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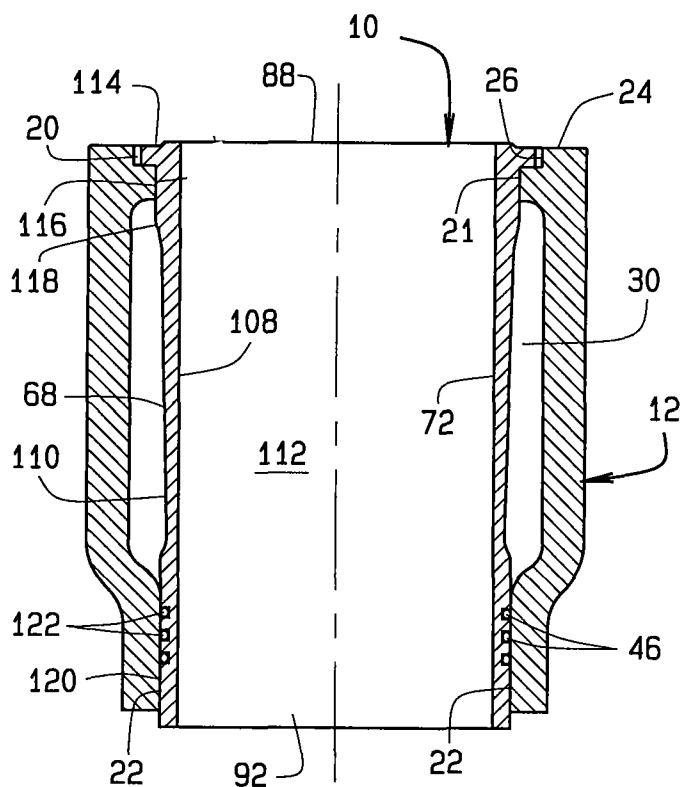
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(54) Title: PROCESS FOR PRODUCING A STEEL CYLINDER LINER



(57) Abstract: To produce a steel liner (10) for a cylinder (112) of an internal combustion engine, a tubular preform (50) of steel is subjected to a flow forming procedure which transforms it into a semi-finished liner (56) having a configuration that corresponds closely to the configuration desired for the cylinder liner. The flow forming process achieves a near-net shape such that only minimal amount of subsequent machining is required to transform the semi-finished liner (56) into the final shape for the cylinder liner (10).



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PROCESS FOR PRODUCING A STEEL CYLINDER LINER

CROSS REFERENCE TO RELATED APPLICATIONS

This application derives and claims priority from U.S. provisional
5 application 60/784,603, filed 22 March 2006, and from U.S. provisional
application 60/865,274, filed 10 November 2006, both of which are
incorporated herein by reference.

TECHNICAL FIELD

This invention relates in general to a process for forming liners for the
10 cylinders of internal combustion engines and, more particularly, to a flow
forming process to form steel liners for cylinders of internal combustion
engines.

BACKGROUND ART

Driven in a large part by tightening emission regulations, peak cylinder
15 pressures and exhaust gas recirculation rates are increasing in many diesel
engine applications. These engines typically employ a cylinder liner which
forms the combustion chamber in which the piston reciprocates. The liners fit
within an engine block where they separate the combustion chambers from a
coolant that circulates around the outer surfaces of the liners. Generally,
20 water-cooled engines, such as medium to heavy-duty diesel engines, use
liners made from cast iron which are machined to fit within the engine blocks.
The cast iron liners are machined in such a way as to minimize friction and
wear during engine operation while confining and guiding the pistons. The
higher peak cylinder pressures and temperatures have caused some
25 traditional cast iron liners to fail earlier than anticipated.

In order to meet pressure requirements of their combustion chambers,
and to retard flexure of the liners and prevent cavitation, the walls of cast iron
liners must necessarily be thicker than those produced from materials with
higher strength and stiffness properties, such as steel. The thicker walls of
30 the cast iron liners limit the available volume for the combustion chambers. In
addition, the thicknesses of the cast iron liners decrease cooling of the

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chambers through thermal conduction. Moreover, cast iron liners are heavy and as such contribute to the weight of the engines in which the cast iron liners are installed. Additionally, in order to provide increased resistance to fatigue, cast iron liners typically require additional surface improvement
5 operations such as roll-burnishing or shot-peening.

So-called "piston slap", when it occurs in a liner, causes the liner to flex momentarily outwardly and then return to its original configuration, producing cavitation in the coolant jacket that is along the wet side of the liner. The cavitation in turn creates cavitation erosion on the external surface of the liner.
10 To prevent cavitation erosion on the external surfaces of the liners, cast iron liners must generally have a thick wall section for a given engine application. The thick walls of the cast iron liners, however, result in the previously mentioned limiting factors.

Most steels possess considerably greater strength and stiffness than
15 cast iron, and some manufacturers have installed steel liners in diesel engines, but at considerably greater expense than cast iron liners. In this regard, good steels cost more than cast iron. Furthermore, such steel liners do not have configurations that optimize combustion pressure profiles. Moreover, these steel liners must be machined from tube stock; this process
20 is referred to as a machined-all-over (MAO) process. This machining, however, requires removal of a considerable amount of steel in the regions having thinner sections, so that the liners will have regions of greater thickness where required. In particular, MAO processes result in very low material utilization, wherein material loss for MAO tubing is often in the range
25 of 30%-60%. Besides wasting the expensive steel, this machining is an expensive operation in its own right.

DESCRIPTION OF THE FIGURES IN THE DRAWINGS

Fig. 1 is a longitudinal sectional view of a typical cast iron cylinder liner of the prior art set into an engine block;

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Fig. 2 is a longitudinal sectional view of a flow-formed steel liner constructed in accordance with and embodying the present disclosure and set into an engine block;

5 Fig. 3 is a schematic elevational view of a flow forming machine with a tubular steel preform installed on it;

Fig. 4 is a schematic elevational view of the flow forming machine transforming the preform into a semi-finished liner in accordance with and embodying the present disclosure, wherein the flow forming machine processes the perform in a direction away from a tailstock of the flow forming
10 machine;

Fig. 5 is a schematic elevational view of the flow forming machine transforming the perform into a semi-finished liner in accordance with and embodying the present disclosure, wherein the flow forming machine processes the perform in a direction toward a headstock of the flow forming
15 machine;

Fig. 6 is a longitudinal sectional view of a semi-finished liner with a near-net shape corresponding closely to the shape desired for the cylinder liner produced by flow forming in accordance with and embodying the present disclosure;

20 Fig. 7 is a longitudinal sectional view of another semi-finished liner with a near-net shape corresponding closely to the shape desired for the cylinder liner produced by flow forming wherein a segment of an external surface of the semi-finished liner has a tapered thickness in accordance with and embodying the present disclosure;

25 Fig. 8 is a longitudinal sectional view of another semi-finished liner with a near-net shape corresponding closely to the shape desired for the cylinder liner produced by flow forming wherein a segment of an external surface of the semi-finished liner has wave-like surface in accordance with and embodying the present disclosure;

30 Fig. 9 is a longitudinal sectional view of another semi-finished liner with a near-net shape corresponding closely to the shape desired for the cylinder

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liner produced by flow forming wherein a segment of an external surface of the semi-finished liner has a surface of varying diameters in accordance with and embodying the present disclosure;

Fig. 10 is a longitudinal sectional view of another semi-finished liner with a near-net shape corresponding closely to the shape desired for the cylinder liner produced by flow forming wherein a segment of an external surface of the semi-finished liner has a surface of varying diameters in accordance with and embodying the present disclosure; and

Fig. 11 is a longitudinal sectional view of another semi-finished liner with a near-net shape corresponding closely to the shape desired for the cylinder liner produced by flow forming wherein a segment of an external surface of the semi-finished liner has a uniform thickness in accordance with and embodying the present disclosure.

DETAILED DESCRIPTION OF THE INVENTION

The following detailed description illustrates the disclosure by way of example and not by way of limitation. The description clearly enables one skilled in the art to make and use the disclosure, describes several embodiments, adaptations, variations, alternatives, and uses of the disclosure, including what is presently believed to be the best mode of carrying out the disclosure.

Referring to the drawings, a cylinder liner 10 of the present disclosure (Fig. 2), which fits into a block 12 of an internal combustion engine, such as a diesel (compression ignition) engine, is produced by flow forming (also known as radial forming) a steel preform in a near-net shape followed by machining that removes a minimal amount of steel to produce the steel liner 10. As will be discussed, the steel liner 10 serves as a substitute for a cast iron liner 14 (Fig. 1) commonly used in diesel engines.

Considering the cast iron liner 14 (Fig. 1) of current manufacture first, the cast iron liner 14 fits into the engine block 12 to provide a cylinder 16 in which a piston 18 reciprocates. To this end, the block 12 confines the liner 14 along upper and lower cylindrical bores 20 and 22. The upper bore 20 opens

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out of a machined surface 24 on the block 12 through a shallow counter bore 26. The surface 24 supports the head for the engine. Between the two confining bores 20 and 22 is a coolant jacket 30.

The cast iron liner 14 has a head end 32 and a tail end 34 and an
5 internal surface 36 and an external surface 38 that extend between the ends 32 and 34. The internal surface 36 is perfectly cylindrical and surrounds and defines the cylinder 16. At the head end 32, the external surface 38 is slightly enlarged in the form of a flange 40 that seats in the counter bore 26 of the block 12. Near the tail end 34, the external surface 38 has an end section 42
10 that is received in the lower bore 22 that is deep within the block 12. The flange 40 is machined into the external surface 38 at the head end 32, while grooves 44 are machined in the end section 42. The grooves 44 contain seals such as O-rings 46 that seat against the surface of the lower bore 22.

Between the flange 40 and the reduced section 42, the external
15 surface 38 has a generally uniform diameter that provides the cast iron liner 14 with a relatively thick wall 48. Indeed, the wall 48 must be thick enough to withstand the high pressures developed within the cylinder 16 when fuel that is injected into it ignites. Owing to its thick wall 48, the cast iron liner 14 is quite heavy. Moreover, the thick wall 48 dissipates heat to a coolant in the
20 coolant jacket 30 less effectively than would a thinner wall.

Turning to Figs. 3 and 4, the present disclosure relates to forming the steel liner 10 by the flow forming process. The flow forming process for manufacturing the steel liner 10 begins with a steel preform 50 (Fig. 3) of cylindrical configuration on both its internal surface 52 and a preform external
25 surface 54. The tubular steel preform 50 may be cut from either seamless or welded tube stock. Regardless of whether the steel preform 50 is cut from seamless or welded tube stock, the steel preform 50 is provided with an inwardly turned end 55, preferably in a roll forming operation. The preform 50 may be produced from a variety of steel grade families including a carbon
30 steel (e.g. 10XX and 15XX series and boron treated), an alloy steel (e.g. 40XX, 41XX, 43XX), a microalloy steel (e.g., vanadium, titanium or niobium

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5 treated) and a stainless steel (e.g. 300, 400 and 500 series). Irrespective of the steel type, the preform 50 preferably has a low sulfur content - preferably, no more than about 0.025% sulfur by weight - particularly if the steel preform 50 must undergo a high reduction at certain sections. Moreover, the steel of the preform 50 preferably is ductile. In an embodiment, the steel of the preform 50 has a hardness rating lower than 35 Rockwell C. If the steel of the preform 50 is not ductile, the preform 50 preferably is annealed. The steel preform 50 achieves benefits over cast iron. For example, the steel material has a higher strength and stiffness which permit liners 10 (Fig. 2) to withstand greater peak cylinder pressures for a given wall section. Additionally, the higher strength and stiffness of the steel results in greater cavitation resistance, results in greater fatigue resistance and may result in reduced exhaust gas blow-by and engine oil consumption via reduced liner flexing during engine operation.

15 Furthermore, the higher strength and stiffness of the steel permits thinner wall configurations for the liner 10. The thinner wall may result in increased engine displacement (i.e., more power) without major engine redesign. In other words, the thinner wall with the higher strength and stiffness of steel results in no change to the engine block design which is of particular interest as exhaust gas recirculation rates continue to increase. Additionally, the thinner steel wall results in lower liner component weight and improves the thermal transfer characteristics from the cylinder liner 10 to the coolant jacket 30 (Fig. 2). Still further, the improved heat transfer characteristics of the thinner steel wall may aid in the reduction of NO_x emissions.

25 Additionally, wrought steel does not have porosity which is inherent in cast iron. This porosity typically leads to internal scrap rates of up to 5% of finished cast iron liners 14 (Fig. 1). The steel of the semi-finished liner 56 also exhibits better machinability than certain other cast irons such as compacted graphite iron. Steels may eliminate the need for surface improvement operations which are typical for the cast iron liners such as roll-burnishing or

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shot-peening. Additionally, cold-formed steel liners 10 may eliminate the need for bore hardening operations such as induction hardening or nitriding. Furthermore, as will be discussed, the enhanced mechanical properties resulting from the cold working operation increases the durability and reliability of steel liners 10 over cast iron liners 14 resulting in reduced engine maintenance, reduced component replacement costs and/or reduced warranty claims for the engine manufacturer.

During the flow forming process, the steel preform 50 is converted into a semi-finished liner 56 (Fig. 6) in a flow forming machine generally shown as 58 (Figs. 3 & 4), with the transformation leaving the semi-finished liner 56 with essentially the same configuration desired for the completed or final liner 10. In other words, the flow forming process produces the semi-finished liner 56 in a near-net shape corresponding closely to the shape desired for the cylinder liner 10 (Fig. 2). To be sure, the semi-finished liner 56 requires some machining, but this machining results in the removal of only minimal amounts of metal. Thus, the flow-forming process effects a near-net shape transformation of the steel preform 50.

The machine 58 for converting the steel preform 50 into the semi-finished liner 56 of near-net shape includes a mandrel 60 having a cylindrical exterior surface, the diameter of which generally matches the inside diameter of the steel preform 50 such that the steel preform 50 fits over the mandrel 60. In addition, the machine 58 has a tailstock 62 that grips the steel preform 50 and prevents it from displacing axially along the mandrel 60. Apart from that, the flow-forming machine 58 has one or more forming rollers 64, preferably three located around the mandrel 60, each being supported by a housing 66 that has the capacity to move axially along the mandrel 60 as well as radially. The tailstock 62 secures the steel preform 50 at the inwardly turned end 55 of the steel preform 50 while the rotating forming rollers 64 advance axially away from the tailstock 62 and the secured end 55 of the steel preform 50 in order to forward flow form the steel preform 50. The forming rollers 64 and

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housings 66 are staggered axially so as to work any specific area of the steel preform 50 successively.

The tailstock 62 grips the steel preform 50 at end 55, so that the steel preform 50 will not displace axially on the mandrel 60 or rotate relative to the mandrel 60. Once the flow forming process imparts rotation to the mandrel 60 and to the steel preform 50 that is on it, the forming rollers 64, which rotate with the same peripheral velocity on the external surface of the steel preform 50, are brought against the external surface of the steel preform 50 (Fig. 3).

While rotating, the forming rollers 64 move axially along the external surface 54 of the steel preform 50 and away from the tailstock 62, and the forming rollers 64 are further displaced radially inwardly and outwardly along the external surface 54 of the steel preform 50. The process is such that it elongates the steel preform 50 and imparts a profile to form an external surface 68 (Figs. 4, 5 & 6) of the semi-finished liner 56. Indeed, the displacement of the forming rollers 64 imparts to the steel preform 50 the external surface 68 that closely corresponds to the external surface for the liner 10 (Fig. 2), thus, transforming the steel preform 50 into the semi-finished liner 56 at near-net shape corresponding closely to the shape designed for the cylinder liner 10. Sometimes one pass axially will suffice, but where the steel preform 50 must undergo a significant reduction in converting to the semi-finished liner 56, two or more passes may be required. The process is capable of achieving reductions in preform blank thicknesses of up to 90%. This high reduction is believed to be attributable in large part to the low sulfur content of the steel. The actual reduction levels required on any given component will vary depending upon the liner design.

Turning to Fig. 5, in an embodiment, the steel preform 50 is secured against a headstock 69 of the flow forming machine 58. The headstock 69 includes serrated or rough surfaces S that grip the steel preform 50. In other words, the serrated surfaces S partially embed within an end of the steel preform 50. The headstock 69 grips the steel preform 50 at one of its ends, so that the steel preform 50 will not displace axially on the mandrel 60 or

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rotate relative to the mandrel 60. Once the flow forming process imparts rotation to the mandrel 60 and to the steel preform 50 that is on it, the forming rollers 64, which rotate with the same peripheral velocity on the external surface of the steel preform 50, are brought against the external surface of the steel preform 50.

While rotating, the forming rollers 64 move axially along the external surface 54 of the steel preform 50 and toward the headstock 69, and the forming rollers 64 are further displaced radially inwardly and outwardly along the external surface 54 of the steel preform 50. In this embodiment, the forming roller 54 advances axially toward the headstock 69 while reverse flow forming the steel preform 50. The process is such that it elongates the steel preform 50 and imparts a profile to form the external surface 68 (Fig. 6) of the semi-finished liner 56. Indeed, the displacement of the forming rollers 64 imparts to the steel preform 50 the external surface 68 that closely corresponds to the external surface for the liner 10 (Fig. 2), thus, transforming the steel preform 50 into the semi-finished liner 56 at near-net shape corresponding closely to the shape designed for the cylinder liner 10.

The flow forming processes (Figs. 3-5) of the present disclosure produce the steel semi-finished liner 56 in the near-net shape which reduces the need for subsequent machining operations. This reduction of machining operations results in lower capital equipment required, lower manufacturing cycle times, lower consumable tooling costs and reduced in-process inventory levels. Additionally, the flow forming processes of the present disclosure result in very high steel material utilization with material losses by flow forming generally being less than 10%. Most of the material loss resides in the removal of the inwardly turned end 55. Accordingly, the weight of the steel preform 50 placed on the mandrel 60 is nearly the same as the weight of the formed steel semi-finished liner 56. Furthermore, given the precision nature of the flow forming equipment, and the fact that the steel preforms 50 are formed against a hardened mandrel 60, the flow forming processes result in very tight dimensional tolerances of the semi-finished liner 56, including inner

diameter, outer diameter, roundness and concentricity. These tight tolerances may result in the reduction or elimination of certain rough machining or rough honing operations, allowing the processor to simply hone the semi-finished liner 56 or harden and then hone the semi-finished liner 56. Given both the
5 tight tolerances and smooth surface finish of the steel semi-finished liner, the processor can eliminate machining the outer diameter water jacket 30.

The flow forming occurs without the application of external heat, and as a consequence, the steel preform 50 is work hardened as it undergoes a reduction in thickness. The work hardening imparts strength to the liner 10,
10 enabling it to withstand higher pressures and temperatures while also increasing hardness to improve both cavitation resistance and wear resistance along its surfaces that define the cylinder 112 (Fig. 2). The work hardening also enables the liner 10 to exhibit greater resistance to deflections caused by piston slap, and this in turn reduces cavitation erosion, which is an
15 added benefit over cast iron liners and liners machined from steel tube stock.

While semi-finished steel liners may be produced via either forward (Fig. 4) or reverse flow forming (Fig. 5) , better dimensional accuracy is typically achieved with forward flow forming (Fig. 4); that is to say movement of the forming rollers 64 away from the inwardly turned end 55 where the
20 preform 50 is gripped. The use of the flow forming process for the production of cold worked, semi-finished steel liners 56 for internal combustion engine liners is extremely flexible and capable of producing straight inner diameter semi-finished liners 56 with a variety of outer diameter profiles for the exterior surface 68 of the semi-finished liner 56.

25 Turning to Figs. 7-11, embodiments having variable configurations of the external surface 68 are shown. In an embodiment, a segment of the external surface 68 has an irregular shape, wherein the irregular shape may comprise a segment of varying outer diameters (Figs. 7-10). Turning to Fig. 7 and referring to Figs. 2-5, the forming roller 64 flow forms the steel preform 50
30 into a semi-finished liner 70 such that a segment 72 of the external surface 68 has a tapered surface 74. This tapered surface 74 can be designed to match

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the pressure gradient within the cylinder 112 (Fig. 2) as the piston travels from top dead center to bottom dead center. Since the tapered surface 74 matches the pressure gradient, the tapered surface 74 results in reduced blow-by and improved thermal transfer properties, increased cavitation resistance, and improved noise, vibration and harshness characteristics. Additionally, the thinner wall thickness of the tapered surface 74 results in reduced component weight of the semi-finished liner 70.

In another embodiment (Fig. 8), the forming roller 64 flow forms the steel preform 50 into another semi-finished liner 76 such that a segment 78 of the external surface has a wave-like surface 80. This wave-like surface 80 also improves heat transfer into the coolant jacket 30 (Fig. 2). During the flow forming process, the pattern of the wave-like surface 80 can be adjusted to engineer the natural frequency of the liner 10 and thereby reduce the liner's tendency to ring at certain engine speeds. Additionally, the profile of the outer diameter of the wave-like surface 80 can reduce cavitation and minimize noise, vibration and harshness effects. In an embodiment, the wave-like surface 80 includes a uniform repeating pattern of wave surfaces. This uniform repeating pattern of wave surfaces may comprise a substantially sinusoidal pattern. In another embodiment, the wave-like surface 80 includes a non-uniform pattern of wave surfaces or "ribs" to further enhance the reduction in cavitation and to minimize noise, vibration and harshness effects.

Referring to Fig. 9, the forming roller 64 flow forms the steel preform 50 into another semi-finished liner 82 such that a segment 84 of the external surface has a first portion 86 near a head end 88 of the semi-finished liner 82 and a second portion 90 near a tail end 92 of the semi-finished liner 82. As shown, the second portion 90 has a greater wall thickness than the first portion 86. Such a profile is representative of certain current top-stop liner geometries in use.

In another embodiment (Fig. 10), the forming roller 64 flow forms the steel preform 50 into another semi-finished liner 94 such that a segment 96 of the external surface has a first portion 98 near the head end 88 of the semi-

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finished liner 94 and a second portion 100 near the tail end 92 of the semi-finished liner 94 wherein the second portion 100 has a lesser wall thickness than the first portion 98. Such a profile is representative of certain current mid-stop liners in use.

5 Referring to Fig. 11, in an embodiment, the forming roller 64 flow forms the steel preform 50 into another semi-finished liner 102 such that a segment 104 of the external surface has a uniform wall thickness 106. Such a profile is representative of certain current top-stop liners in use.

Turning to Figs. 2 and 6 and referring to Figs. 7-11, the liner 10 is
10 formed from steel in the flow forming operation wherein the liner 10 has a cylindrical interior surface 108 and the exterior surface 68 so that a liner wall 110 exists between the internal surface 108 and external surface 68. In the illustrated embodiments, the external surface 68 has segments 72, 78, 86, 98 and 106 that lies along a region of the cylinder 112 (Fig. 2) that experiences
15 elevated pressure and temperature from the combustion of fuel in the cylinder 112.

The steel liner 10 (Fig. 2) includes the head end 88 and tail end 92 as well as the internal surface 108 and the external surface 68. The internal surface 108 is perfectly cylindrical between the head end 88 and the tail end
20 92, thus providing the cylinder 112 in which a piston can reciprocate. At the end 88, the external surface 68 flares outwardly in the provision of a slight flange 114. Leading up to the tail end 92 is an end section 120 of generally uniform diameter on the external surface 68, and it has annular grooves 122 opening out of it. Between the head end 88 and the tail end 92, the external
25 surface 68 has a segment that lies along a region of the cylinder 112 that experiences elevated pressures from the combustion of the fuel in the cylinder 112.

The flow forming converts the steel preform 50 into the semi-finished liner 56 (Figs. 6-11) that is machined lightly to provide the internal surface
30 108. While much of the external surface 68 may be left generally as formed (made to near-net shape), certain features such as the annular grooves 122,

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the portion of the end section 120 out of which the grooves 122 open, the flange 114, and enlarged head region 118 are machined into the external surface 68 after flow forming. The internal surface 108 of liner 10 may then be treated to harden it, such as by induction hardening, nitriding, or carbo-
5 nitriding. Alternatively, the internal surface 108 may remain untreated, as warranted by the specific application to which the liner 10 is put. The internal surface 108 is honed to create an engineered surface that optimizes engine performance and interaction with the particular piston rings.

As an illustrated example, the now finished steel cylinder liner 10 (Fig.
10 2) fits into the block 12 or a similarly configured block, with its enlarged head region 118 received in the upper bore 21 of the block 12 and its flange 114 seated in the counter bore 26 that opens out of the end surface. The end section 120 fits into the lower bore 22 with the O-rings seals 46 effecting fluid barriers along the surface of the lower bore 22. Between the enlarged head
15 region 118 and the end section 120, the external surface 68 has the irregularly shaped segment, thus providing the liner wall 110 with varying diameters. The variation in thickness for the liner wall 110 correlates with the pressure gradient in the cylinder 112 when a fuel undergoes combustion in the cylinder 112. As shown, the liner wall 110 is exposed to a coolant in the
20 coolant jacket 30.

Being formed from steel, the liner 10 has higher strength, stiffness and toughness characteristics than the liner 14 (Fig. 1) that is formed from cast iron. For that reason, the liner wall 110 of the steel liner 10 may be thinner than the thick wall 30 (Fig. 1) of the cast iron liner 14. The thickest portion of
25 the liner wall 110, of course, exists near the head end 88 of the liner 10 where pressures within the cylinder 112 are greatest and the temperatures are highest. From the head end 88, the thickness of the liner wall 110 varies generally in correlation with the pressure gradient in the cylinder 112. Indeed, the liner wall 110 enables the liner 10 to optimally withstand pressures from
30 the ignition of fuel within the cylinder 112.

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The liner 10, having its liner wall 110 of varying thicknesses, achieves improved heat transfer to the exterior liquid media contained in the coolant jacket 30 of the engine block 12. Additionally, the liner wall 110 reduces the overall weight of the liner 10 and the engine of which it is a component.

5 Furthermore, for a given engine block 12, the liner 10 allows an increase in engine displacement resulting in increased power per unit weight of the engine.

The external surface 68 of liner 10 generally matches the pressure profile of the internal combustion during the typical stroke of the piston, at the
10 liner wall 110; thereby reducing bore distortion and oil loss due to engine blow-by. As previously noted, the blow-by may occur in the cast iron liner 14 due to flexing of a liner wall 30 during the piston travel. The thickness of the liner wall 110 reduces or eliminates the blow-by issues. The liner 10 also enhances resistance to cavitation in the coolant jacket 30 along the liner wall
15 110. Additionally, the liner 10 may improve noise, harshness and vibration characteristics of the engine. Fig. 2 illustrates the varying diameters of the liner wall 110 in the form of the tapered segment 72 for illustrative purposes. Other embodiments (Figs. 8-11) of the semi-finished liner 56 may also be processed and placed within block 12 or a similarly configured block.
20 Additionally, Figs. 6-11 illustrate exemplary categories of profiles for the near net shape liner. Other categories of profiles may also be processed to produce near net shaped liners by the flow forming processes.

In view of the above, it will be seen that the several advantageous results are obtained. As various changes could be made in the above
25 constructions without departing from the scope of the disclosure, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

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CLAIMS:

1. A process for producing a cylinder liner for a cylinder of an internal combustion engine, the process comprising:
 - placing a steel preform over a mandrel;
 - 5 rotating the mandrel and the steel preform on it; and
 - subjecting the steel preform to a forming roller that moves axially along an external surface of the preform and radially inwardly and outwardly along the preform external surface wherein the forming roller flow forms the steel preform into a semi-finished liner having a cylindrical internal surface
 - 10 and an external surface forming a near-net shape of the semi-finished liner corresponding closely to a final shape desired for the cylinder liner.
2. The process according to claim 1 wherein the forming roller flow forms the steel preform such that a segment of the external surface has an irregular shape.
- 15 3. The process according to claim 1 wherein the forming roller flow forms the steel preform such that a segment of the external surface has a tapered surface.
4. The process according to claim 1 wherein the forming roller flow forms the steel preform such that a segment of the external surface has a
- 20 wave-like surface.
5. The process according to claim 4 wherein the wave-like surface includes a uniform repeating pattern of wave surfaces.
6. The process according to claim 5 wherein the uniform repeating pattern is a substantially sinusoidal pattern.
- 25 7. The process according to claim 4 wherein the wave-like surface includes a non-uniform pattern of wave surfaces.
8. The process according to claim 1 wherein the forming roller flow forms the steel preform such that a segment of the external surface has a uniform wall thickness.
- 30 9. The process according to claim 1 wherein the forming roller flow forms the steel preform such that a segment of the external surface has a first

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portion near a head end of the semi-finished liner and a second portion near a tail end of the semi-finished liner wherein the second portion has greater wall thickness than the first portion.

10. The process according to claim 1 wherein the forming roller flow
5 forms the steel preform such that a segment of the external surface has a first portion near a head end of the semi-finished liner and second portion near a tail end of the semi-finished liner wherein the second portion has lesser wall thickness than the first portion.

11. The process according to claim 1 further comprising machining
10 the semi-finished liner to provide the final shape of the cylinder liner.

12. The process according to claim 1 wherein the steel preform comprises a carbon steel.

13. The process according to claim 1 wherein the steel preform comprises an alloy steel.

14. The process according to claim 1 wherein the steel preform
15 comprises a microalloy steel.

15. The process according to claim 1 wherein the steel preform comprises a stainless steel.

16. The process according to claim 1 wherein the steel preform
20 initially placed over the mandrel is ductile, having not undergone hardening.

17. The process according to claim 1 wherein the steel preform contains no more than about 0.025% sulfur by weight.

18. The process according to claim 1 wherein the forming roller flow forms the steel perform such that the steel performs achieves a reduction in
25 wall thickness of up to 90 percent as the steel preform transforms into the semi-finished liner.

19. The process according to claim 1 wherein the steel preform is secured between a tailstock and the mandrel at an end of the steel preform, and the forming roller advances axially away from that end.

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20. The process according to claim 1 wherein the steel preform is secured against a headstock, and the forming roller advances axially toward the headstock.

21. The process according to claim 1 wherein the flow forming of the forming roller work hardens the steel preform.

22. A liner for a cylinder of an internal combustion engine, the liner being formed from steel in a flow forming operation and having a cylindrical interior surface and an exterior surface.

23. The liner according to claim 22 wherein the exterior surface has a uniform wall thickness.

24. The liner according to claim 22 wherein the exterior surface has an irregular surface.

25. The liner according to claim 24 wherein the irregular surface comprises a segment of varying outer diameters.

26. The liner according to claim 25 wherein a segment of the irregular surface is tapered.

27. The liner according to claim 25 wherein the irregular surface comprises a segment of a wave-like surface.

28. A liner for a cylinder of an internal combustion engine, the liner being flow formed from steel and having a head end and a tail end and also having a cylindrical internal surface and an external surface, so that a liner wall exists between the internal and external surfaces wherein the external surface has a segment that lies along a region of the cylinder that experiences elevated pressure from the combustion of fuel in the cylinder such that a thickness of the liner wall along the region generally correlates with a pressure gradient experienced within the region of the cylinder.

29. The liner according to claim 28 wherein the segment imparts an irregular thickness to the liner wall.

30. The liner according to claim 28 wherein the segment imparts varying outer diameters to the thickness of the liner wall.

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31. The liner according to claim 28 wherein the segment imparts a tapered thickness to the liner wall.

32. The liner according to claim 28 wherein the segment imparts a wave-like thickness to the liner wall.

5 33. The liner according to claim 28 wherein a segment of the external surface has a first portion near a head end of the semi-finished liner and a second portion near a tail end of the semi-finished liner wherein the second portion has a greater thickness of the liner wall than the first portion.

10 34. The liner according to claim 28 wherein a segment of the external surface has a first portion near a head end of the semi-finished liner and second portion near a tail end of the semi-finished liner wherein the second portion has a lesser thickness of the liner wall than the first portion.

35. The process according to claim 28 wherein the steel preform comprises a carbon steel.

15 36. The process according to claim 28 wherein the steel preform comprises an alloy steel.

37. The process according to claim 28 wherein the steel preform comprises a microalloy steel.

20 38. The process according to claim 28 wherein the steel preform comprises a stainless steel.

39. The liner according to claim 28 wherein the steel has no more than about 0.025 percent sulfur by weight.

40. The liner according to claim 28 wherein the steel is work hardened.

25 41. The liner according to claim 28 in combination with an engine block having a coolant jacket, with the segment of the external surface that is along the region that experiences elevated pressures being exposed to the coolant jacket.

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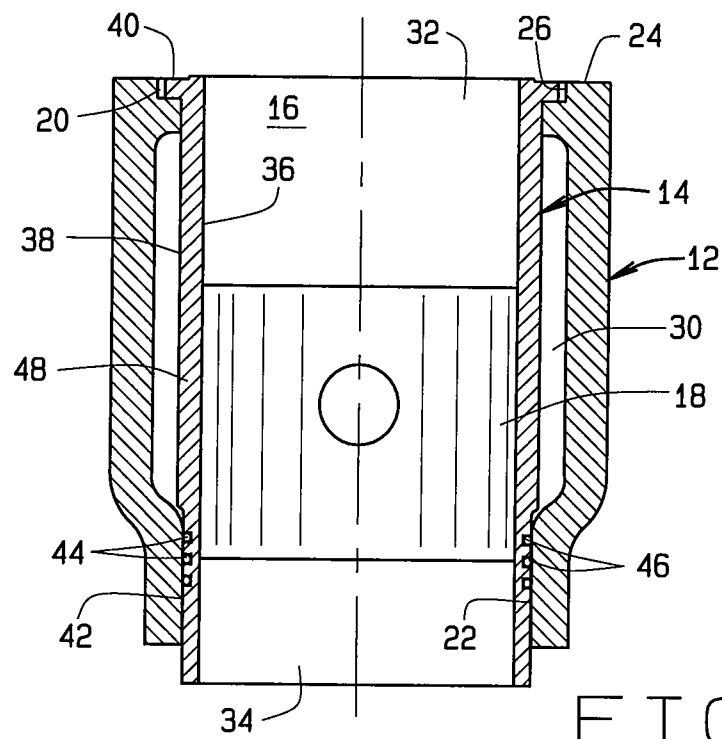


FIG. 1
PRIOR ART

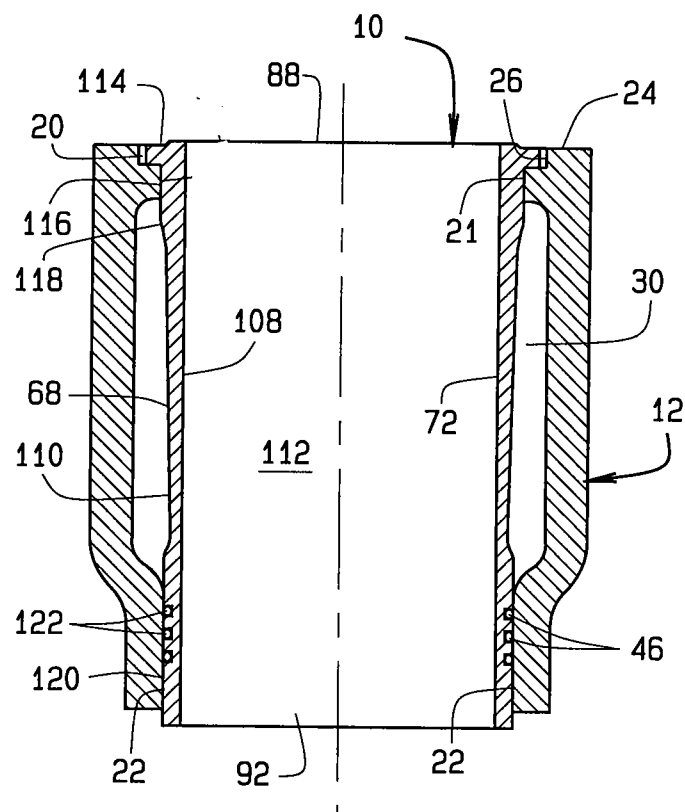
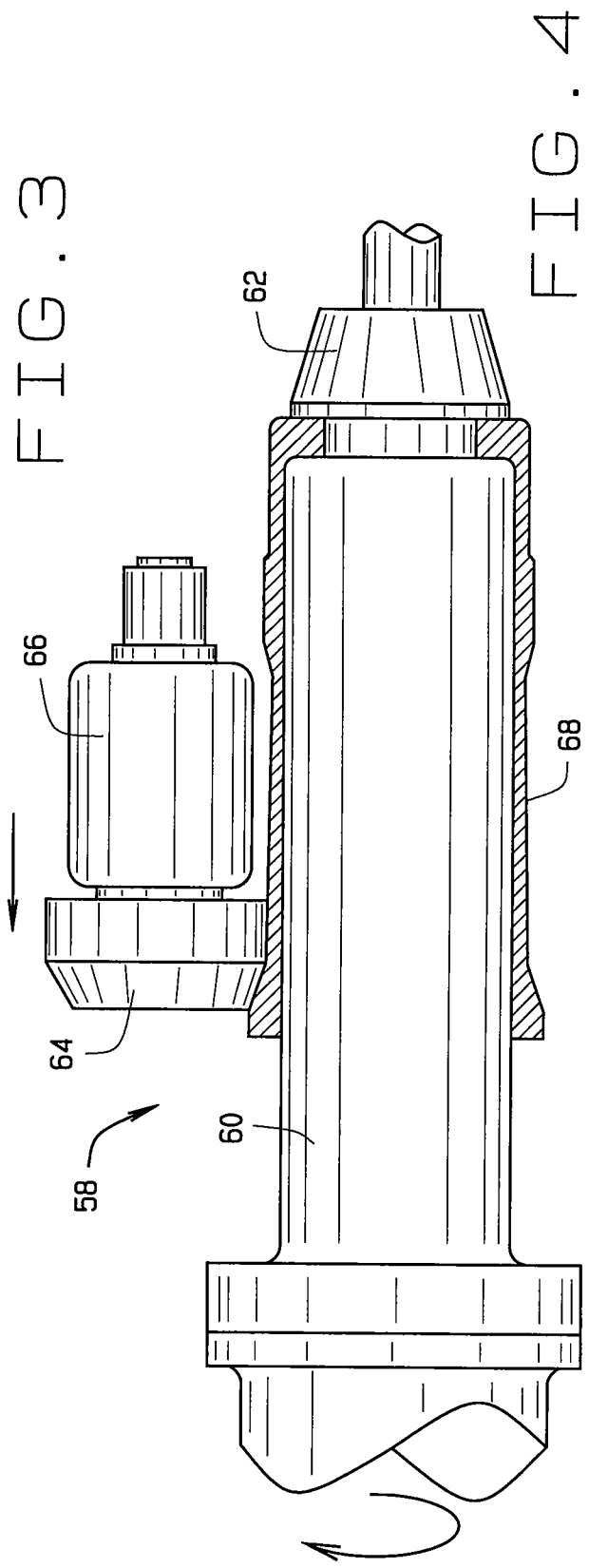
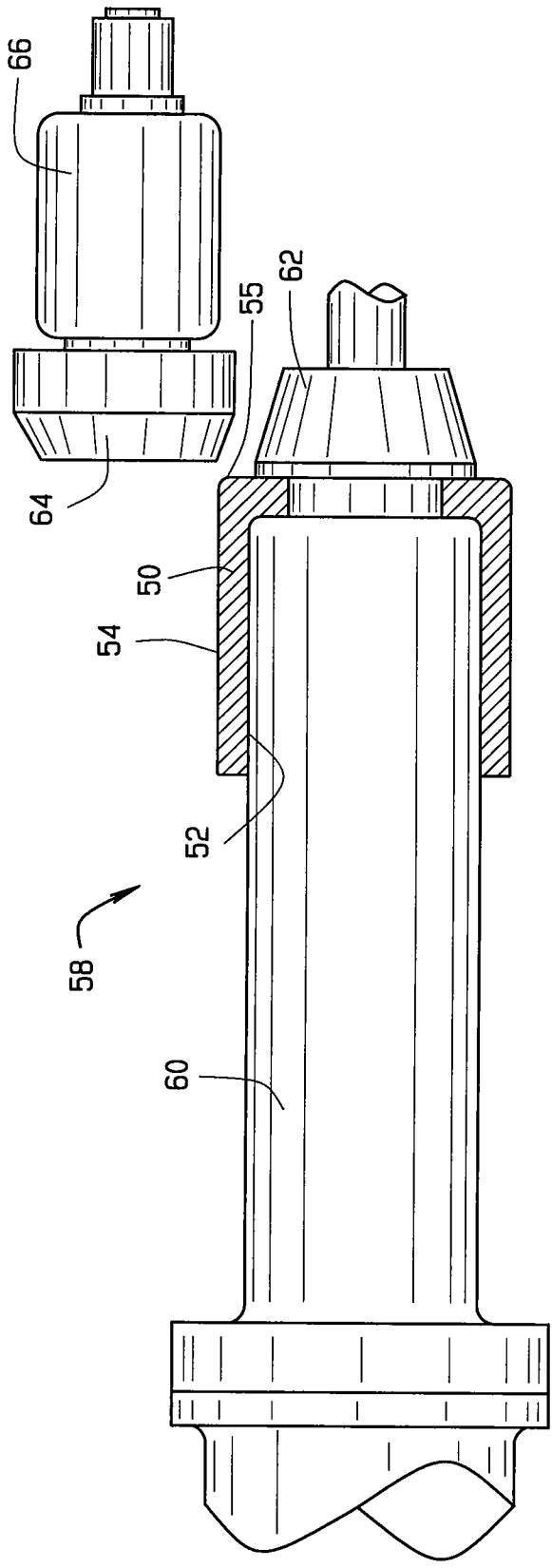


FIG. 2



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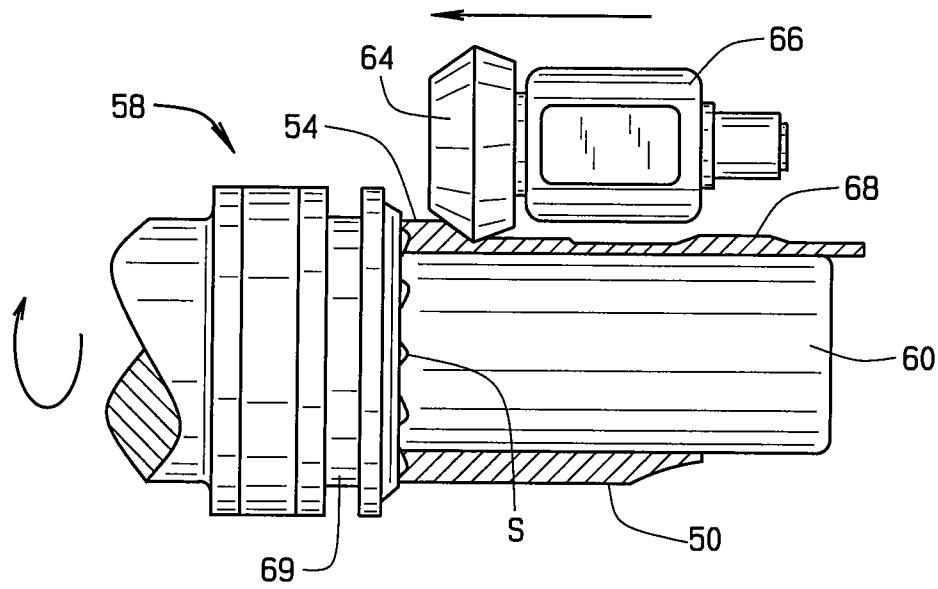


FIG. 5

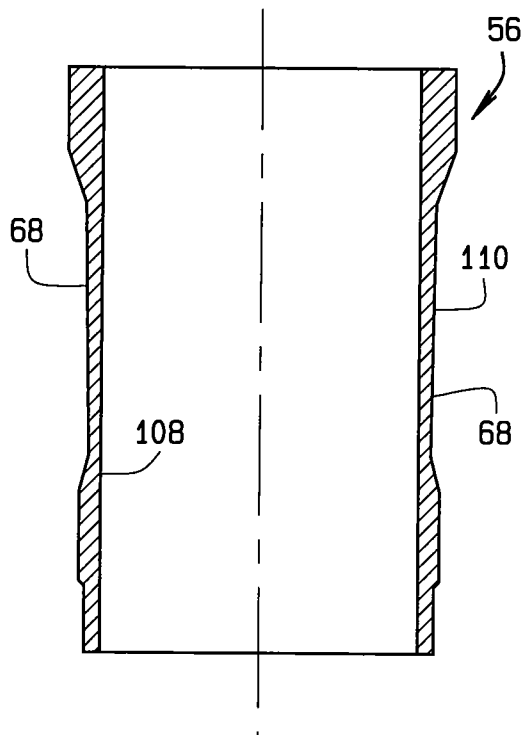


FIG. 6

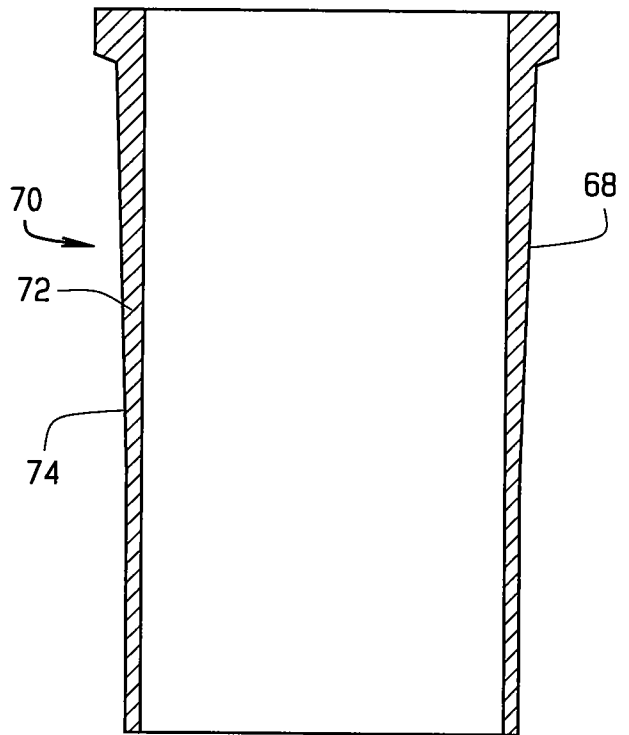


FIG. 7

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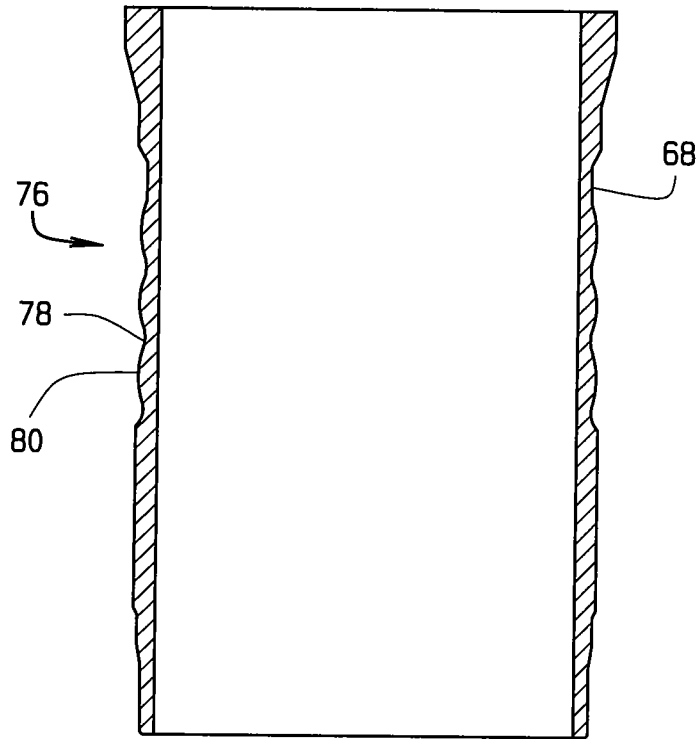


FIG. 8

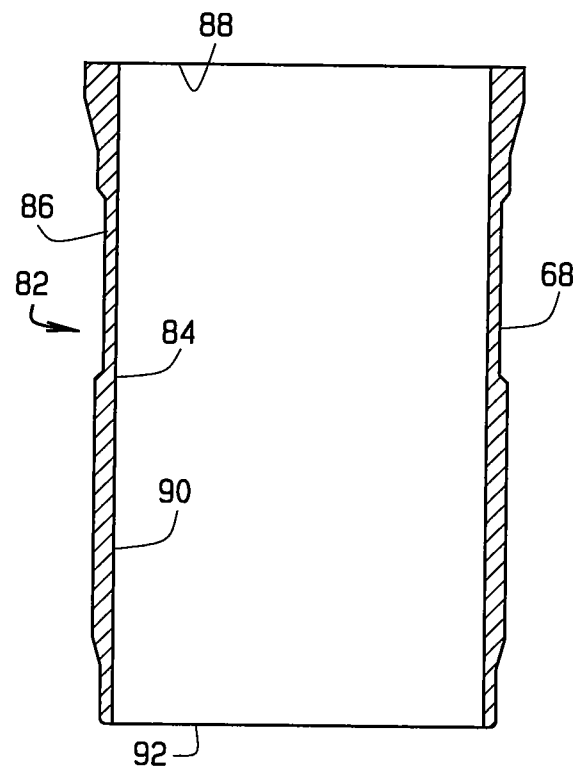


FIG. 9

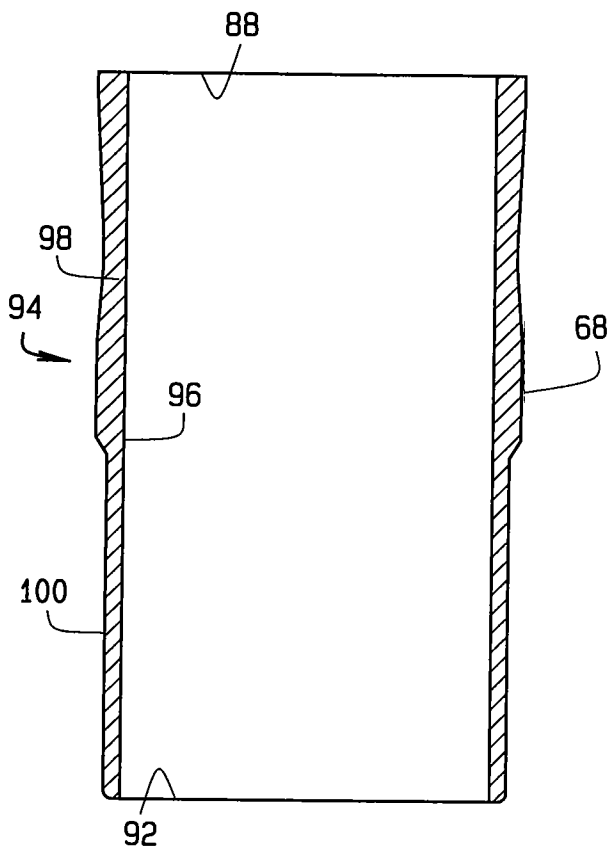


FIG. 10

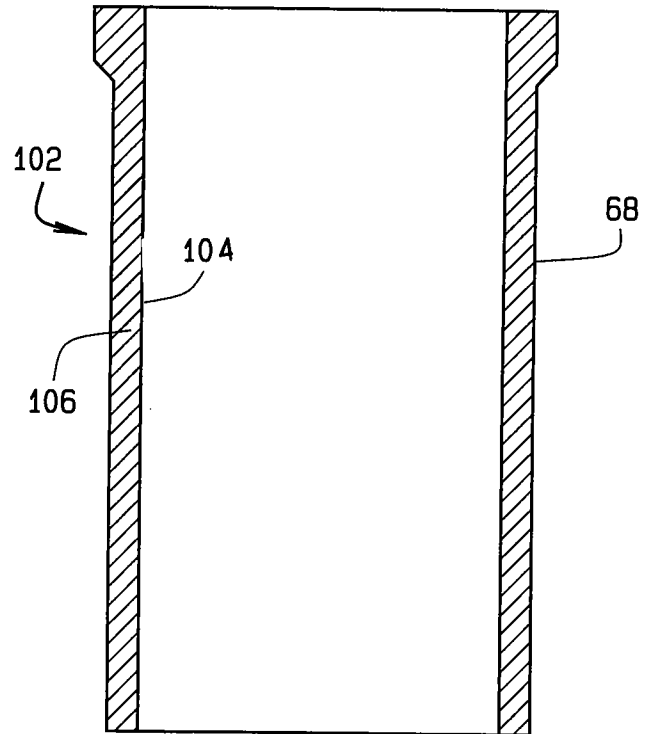


FIG. 11