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(54) **ULTRASONIC WELDING OF ANNULAR COMPONENTS**

(71) Applicant: **General Electric Company**, Schenectady, NY (US)

(72) Inventor: **Todd Jay Rockstroh**, Maineville, OH (US)

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(57) **ABSTRACT**

A method of making an annular component includes forming sheet feedstock into an annular shape disposed about a central axis; and bonding one portion of the feedstock to another portion of the feedstock using ultrasonic welding, so as to fix the annular shape.

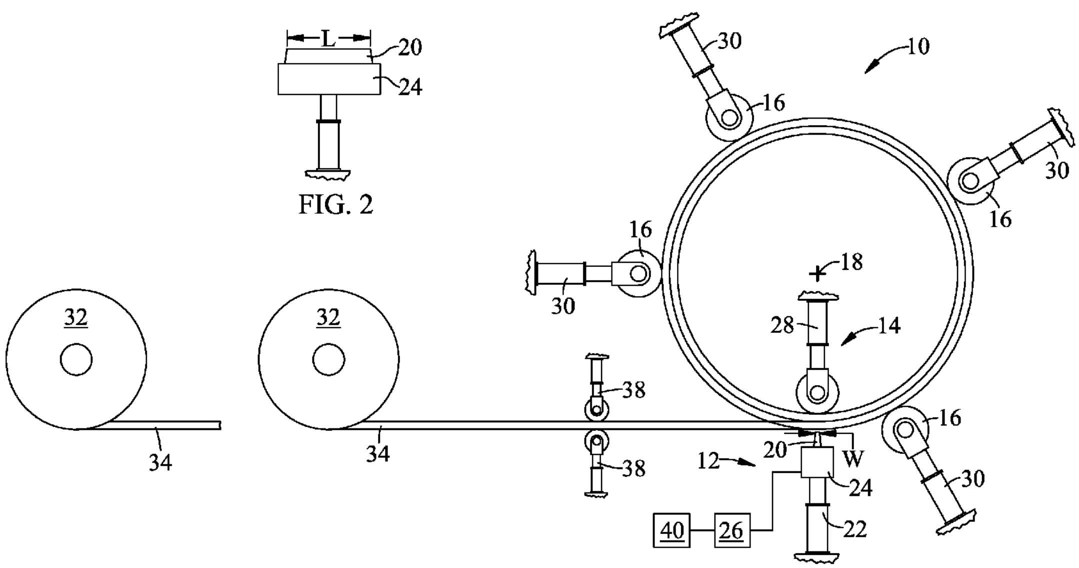

FIG. 2

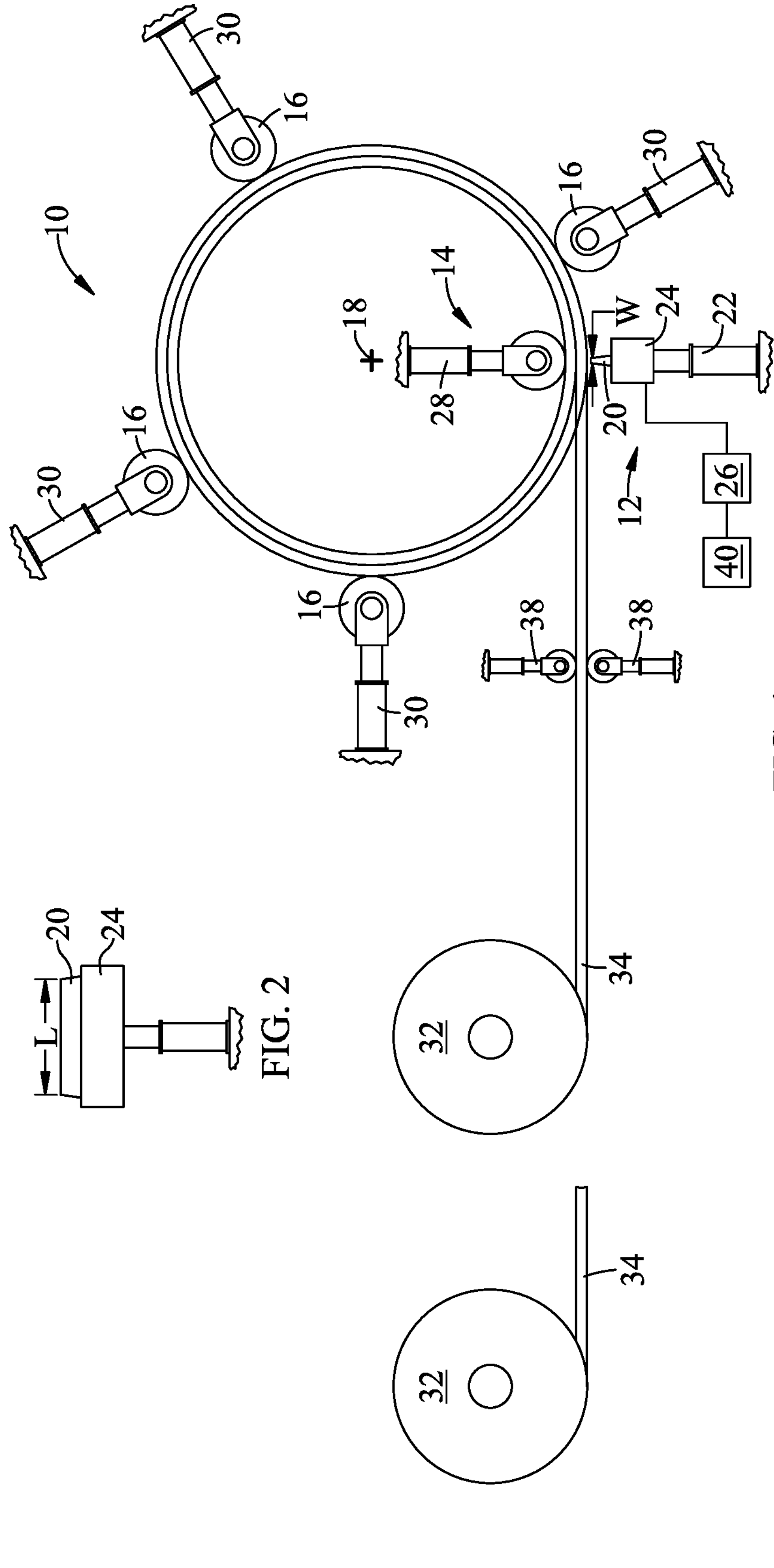
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FIG. 1

FIG. 2

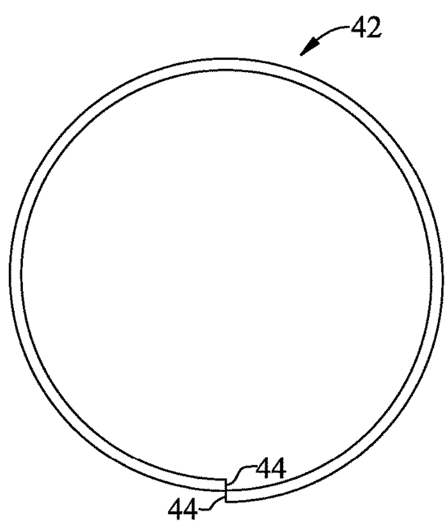

FIG. 3

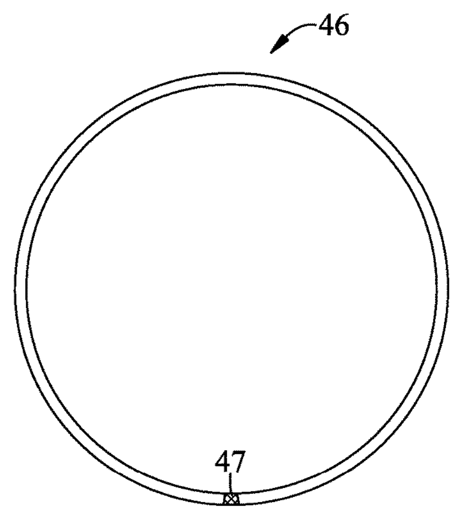

FIG. 4

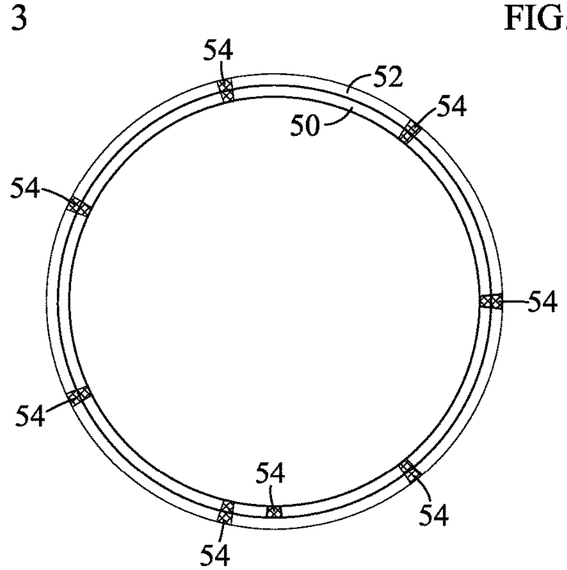

FIG. 5

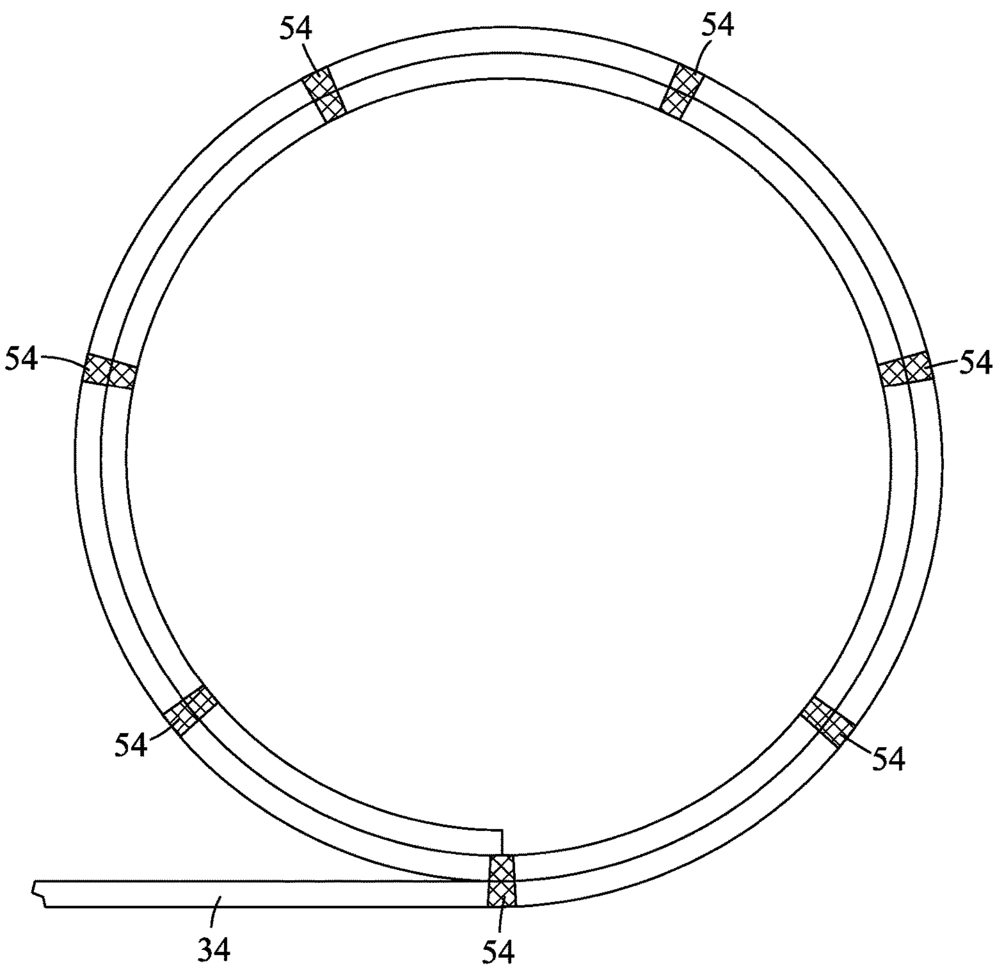

FIG. 6

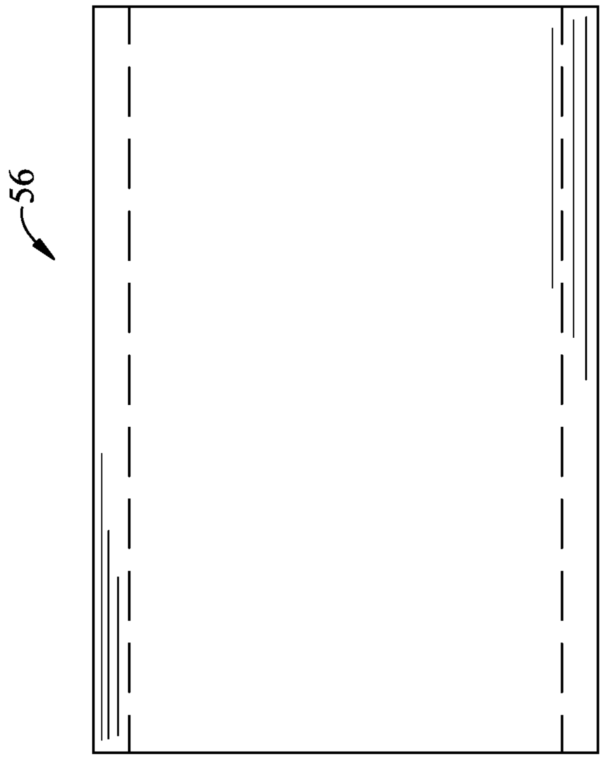

FIG. 8

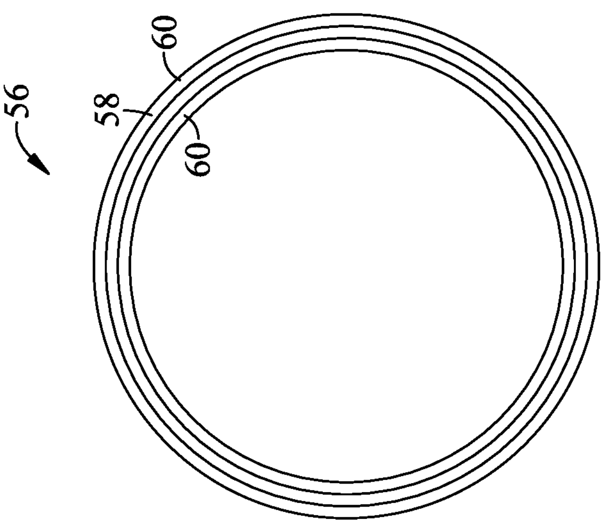

FIG. 7

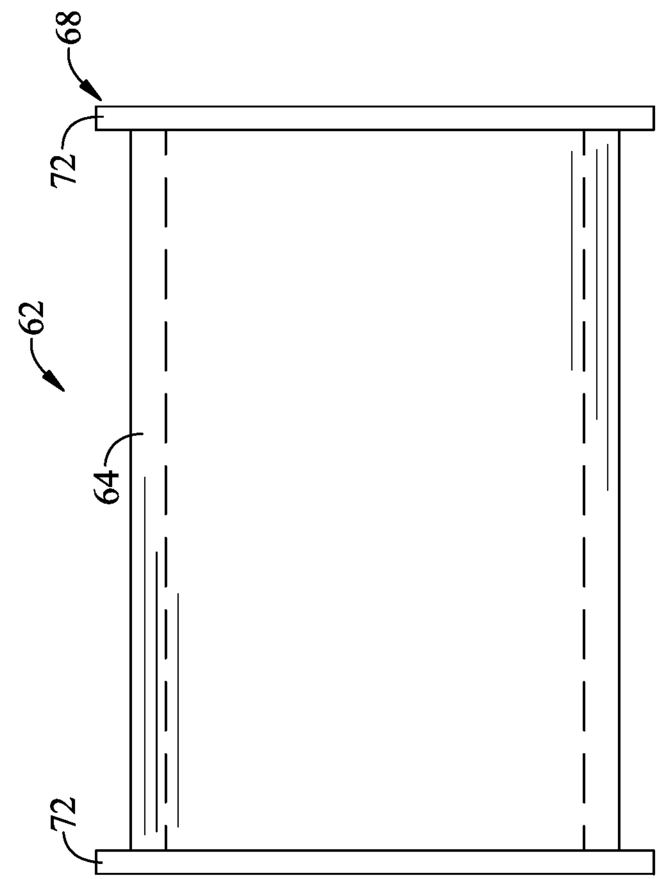

FIG. 10

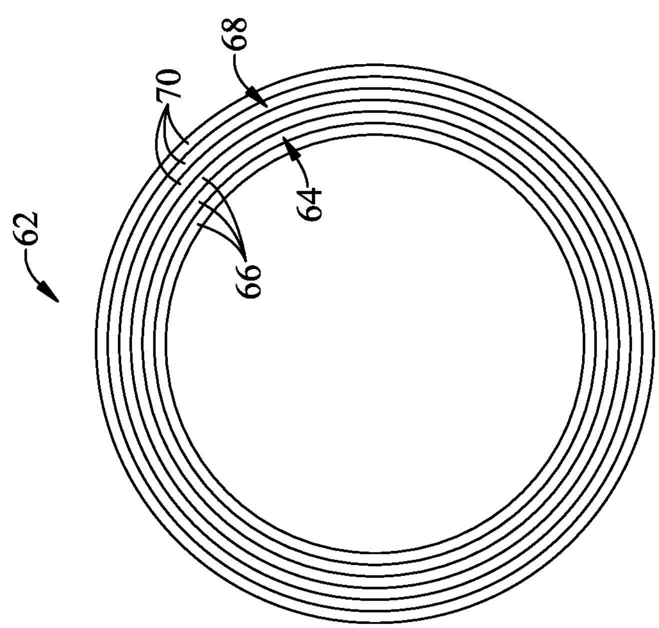

FIG. 9

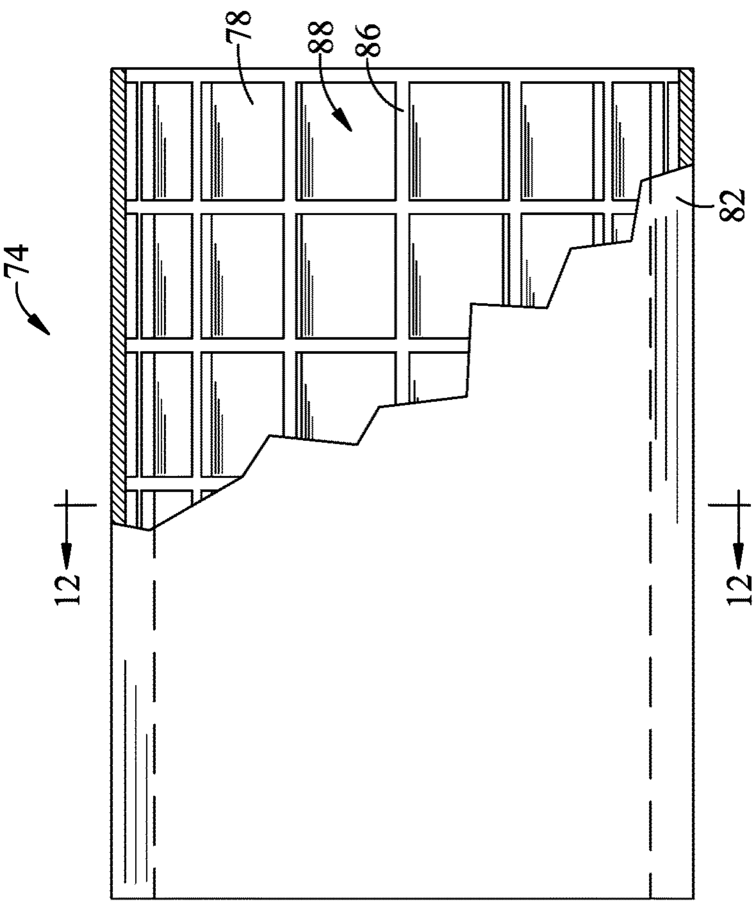

FIG. 11

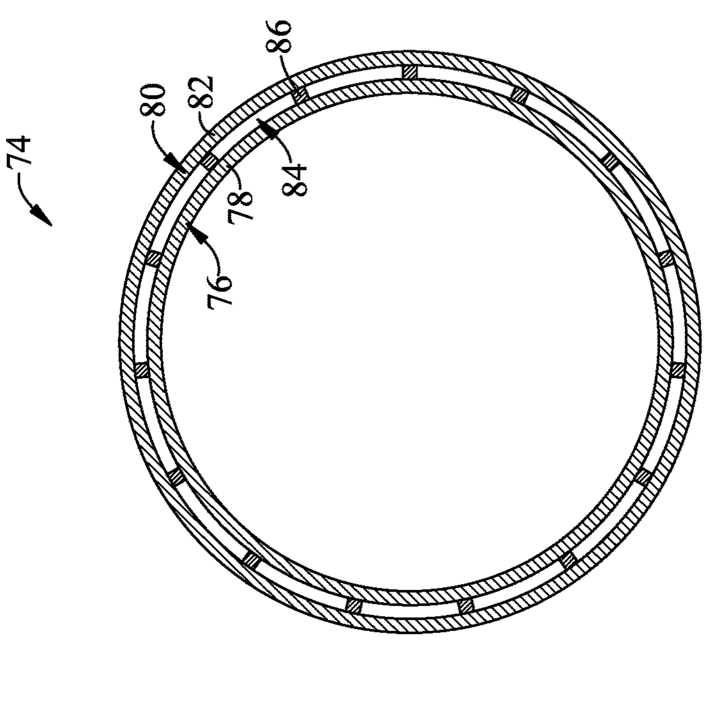

FIG. 12

ULTRASONIC WELDING OF ANNULAR COMPONENTS

BACKGROUND OF THE INVENTION

[0001] This invention relates generally to component manufacturing, and more particularly to apparatus and methods for manufacturing large shell-type structures.

[0002] Numerous products incorporate structures or components which have an annular shape in the form of a cylinder, cone, or partial cylinder. An example would be a cylindrical casing for a gas turbine engine.

[0003] Especially in the case of large-scale annular components, it can be difficult to manufacture these components in an economical manner, as they must be cast or forged to have adequate material properties. If they are built up from sub-components, conventional joining processes such as fusion welding can lower the material properties undesirably.

[0004] One alternative joining process is ultrasonic welding. This process uses an "ultrasonic horn" which is a thin blade or rib tool powered by a piezoelectric transducer and actuated at its resonant frequency to put ultrasonic energy into the workpiece. This does generate heat but it is not fusion welding; rather it is a solid-state bond.

[0005] One problem with existing ultrasonic welding processes is that they are not capable of forming curved or annular components.

BRIEF DESCRIPTION OF THE INVENTION

[0006] This problem is addressed by a method of using an ultrasonic welding process combined with a rolling or bending process to form annular structures.

[0007] According to one aspect of the technology described herein, a method of making an annular component includes: forming sheet feedstock into an annular shape disposed about a central axis; and bonding one portion of the feedstock to another portion of the feedstock using ultrasonic welding, so as to fix the annular shape.

[0008] According to another aspect of the technology described herein, a method of making an annular turbine engine component includes: forming sheet metal feedstock into an annular shape; bonding one portion of feedstock to another portion of the feedstock using ultrasonic welding; repeating the steps of forming and bonding the feedstock to create a plurality of concentric layers; and forming bonds between the layers using ultrasonic welding.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The invention may be best understood by reference to the following description taken in conjunction with the accompanying drawing figures in which:

[0010] FIG. **1** is a schematic, end view of an exemplary ultrasonic welding apparatus;

[0011] FIG. **2** is a schematic side view of an ultrasonic welding head of the apparatus shown in FIG. **1**;

[0012] FIG. **3** is a schematic end view showing a first step of a component forming process using the apparatus of FIG. **1**;

[0013] FIG. **4** is a schematic end view showing a second step of the component forming process shown in FIG. **3**;

[0014] FIG. **5** is a schematic end view showing a third step of the component forming process shown in FIG. **3**;

[0015] FIG. **6** is a schematic end view showing an alternative component forming process using the apparatus of FIG. **1**;

[0016] FIG. **7** is a schematic end view of an exemplary multi-layer structure manufactured using the apparatus of FIG. **1**;

[0017] FIG. **8** is a side elevation view of the structure shown in FIG. **7**;

[0018] FIG. **9** is a schematic end view of another exemplary multi-layer structure manufactured using the apparatus of FIG. **1**;

[0019] FIG. **10** is a side elevation view of the structure shown in FIG. **9**;

[0020] FIG. **11** is a schematic, partially-broken-away side elevation view of another exemplary multi-layer structure manufactured using the apparatus of FIG. **1**; and

[0021] FIG. **12** is a view taken along lines **12-12** of FIG. **11**.

DETAILED DESCRIPTION OF THE INVENTION

[0022] Referring to the drawings wherein identical reference numerals denote the same elements throughout the various views, FIG. **1** illustrates schematically a welding and forming apparatus **10** suitable for carrying out a combined ultrasonic welding and forming operation. Basic components of the apparatus **10** include an ultrasonic welding head **12**, a workpiece support **14**, and a plurality of forming elements **16**, all arrayed about a central axis **18**. Each of these components will be described in more detail below.

[0023] The ultrasonic welding head **12** comprises a probe or "ultrasonic horn" **20** which is configured, in accordance with known techniques, to be actuated at its resonant frequency to transfer ultrasonic energy into a workpiece that the probe **20** is contacting, resulting in workpiece heating and creation of a solid-state bond. In the example shown in FIGS. **1** and **2**, the probe **20** has a small width "W", for example about 1 mm (0.04 inches), and an overall length "L" as required to suit a particular application, for example several centimeters (inches). The length (i.e. longest dimension) of the probe **20** is oriented parallel to the central axis **18** of the apparatus **10** and appropriate actuator or adjustment device **22** may be provided to move the ultrasonic welding head **12** in the radial direction relative to the central axis **18** (i.e. towards or away from the workpiece).

[0024] The probe **20** is mechanically coupled to a driver **24** (shown schematically) configured to vibrate the probe **20** at one of its resonant frequencies. One example of a known type of driver is a piezoelectric transducer. The driver **24** may be coupled to an appropriate electrical power supply **26**.

[0025] The workpiece support **14** includes a surface positioned facing the probe **20** and configured to be pressed against a workpiece in opposition to the probe **20**, in order to provide support and prevent deflection of the workpiece. In the illustrated example, the workpiece support **14** comprises a cylindrical roller. An appropriate actuator or adjustment device **28** may be provided to move the backside pressure device in the radial direction and/or adjust the pressure applied to the workpiece.

[0026] The forming elements **16** include one or more surfaces positioned and configured to apply pressure to a workpiece causing it to form in a curved shape as it is fed into the apparatus **10**. In the illustrated example, the forming elements **16** include a plurality of cylindrical rollers arrayed in appropriate locations around the central axis **18**. An appropriate actuator or adjustment device **30** may be provided to move the forming elements **16** in the radial direction and/or adjust the pressure applied to the workpiece. Additional actuators or mechanical elements (not shown) may be provided to move the forming elements **16** through one or more forming motions (sliding, moving in an arc, etc.) in accordance with conventional practice for sheet metal bending processes.

[0027] One or more supply rolls **32** are provided in proximity to the apparatus **10**. Each supply roll **32** contains a supply of feedstock **34**, in the form of sheet material wound about a central mandrel.

[0028] The feedstock **34** may be any material which capable of being bonded using ultrasonic welding and which is also capable of being formed into a curved or annular shape without fracturing (e.g. a material which is ductile rather than brittle). An example of a suitable feedstock material is a metal alloy in sheet form. The thickness of the feedstock is limited by the depth of penetration of the ultrasonic welding process. As one example, the metal alloy sheet may be about 0.5 mm (0.010 inches) thick or less.

[0029] Optionally, the apparatus **10** may include a feed mechanism configured to pull material from the supply rolls **32** and feed it into the apparatus **10**. In the illustrated example, the feed mechanism comprises a pair of opposed feed rollers **38** which engage in clamp the feedstock **34** from opposite faces. The feed rollers **38** may be driven, for example, by one or more electric motors (not shown).

[0030] The operation of the apparatus **10** described above including the welding head **12**, workpiece support **14**, forming elements **16**, and feeding mechanism may be controlled, for example, by software running on one or more processors embodied in one or more devices such as a programmable logic controller ("PLC") or a microcomputer (shown schematically at **40**). Such processors may be coupled to various sensors and operating components, for example, through wired or wireless connections. The same processor or processors may be used to retrieve and analyze sensor data, for statistical analysis, and for feedback control.

[0031] A method of using the apparatus **10** described above to form an annular component will now be described with reference to FIGS. **1**, **3**, and **4**.

[0032] Initially, feedstock **34** in sheet form is fed from the supply rolls **32** into the apparatus **10**. In the illustrated example, the feedstock **34** is driven into the apparatus **10** by the powered feed rollers **38**.

[0033] As the feedstock **34** enters the apparatus **10**, contact with the forming elements **16** deflects the feedstock **34**, causing it to bend and form into a curve. The feeding and bending process continues until the feedstock **34** forms a complete 360° annulus, defining a generally annular shape. The annular shape may be cylindrical or it may be tapered, resulting in a conical or frustoconical shape.

[0034] Once the complete annulus is formed, the feedstock **34** may be cut off by conventional means such as a metal shear (not shown), leaving an annular workpiece **42** formed with free ends **44** (FIG. **3**).

[0035] The welding head **12** is then used to join the free ends **44** by ultrasonically welding them together, thereby fixing the annular shape. This step may be carried out while the workpiece **42** is still in the apparatus **10**, surrounded by the forming elements **16**. The joint may be, for example a butt joint or a lap joint. If a lap joint is used, a machining process may be used to remove excess material thickness. The result is a single-layer annular component **46** (FIG. **4**). An exemplary ultrasonic weld joint is shown at **47**.

[0036] The process may be repeated to create another layer on top of (e.g. radially outside of) the annular component **46**, resulting in a multi-layer annular component, seen in FIG. **5** with exemplary layers **50**, **52**. Ultrasonic welding may be used to join the first layer **50** to the second layer **52** at intervals around the component's periphery. Exemplary ultrasonic weld joints are shown at **54**. This process may be repeated as many times as necessary, with each new layer being bonded to the previous layer by an ultrasonically-welded joint to build up a desired material thickness, resulting in a finished multi-layer component.

[0037] Alternatively, the layers may be built up in a continuous process. More specifically, the feedstock **34** may be fed in continuously and built up in a spiral shape, using the welding head **12** to join the layers together at selected intervals. This process is illustrated in FIG. **6**; exemplary weld joints are shown at **54**.

[0038] Once the build-up of layers is complete, the annular component is then ready for additional processes such as finish machining, coating, inspection, etc.

[0039] The basic method described above permits multiple variations to produce diverse types of annular structures.

[0040] One option is to produce vary the structure by using different materials in different layers. For example, FIGS. **7** and **8** illustrate a generally cylindrical annular component **56** produced by the method described above and comprising a plurality of layers. Several of the layers, labeled **58** comprise a first metal alloy, and others of the layers, labeled **60** comprise a second metal alloy. Any combination of alloys is possible, for example every layer could be a unique alloy. Various combinations and alloys may be used to produce a component having desirable composite properties. For example, a component could include layers made of high-strength alloys such as nickel alloys, alternated with layers having high thermal conductivity, such as copper alloys.

[0041] It is also possible for one or more of the layers of the multi-layer annular component to be discontinuous rather than continuous. For example, the layers may include openings such as, holes, slots, or grooves. Alternatively, individual layers may be formed as a series of spaced-apart ribs in order to define internal structures and hollow spaces.

[0042] A combination of continuous and discontinuous layers, or layers of different dimensions, may be used to form structures such as flanges, ribs, etc., or to form voids or hollow spaces. For example, one or more layers may be in the form of bands or strips having a different width than the other layers.

[0043] For example, FIGS. **9** and **10** illustrate an annular multi-layer component **62** comprising an inner portion or body **64** formed of one or more layers **66** which are continuous defining a cylinder, and an outer portion **68** formed of one or more continuous layers **70** each having a width (i.e. dimension measured parallel to axis **18**) less than the layers **66**. These layers **70** extend out radially to form flanges **72**. A similar process may be used to selectively form thicker portions to be later machined into bosses, flanges, etc.

[0044] As another example, FIGS. **11** and **12** illustrate an annular multi-layer structure **74** comprising an inner wall **76**

formed of one or more layers **78** which are continuous, radially spaced-away from an outer wall **80** formed of one or more layers **82** which are continuous, and an interior structure **84** formed of one or more layers which are discontinuous and which include solid portions **86** defining internal open voids or hollow spaces **88**. Alternatively, the interior structure **84** could comprise spaced-apart continuous layers which are narrower than the inner and outer walls **76**, **80** (e.g. ribs or bands).

[0045] If a layer of a multi-layer structure includes voids, those voids may be filled using any material that can withstand the elevated temperatures of the ultrasonic welding process. For example, any opening in a metallic layer could be filled with a nonmetallic material. Nonlimiting examples of suitable nonmetallic materials having elevated temperature capability include polyetherimide resin (e.g. ULTEM) or aramid

[0046] The method described herein has several advantages over the prior art. In particular, it reduces raw material costs and tooling costs for large annular structures, compared to forgings. The use of solid-state bonding avoids material property debits normally associated with welding processes, enabling a structure closer to or equivalent to forged structure. It offers the opportunity for performance improvements in annular structures by mixing/layering alternative layers of materials. It also permits alternating structural material layers with lighter weight layers for reduced specific fuel consumption ("SFC").

[0047] The foregoing has described an apparatus and method for forming large structural components using an ultrasonic welding process. All of the features disclosed in this specification (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.

[0048] Each feature disclosed in this specification (including any accompanying claims, abstract and drawings) may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

[0049] The invention is not restricted to the details of the foregoing embodiment(s). The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

What is claimed is:

1. A method of making an annular component, comprising:

forming sheet feedstock into an annular shape disposed about a central axis; and

bonding one portion of the feedstock to another portion of the feedstock using ultrasonic welding, so as to fix the annular shape.

2. The method of claim **1** further comprising repeating the steps of forming and bonding the feedstock to create a plurality of concentric layers; and

forming bonds between the layers using ultrasonic welding.

3. The method of claim **2** wherein at least one of the layers is discontinuous and at least one of the layers is continuous.

4. The method of claim **2** wherein the layers have varying widths.

5. The method of claim **4** further comprising machining the component to define one or more features.

6. The method of claim **2** wherein at least one of the layers comprises a first metal alloy, and wherein at least one of layers comprises a second metal alloy different from the first metal alloy.

7. The method of claim **2** further comprising:

forming the feedstock into a first group of layers which are continuous; and

forming the feedstock into a second group of layers which are discontinuous or which have a different width than the first group of layers, so as to define at least one raised feature on an inner or outer surface of the annular component.

8. The method of claim **2** further comprising:

forming the feedstock into a first group of layers which are continuous;

forming the feedstock into a second group of layers which define open spaces therebetween; and

forming the feedstock into a third group of layers which are continuous, so as to define at least one interior space which is bounded by the, first, second, and third groups of layers.

9. The method of claim **8** further comprising disposing a nonmetallic filler into the interior space.

10. The method of claim **1** wherein the forming step creates an annular shape having free ends, and ultrasonic welding is used to bond the free ends together, forming a butt joint or a lap joint therebetween.

11. The method of claim **1** wherein the forming step is performed by feeding the feedstock against one or more forming elements arrayed around the central axis.

12. The method of claim **11** wherein the forming elements include a plurality of rollers.

13. The method of claim **11** wherein the ultrasonic welding is carried out while the feedstock is surrounded by the forming elements.

14. The method of claim **1** further comprising:

forming the feedstock into a continuous spiral shape so as to define a plurality of layers; and

forming bonds between the layers using ultrasonic welding.

15. The method of claim **1** wherein the annular component has a generally cylindrical shape.

16. A method of making an annular turbine engine component, comprising:

forming sheet metal feedstock into an annular shape;

bonding one portion of feedstock to another portion of the feedstock using ultrasonic welding;

repeating the steps of forming and bonding the feedstock to create a plurality of concentric layers; and

forming bonds between the layers using ultrasonic welding.

17. The method of claim **16** wherein at least one of the layers is discontinuous and at least one of the layers is continuous.

18. The method of claim **16** wherein the layers have different widths.

19. The method of claim **16** wherein at least one of the layers comprises a first metal alloy, and at least one of layers comprises a second metal alloy different from the first metal alloy.

20. The method of claim **16** further comprising:
forming the feedstock into a first group of layers which are continuous;
forming the feedstock into a second group of layers which define open spaces therebetween; and
forming the feedstock into a third group of layers which are continuous, so as to define at least one interior space bounded by the first, second, and third groups of layers.

* * * * *