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(54) **Flow forming method**

(57) A method of forming a shaped article. The method comprises providing a pre-form 40 comprising a chromium molybdenum vanadium steel alloy, heat treating the pre-form to obtain a surface hardness of between 420 and 480 according to the Vickers hardness test, and, subsequent to the heat treating step, flow forming the pre-form 40 to shape the pre-form.

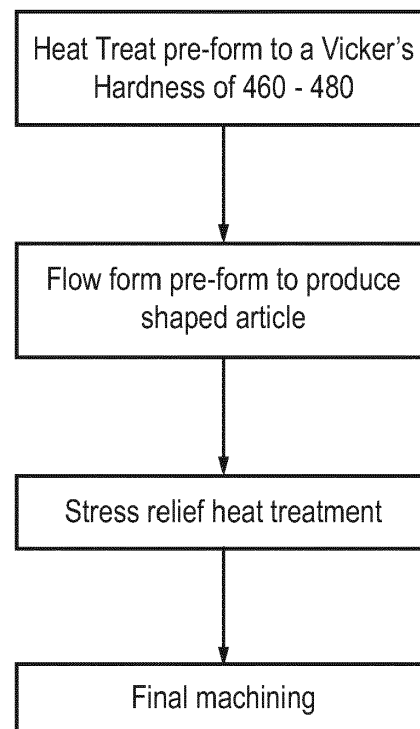


FIG. 4

Description

Field of the Invention

[0001] The present invention relates to a method of forming a shaped article. In particular, the invention relates to a method of flow forming an article, and an article formed by the method.

Background to the Invention

[0002] Flow forming is a known machining method for producing a cylindrically symmetrical shaped article from a blank using a cold rolling process. Fig. 1 shows a typical flow forming apparatus 1. The apparatus 1 comprises forming rollers 2 configured to plastically deform a workpiece in the form of an initial machined generally tubular pre-form 3 over a mandrel 4 to create a shaped article. The workpiece 3 has to be a good fit to the mandrel 4. The rollers 2 move over the workpiece 3 along a mandrel axis X, and both the mandrel 4 and rollers 2 rotate. As the mandrel 4 and rollers 2 rotate, and the rollers 2 are moved against the workpiece 3, the workpiece is plastically formed, such that the work piece 2 is elongated and the walls of the tubular workpiece 2 are thinned, to produce a shaped article.

[0003] There are two types of flow forming processes - forward flow forming and reverse flow forming. In forward flow forming, the material of the pre-form 2 flows axially in the same direction as the traversing direction of the rollers 1. Forward flow forming is described in US patent 2010083783. In reverse flow forming, a distal end 3a of the pre-form is held in position against a tailstock 5, and the material flows through the rollers 2 in the opposite direction to the traversing direction of the rollers 2. During either method, friction between the rollers 2 and the mandrel 4 must be kept to a minimum. This is generally achieved by hardening the mandrel surface, improving the mandrel surface finish, and the application of pressure insensitive lubricants to the mandrel 4. The heat built up during flow forming needs to be dissipated to ensure close tolerances. This is achieved by flooding the work piece 3 with refrigerated and filtered coolant.

[0004] Typically, the wall thickness of the flow formed sections of the tubular workpiece 3 is reduced between a minimum of 20% and a maximum of 80% during a pass, which enables modest contour changes on the outside diameter that cannot be achieved by alternative processes such as extrusion or drawing. Reducing the wall thickness consequently elongates the pre-form along the longitudinal axis. Typical elongations range between 100 and 400%.

[0005] Flow forming has been found to be suitable for manufacturing cylindrical components for aerospace applications, including undercarriage components, hydraulic cylinders, helicopter drive shafts and thrust struts, and drive shafts for gas turbine engines. Materials suitable for flow forming include Inconel and some high strength

steels such as 4130 Steel (i.e. steel having a nominal composition of 0.3% C, 0.8% Cr, 0.5% Mn, 0.2% Mo, 0.25% Si and the balance comprising Fe). However, some steels, such as steels comprising Chromium, Molybdenum and Vanadium (CMV) are difficult to flow form, since distortion of the shaped article may occur to unacceptable levels where flow forming using conventional parameters and procedures are utilised.

[0006] Drive shafts for aerospace gas turbine engines have highly demanding requirements. They must be lightweight, while being capable of delivering high torque in a relatively hot environment with a relatively small diameter, and must operate reliably for many thousands of hours. Materials such as "CMV" and "Super CMV" have been developed for use in such applications.

[0007] CMV is a martensitic chromium, molybdenum vanadium steel alloy conforming to BS 3S 132 and specification MSRR6097 (incorporated herein by reference) having the compositional range given in table 1 below.

Table 1

Element	Percentage by weight
Carbon	0.35 - 0.43
Silicon	0.1 - 0.35
Chromium	3.0 - 3.35
Molybdenum	0.8 - 1.10
Vanadium	0.15 - 0.25
Magnesium	0.4 - 0.7
Iron	Balance

[0008] CMV alloy also generally includes further trace elements. Super CMV conforms to specification MSRR6119 (incorporated herein by reference), and has a similar composition to CMV, having the same range percentage by weight of carbon, silicon, chromium, molybdenum and vanadium. However, Super CMV, is manufactured such that some further trace elements or contaminants are controlled to contain less than a specified concentration, as shown in Table 2:

Table 2

Element	Maximum percentage by weight
Phosphorous	<0.007
Silicon	<0.002
Nickel	<0.3
Arsenic	<0.002
Antimony	<0.008

[0009] Super CMV is subjected to a triple melting forging process, which may comprise either air melting or

vacuum induction melting, followed by electro slag re-melting, followed by vacuum arc re-melting which helps control the trace elements to the levels shown in Table 2. The billet may then subjected to a tempering process at a temperature of approximately 560 to 580 °C to obtain an ultimate tensile strength of between 1470 MPa to 1670 MPa, compared to a typical tensile strength of CMV of between 1240 MPa and 1390 MPa..

[0010] The present invention describes a method of forming a shaped article which seeks to overcome some or all of the above problems.

Summary of the Invention

[0011] According to a first aspect of the present invention, there is provided a method of forming a shaped article, the method comprising:

providing a pre-form comprising a steel alloy comprising chromium, molybdenum and vanadium;
heat treating the pre-form to obtain a surface hardness of between 420 and 480 according to the Vickers hardness test; and
subsequent to the heat treating step, flow forming the pre-form to form a shaped article.

[0012] It has been found that, by subjecting the pre-form to a heat treatment step to harden the pre-form prior to flow forming, the final shaped article is distorted to a lesser degree compared to conventional flow forming procedures, in which the final shaped article is heat treated after the flow forming step. It has been further found that the heat treatment step must be performed to obtain a hardness range which is considerably narrower than for other materials. Such a hardness range is counterintuitive, since flow forming is normally carried out a lower hardness, and within a wider range. Accordingly, the invention provides a method of forming a shaped article made of a chrome vanadium molybdenum alloy which results in a shaped article relatively free of distortions.

[0013] The step of heat treating the pre-form may be carried out to obtain a surface hardness of between 450 and 480, and preferably may be carried out to obtain a surface hardness of between 460 and 480 according to the Vickers hardness test.

[0014] The step of heat treating the pre-form prior to the flow forming step may comprise one or both of a hardening process to increase the hardness of the pre-form, and a tempering process to reduce the hardness of the pre-form. The step of hearing treating the pre-form prior to the flow forming step may comprise hardening the pre-form followed by tempering the pre-form.

[0015] The hardening process may comprise heating the pre-form to a temperature of between approximately 935 and 945 °C followed by quenching, which may comprise oil quenching to rapidly reduce the temperature of the pre-form. The hardening process gives desired properties of the material. By carrying out the hardening proc-

ess prior to the flow forming step, deformation of the material during flow forming is reduced or substantially prevented.

[0016] The tempering process may comprise one or more tempering cycles, each tempering cycle comprising heating the pre-form to a dwell temperature of between 500 and 600 °C, and may comprise heating the pre-form to a dwell temperature between 560 and 580 °C. Each tempering cycle may comprise maintaining the pre-form at a dwell temperature of approximately 575°C for approximately 2 to 6 hours, and preferably 2.5 hours. The tempering process may comprise two tempering cycles. By tempering the pre-form prior to the flow forming process, the hardness can be reduced, thereby preventing excessive "spring off" during the flow forming step. It has been found that spring off occurs to an unacceptable extent where the hardness exceeds 480 Hv.

[0017] The method may comprise a stress relief heat treatment step subsequent to the flow forming step, the stress relief heat treatment step comprising heating the shaped article to a stress relief temperature of between 500° C and 575 ° C for a duration of between 5 and 16 hours. For example, a heat treatment step at 575° C may take 5 hours, while a heat treatment step at 500° C may take 16 hours.

[0018] According to a second aspect of the present invention there is provided a shaped article formed according to the method of the first aspect of the invention.

[0019] The shaped article may comprise a shaft for a gas turbine engine Alternatively, the shaped article may comprise a seal or may comprise a bushing.

Brief Description of the Drawings

[0020]

Fig. 1 shows a flow forming apparatus

Fig. 2 shows a gas turbine engine;

Figs. 3a and 3b respectively show a pre-form and a shaped article comprising a shaft of the gas turbine engineer of Fig. 2, shaped in accordance with the method of the present invention; and

Fig. 4 is a flow chart illustrating a method of forming a shaped article in accordance with the present invention.

Detailed Description

[0021] With reference to Figure 2 a high-bypass gas turbine engine is indicated at 10. The engine 10 comprises, in axial flow series, an air intake duct 11, an intake fan 12, a bypass duct 13, an intermediate pressure compressor 14, a high pressure compressor 16, a combustor 18, a high pressure turbine 20, an intermediate pressure turbine 22, a low pressure turbine 24 and an exhaust

nozzle 25. The fan 12, compressors 14, 16 and turbines 20, 22, 24 all rotate about the major axis of the gas turbine engine 10 and so define the axial direction of gas turbine engine.

[0022] Air is drawn through the air intake duct 11 by the intake fan 12 where it is accelerated. A significant portion of the airflow is discharged through the bypass duct 13 generating a corresponding portion of the engine 10 thrust. The remainder is drawn through the intermediate pressure compressor 14 into what is termed the core of the engine 10 where the air is compressed. A further stage of compression takes place in the high pressure compressor 16 before the air is mixed with fuel and burned in the combustor 18. The resulting hot working fluid is discharged through the high pressure turbine 20, the intermediate pressure turbine 22 and the low pressure turbine 24 in series where work is extracted from the working fluid. The work extracted drives the intake fan 12, the intermediate pressure compressor 14 and the high pressure compressor 16 via low pressure, intermediate pressure and high pressure shafts 26, 28, 30 respectively. Further shafts may also be provided, such as an angle drive (not shown). The working fluid, which has reduced in pressure and temperature, is then expelled through the exhaust nozzle 25 and generates the remaining portion of the engine 10 thrust. One or more of the shafts 26, 28, 30 are formed by a flow forming method in accordance with the present invention.

[0023] Figs. 3a and 3b show the low pressure shaft 30 prior to and subsequent to a flow forming process respectively. The flow forming process is outlined in Fig. 4.

[0024] Prior to the forming process, the low pressure shaft 30 is provided in the form of a machined pre-form 40 comprising "Super CMV" alloy having the compositional range described in tables 1 and 2 above. The Super CMV pre-form 40 is manufactured by a triple melting forging process, which may comprise either air melting (AM) or vacuum induction melting (VIM), followed by electro slag re-melting (ESM or EFM), followed by vacuum arc re-melting (VAM) which helps control the trace elements to the levels shown in Table 2 above. The pre-form may be supplied as a forged solid billet or a back extruded forging. Other feed stocks may be appropriate, such as extruded section, solid forging, radial hollow forging. The pre-form 40 comprises a generally hollow cup shaped blank, having an open distal end 42, a closed proximal end 44 and a flange 46 where forward flow forming is employed. Where reverse flow forming is to be employed, the pre-form comprises a tubular shaped blank having open proximal and distal ends. The pre-form 40 may comprise a foreshortened version of the final shaped article. As there is a geometrical relationship between the pre-form and final part then tight control over dimensions and hardness of the pre-form will reflect tolerances in the final part. Tolerances on the diameters of a pre-form are typically just as good as the final part.

[0025] In a first process step, the pre-form 40 is subjected to a two stage heat treatment step. The first stage

of the heat treatment step comprises a hardening process to increase the hardness of the pre-form 40. The hardening process comprises heating the preform to a temperature of between approximately 935 and 945 °C followed by oil quenching to rapidly reduce the temperature of the pre-form 40. This hardening step provides a martensitic transformation. Subsequent to the hardening step, the pre-form 40 typically has a hardness of more than 500 Hv, and in some cases, as much as 700 Hv, as determined by the Vickers hardness test. However, the pre-form is still relatively brittle, and requires tempering in order to reduce this brittleness. Furthermore, it has been found that flow forming a Super CMV pre-form having a hardness significantly greater than 480 HV results in excessive "spring off" as elastic energy is released after material has passed through the rollers. Spring off is encountered in flow forming of CMV having a hardness of as little as 420 Hv - however, it has been found that spring off is manageable at this level. This spring off effect results in variations in internal diameter of the flow formed part which may be beyond acceptable limits were the initially hardened pre-form 40 to be flow formed. Consequently, it has been found that the hardness of the pre-form 40 must be reduced prior to flow forming.

[0026] In a second stage of the heat treatment step therefore, the Super CMV pre-form 40 is subjected to a tempering step comprising at least one tempering cycle. In each tempering cycle, the pre-form is heated to a heat treatment temperature of between 500 °C and 600 °C, and preferably approximately between 560 and 580 °C, and is held at this temperature for a duration of approximately 2 to 3 hours in a suitable furnace, in an oxygen free environment, and preferably in a vacuum. Subsequent to each heat treatment cycle, the pre-form 40 is removed from the furnace and allowed to cool. After each tempering cycle, the hardness of the pre-form is reduced. A Vickers hardness test is then performed after each tempering cycle to determine the surface hardness of the pre-form 40. The hardness test is carried out on a surface of the pre-form, but the hardness of the pre-form following the hardening and tempering cycles has been found to be generally consistent throughout. The tempering cycle is then repeated as many times as it necessary to obtain a hardness of between 420 and 480 Hv, and in some cases, for example for the component 30, to a hardness of between 460 and 480 Hv. As mentioned above, pre-forms having a higher hardness are subject to excessive spring off. On the other hand, a hardness of at least 420 is required prior to the flow forming process, since areas of the pre-form that are not subject to flow forming, and will not benefit from work hardening during the flow forming process, will typically reduce in hardness because of the heat treatments applied to the flow formed article after flow forming has taken place. In some cases, a hardness greater than 420 (such as approximately 460 Hv) is required - however, a hardness greater than 480 Hv has been found to be unacceptable, due to excessive spring off. Once this surface hardness range is achieved, the

heat treatment step is considered complete. Further machining may then be performed to obtain a required pre-form geometry.

[0027] In a second process step, the pre-form is then flow formed on a flow forming apparatus such as the apparatus 1 shown in Fig. 1. The flow forming process may comprise either forward or reverse flow forming. In the described embodiment, a forward flow forming apparatus 1 is used, having a headstock 6 for holding the proximal end 42 of the preform 40 in place via the flange 46. The apparatus 1 comprises three rollers 2, though in some cases, two or four or more rollers could be employed.

[0028] In the flow forming step, the pre-form 40 is first placed over the mandrel 4. The rollers 2 are then positioned at a required position relative to the mandrel 4 and pre-form 40. In the example shown, a clearance of approximately 0.1 mm is provided between the preform 40 and the mandrel 4, with the rollers 2 in contact with the pre-form 40. The rollers 2 and mandrel 4 are then rotated, and moved axially along the mandrel 4 to deform the pre-form to form the shaped article 40 shown in Fig. 3b. During forming, a liquid coolant is supplied to the pre-form 40. Process parameters such as rotation rates, roller axial movement rates and clearances will be dependent on the requirements for each individual component, as would be readily understood by the skilled person. A reduction in thickness of the pre-form of between 20% and 80% may be achieved with a corresponding increase in length, such that, for example, a 10mm thick preform may be reduced to a 2mm to 8mm thick shaped article. Typical elongations range between 100 and 400%. Generally, only a single flow forming pass is required. However, several passes may be made in some cases.

[0029] During the flow forming step, only part of the pre-form 40 is flow formed. The flow formed part is work hardened, resulting in a change in surface hardness. However, in other areas of the part that are not flow formed, such as the flanges 42, no work hardening is done by the flow forming process. However, it has been found that the typical wall thickness following the flow forming process is too thin to allow hardening heat treatment subsequent to the flow forming process without causing unacceptable distortion. Consequently, the pre-form must have the required hardness prior to the flow forming process. The hardness produced by the pre-heating step prior to the flow forming step therefore provides a shaped article having the required surface hardness, while also permitting flow forming to take place.

[0030] As well as causing work hardening, the flow forming step may cause residual stress in the shaped article. This may be undesirable in the final part, and so the shaped article may be subjected to an optional stress relief heat treatment step subsequent to the flow forming step. The stress relief heat treatment step comprising heating the shaped article to a stress relief temperature of between 500° C and 575 ° C for a duration of approximately 5 hours. This stress relief heat treatment is made at a temperature below the temperature required for

hardening of CMV alloy, and so the shaped article is not deformed to a significant extent.

[0031] Once the stress relief heat treatment is completed, the shaped article may be further machined to provide a desired surface finish, and to form surface features not provided by the flow forming process.

[0032] While the invention has been described in conjunction with the exemplary embodiments described above, many equivalent modifications and variations will be apparent to those skilled in the art when given this disclosure. Accordingly, the exemplary embodiments of the invention set forth above are considered to be illustrative and not limiting. Various changes to the described embodiments may be made without departing from the spirit and scope of the invention.

[0033] For example, the process may be applied to articles other than shafts for gas turbine engines. Suitable examples include stubshafts, drive shafts, seals and bushes for gas turbine engines. Particular examples of suitable drive shafts of gas turbine engines include low pressure fan shafts and intermediate pressure turbine shafts in three shaft engines, and low pressure shafts in two shaft engines. ,

Claims

1. A method of forming a shaped article, the method comprising:

providing a pre-form comprising a steel alloy comprising chromium, molybdenum and vanadium;

heat treating the pre-form to obtain a surface hardness of between 420 and 480 according to the Vickers hardness test; and

subsequent to the heat treating step, flow forming the pre-form to form a shaped article.

2. A method according to claim 1, wherein the step of heat treating the pre-form is carried out to obtain a surface hardness of between 450 and 480 according to the Vickers hardness test.

3. A method according to claim 2, wherein the step of heat treating the pre-form is carried out to obtain a surface hardness of between 460 and 480 according to the Vickers hardness test

4. A method according to any of the preceding claims, wherein the step of heat treating the pre-form to obtain a surface hardness of between 420 and 480 according to the Vickers hardness test may comprise one or both of a hardening process to increase the hardness of the pre-form, and a tempering process to reduce the hardness of the pre-form.

5. A method according to claim 4, wherein the step of

heat treating the pre-form comprises hardening the pre-form followed by tempering the pre-form.

6. A method according to claim 4 or claim 5, wherein the hardening process comprises heating the pre-form to a temperature of between approximately 935 and 945 °C followed by quenching. 5
7. A method according to any of claims 4 to 6, wherein the tempering process comprises one or more tempering cycles, each tempering cycle comprising heating the pre-form to a dwell temperature of between 500 and 600 °C. 10
8. A method according to claim 8, wherein the dwell temperature is between 560 and 580 °C. 15
9. A method according to claim 7 or claim 8, wherein each tempering cycle comprises maintaining the pre-form at the dwell temperature for approximately 2.5 hours. 20
10. A method according to any of the preceding claims, wherein the method comprises a stress relief heat treatment step subsequent to the flow forming step. 25
11. A method according to claim 10, wherein the stress relief heat treatment step comprises heating the shaped article to a stress relief temperature. 30
12. A method according to claim 11, wherein the stress relief temperature is between 500° C and 575 ° C.
13. A method according to claim 11 or claim 12, wherein the stress relief heat treatment step comprises heating the shaped article to the stress relief temperature for a duration of approximately 5 hours. 35
14. A method according to any of the preceding claims, wherein the steel alloy comprises, in weight percent, 0.35 to 0.43% carbon, 0.1 to 0.35% Silicon, 3.0 to 3.5% chromium, 0.8 to 1.1 % molybdenum, 0.15 to 0.25% vanadium, and 0.4 to 0.7% magnesium, the balance comprising iron. 40
15. A method according to claim 14, wherein the steel alloy comprises, in weight percent, less than 0.007% phosphorus, less than 0.002% sulphur, less than 0.3% nickel, less than 0.002 arsenic, and less than 0.008% antimony. 45

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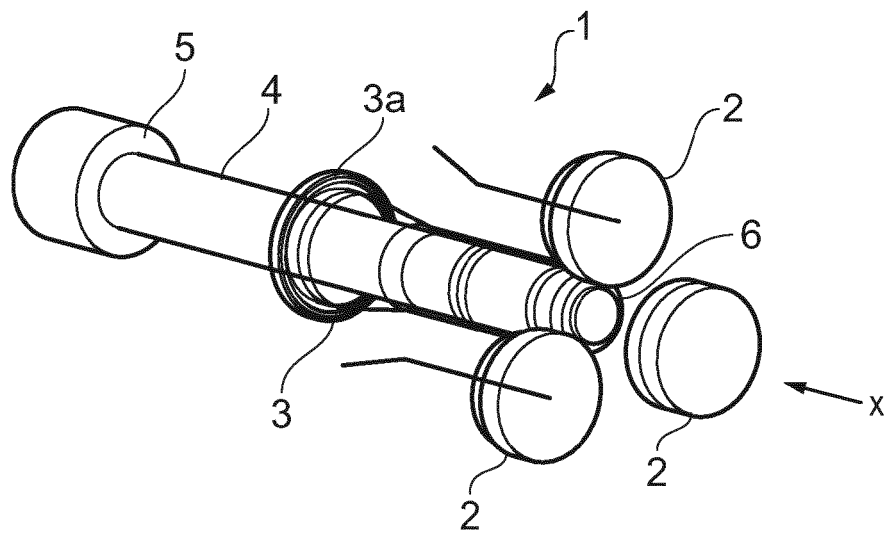


FIG. 1

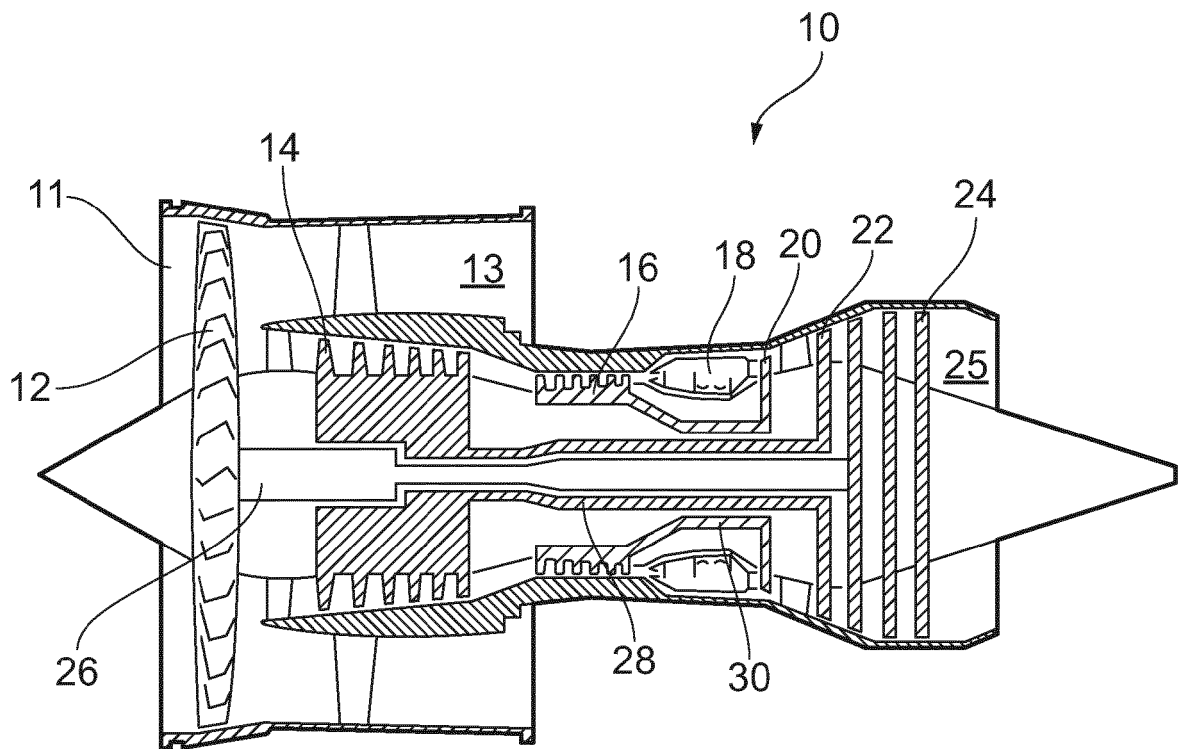


FIG. 2

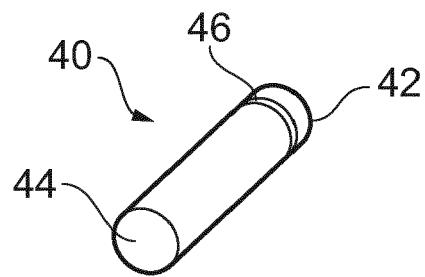


FIG. 3a

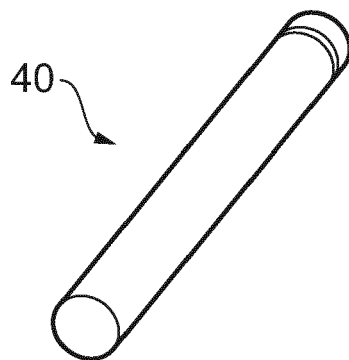


FIG. 3b

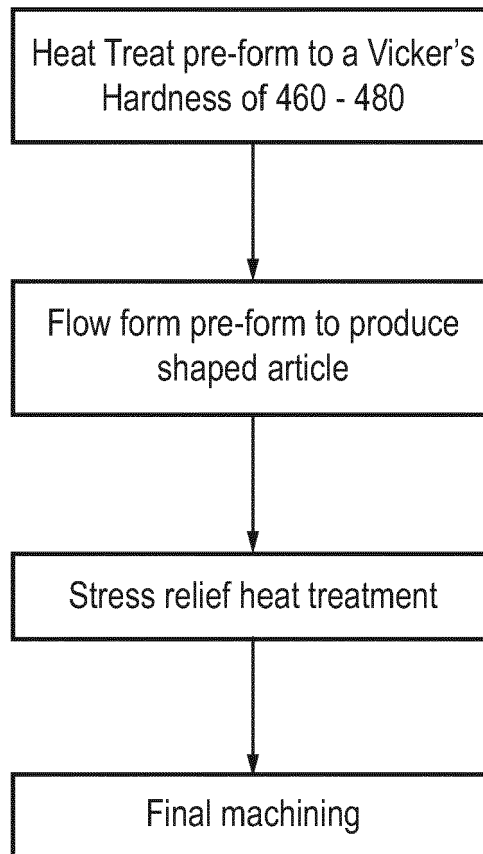


FIG. 4

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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