure **1018** may have a pattern of diamonds. Patterns of other polygonal shapes or non-polygonal shapes may be used in other embodiments. In some embodiments, as shown, the pattern of geometric shapes may be a repeating pattern. In other embodiments, the pattern of geometric shapes may be a non-repeating pattern. Further, in other embodiments, the external geometric structure **1018** may include various irregular or non-geometric forms. As noted above, in some embodiments, the shaft body **1016** may be omitted, such that the external geometric structure **1018** itself constitutes the golf shaft **1010**, and the golf shaft **1010** may be devoid of any thin-walled cylindrical segments.

[0122] It will be appreciated that the configurations of the external geometric structures **618**, **718**, **818**, **918**, **1018** shown in FIGS. 6-10 are merely a few examples of external geometric structures for a golf shaft, and that various other configurations may be used in other embodiments.

[0123] Example Embodiments of Methods for Manufacturing Golf Shafts

[0124] The golf shafts **110**, **210**, **310**, **410**, **510**, **610**, **710**, **810**, **918**, **1018** described herein may be manufactured by various methods, including, in some instances, conventional shaft fabrication techniques, when possible. However, in view of complex geometries, such as shaft portions having a continuously-varying outer diameter, inner diameter, and/or wall thickness, internal lattice structures, and/or external geometric structures according to different embodiments, the use of additive manufacturing techniques may be particularly advantageous for fabricating the shafts **110**, **210**, **310**, **410**, **510**, **610**, **710**, **810**, **918**, **1018**. Moreover, as discussed above, the use of additive manufacturing techniques to fabricate the shafts **110**, **210**, **310**, **410**, **510**, **610**, **710**, **810**, **918**, **1018** advantageously may provide the ability to vary the shaft's wall thickness to provide an optimal stiffness profile for a particular user or for a particular subset of users having closely-similar swing speeds, while avoiding the high tooling costs associated with conventional shaft manufacturing methods. Further benefits of using additive manufacturing over conventional techniques will be appreciated by one of ordinary skill in the art in view of the unique features and customizable nature of the shafts **110**, **210**, **310**, **410**, **510**, **610**, **710**, **810**, **918**, **1018**.

[0125] An example method for manufacturing a golf shaft may include receiving a CAD model corresponding to the golf shaft, and forming, based at least in part on the CAD model, the golf shaft using one or more additive manufacturing techniques. The golf shaft may be any one of the shafts **110**, **210**, **310**, **410**, **510**, **610**, **710**, **810**, **918**, **1018** or variations described herein. In some embodiments, the golf shaft may be formed of one or more metals or metal alloys using one or more metal additive manufacturing techniques. In some embodiments, the one or more metals or metal alloys may include at least one of: steel, a steel alloy, titanium, a titanium alloy, aluminum, or an aluminum alloy.

In some embodiments, the golf shaft may be formed using one or more powder bed fusion techniques, such as direct metal laser sintering (DMLS), selective laser melting (SLM), or electron beam melting (EBM). In some embodiments, the golf shaft may be formed using one or more metal binder jetting techniques, such as 3D printing. In some embodiments, the golf shaft may be formed using one or more direct energy deposition techniques, such as laser engineered net shaping (LENS), direct metal deposition (DMD), or laser metal deposition (LIVID). In some embodiments, the golf shaft may be formed using metal material extrusion. In some embodiments, the golf shaft may be formed using one or more material jetting techniques, such as liquid metal additive manufacturing. In some embodiments, the golf shaft may be formed using joule printing. In some embodiments, the golf shaft may be formed using digital light projection metal printing. In some embodiments, the golf shaft may be formed using cold spray metal printing. Still other types of additive manufacturing techniques may be used in other embodiments. In some embodiments, the golf shaft may be formed as a single component using additive manufacturing techniques. In some embodiments, two or more segments of the golf shaft may be separately formed using additive manufacturing techniques and then fixedly coupled to one another, for example, by welding. This approach may be used, for example, when the additive manufacturing equipment being used is not able to accommodate fabrication of a single component having the desired overall length of the golf shaft. As discussed above, the golf shaft may be customized for a particular user based on one or more characteristics of the user's swing pattern. Accordingly, in some embodiments, the method also may include determining user data corresponding to a swing pattern of a predetermined user of the golf shaft, and generating the CAD model based at least in part on the user data. In some embodiments, a stiffness profile of the golf shaft may be determined based at least in part on the user data, and the CAD model may be generated based at least in part on the stiffness profile.

[0126] Although various types of additive manufacturing techniques may be used to produce the golf shafts described herein, SLM or DMLS may be particularly well suited for manufacturing the shafts. Example parameters for manufacturing the golf shafts via SLM or DMLS may include one or more (in any combination), or all, of the following: a powder particle size of greater than 1 nm and less than 1 mm; a continuous or pulsed laser with a wavelength of greater than 1 nm and less than 1 m; a laser power of greater than 0 W and less than 20,000 W; a layer thickness of greater than 0 mm and less than 2 mm; a scan speed of greater than 0 mm/s and less than 20,000 mm/s; a build plate temperature of greater than 0° C. and less than 500° C.; use of a soft silicone, brush, or metal recoating blade; and use of an argon, nitrogen, or inert gas atmosphere.

[0127] Although specific embodiments of the disclosure have been described, one of ordinary skill in the art will recognize that numerous other modifications and alternative embodiments are within the scope of the disclosure. For example, while various illustrative implementations and structures have been described in accordance with embodiments of the disclosure, one of ordinary skill in the art will appreciate that numerous other modifications to the illustrative implementations and structures described herein are also within the scope of this disclosure.

[0128] Although embodiments have been described in language specific to structural features and/or methodological acts, it is to be understood that the disclosure is not necessarily limited to the specific features or acts described. Rather, the specific features and acts are disclosed as illustrative forms of implementing the embodiments. Conditional language, such as, among others, “can,” “could,” “might,” or “may,” unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments could include, while other embodiments do not include, certain features, elements, and/or steps. Thus, such conditional language is not generally intended to imply that features, elements, and/or steps are in any way required for one or more embodiments.

What is claimed is:

1. A golf shaft comprising:

a first end; and

a second end disposed opposite the first end along a longitudinal axis of the golf shaft,

wherein the golf shaft defines one or more internal cavities extending along the longitudinal axis,

wherein the golf shaft has an overall length from the first end to the second end, an outer diameter, an inner diameter, and a wall thickness,

wherein the wall thickness varies along the overall length, and

wherein a variation of the wall thickness between any two cross-sections of the golf shaft taken perpendicular to the longitudinal axis is equal to or greater than 0.001 inches.

2. The golf shaft of claim 1, wherein at least one of the inner diameter or the outer diameter varies in a non-linear manner along at least a portion of the golf shaft.

3. The golf shaft of claim 1, wherein at least one of the inner diameter or the outer diameter varies along at least a portion of the golf shaft such that a taper rate of the at least one of the inner diameter or the outer diameter changes more than once along the at least a portion of the golf shaft.

4. The golf shaft of claim 1, wherein the golf shaft comprises one or more metals or metal alloys.

5. The golf shaft of claim 1, wherein the golf shaft comprises a single component.

6. The golf shaft of claim 1, further comprising an internal lattice structure disposed within at least one of the one or more internal cavities.

7. The golf shaft of claim 1, further comprising an external geometric structure disposed along an outer surface of the golf shaft, and wherein the external geometric structure has a pattern of geometric shapes.

8. The golf shaft of claim 7, wherein the pattern of geometric shapes is a repeating pattern.

9. A method for manufacturing a golf shaft, the method comprising:

receiving a CAD model corresponding to the golf shaft; and

forming, based at least in part on the CAD model, the golf shaft using one or more additive manufacturing techniques, the golf shaft comprising:

a first end and a second end disposed opposite one another along a longitudinal axis of the golf shaft, wherein the golf shaft defines one or more internal cavities extending along the longitudinal axis, wherein the golf shaft has an overall length from the

first end to the second end, an outer diameter, an inner diameter, and a wall thickness, wherein the wall thickness varies along the overall length, and wherein a variation of the wall thickness between any two cross-sections of the golf shaft taken perpendicular to the longitudinal axis is equal to or greater than 0.001 inches.

10. The method of claim **9**, wherein at least one of the inner diameter or the outer diameter varies in a non-linear manner along at least a portion of the golf shaft.

11. The method of claim **9**, wherein at least one of the inner diameter or the outer diameter varies along at least a portion of the golf shaft such that a taper rate of the at least one of the inner diameter or the outer diameter changes more than once along the at least a portion of the golf shaft.

12. The method of claim **9**, wherein forming the golf shaft using one or more additive manufacturing techniques comprises forming the golf shaft of one or more metals or metal alloys using one or more metal additive manufacturing techniques.

13. The method of claim **9**, wherein forming the golf shaft using one or more additive manufacturing techniques comprises forming the golf shaft as a single component using the one or more additive manufacturing techniques.

14. The method of claim **9**, further comprising:

determining user data corresponding to a swing pattern of a predetermined user of the golf shaft;

generating the CAD model based at least in part on the user data.

15. The method of claim **14**, further comprising determining a stiffness profile of the golf shaft based at least in part on the user data, wherein generating the CAD model

based at least in part on the user data comprises generating the CAD model based at least in part on the stiffness profile.

16. The method of claim **9**, wherein the golf shaft further comprises an internal lattice structure disposed within at least one of the one or more internal cavities.

17. The method of claim **9**, wherein the golf shaft further comprises an external geometric structure disposed along an outer surface of the golf shaft, and wherein the external geometric structure has a pattern of geometric shapes.

18. A method for manufacturing a golf shaft, the method comprising:

receiving a CAD model corresponding to the golf shaft; and

forming, based at least in part on the CAD model, the golf shaft using one or more additive manufacturing techniques, the golf shaft comprising:

a first end;

a second end disposed opposite the first end along a longitudinal axis of the golf shaft, wherein the golf shaft has an overall length from the first end to the second end;

a shaft body extending from the first end to the second end and having an outer surface, wherein the shaft body defines an internal cavity extending along the longitudinal axis; and

an external geometric structure disposed along the outer surface, wherein the external geometric structure has a pattern of geometric shapes.

19. The method of claim **18**, wherein the pattern of geometric shapes is a repeating pattern.

20. The method of claim **18**, wherein the pattern of geometric shapes is a non-repeating pattern.

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