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(54) CREEP FORMING A WORK PIECE

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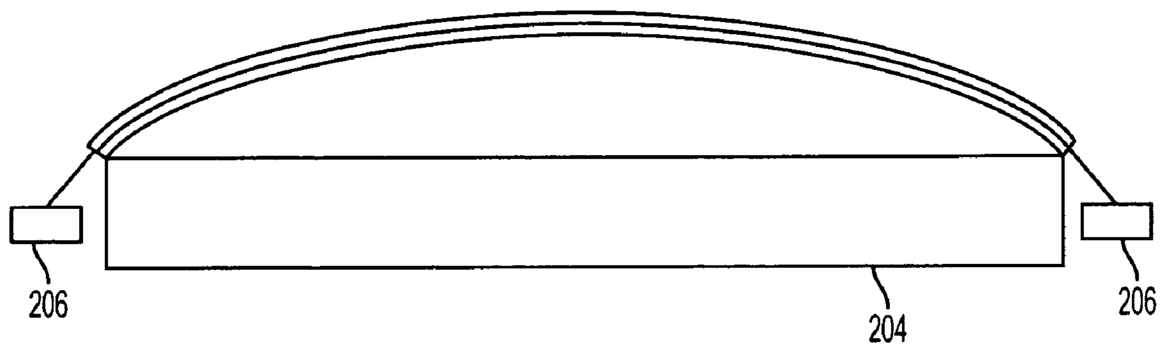
(57) **ABSTRACT**

A method of forming a work piece using a die and a load is provided. The method comprises placing the work piece on a die having a predetermined contour and applying a load on the work piece. The work piece, the die and the load are then heated to an annealing temperature of the work piece such that the work piece, the die and the load are iso-thermal. The method also includes creep forming the work piece such that the work piece develops the predetermined contour during the annealing operation. The work piece, the die and the load are then slow cooled such that the work piece, the die and the load are iso-thermal.



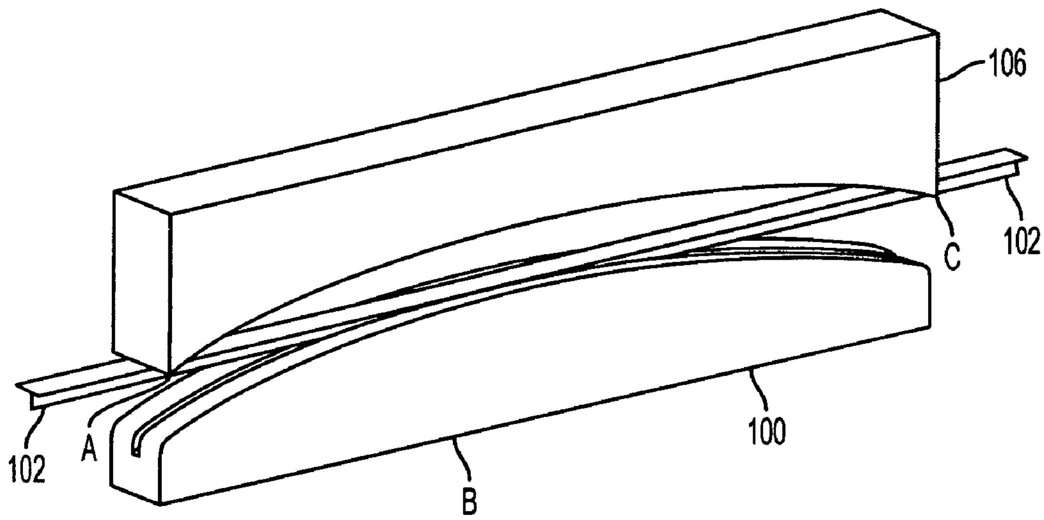


FIG. 1A
PRIOR ART

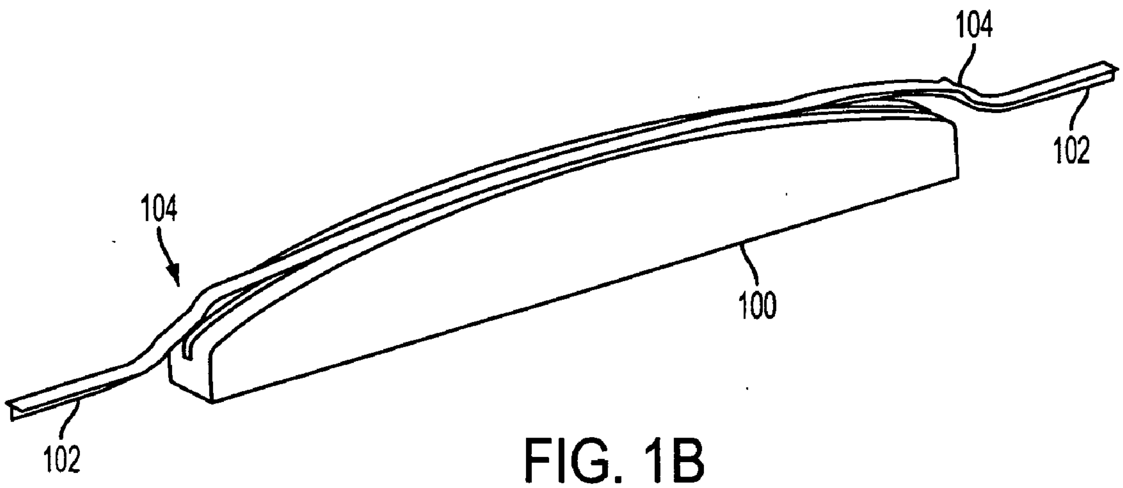


FIG. 1B
PRIOR ART

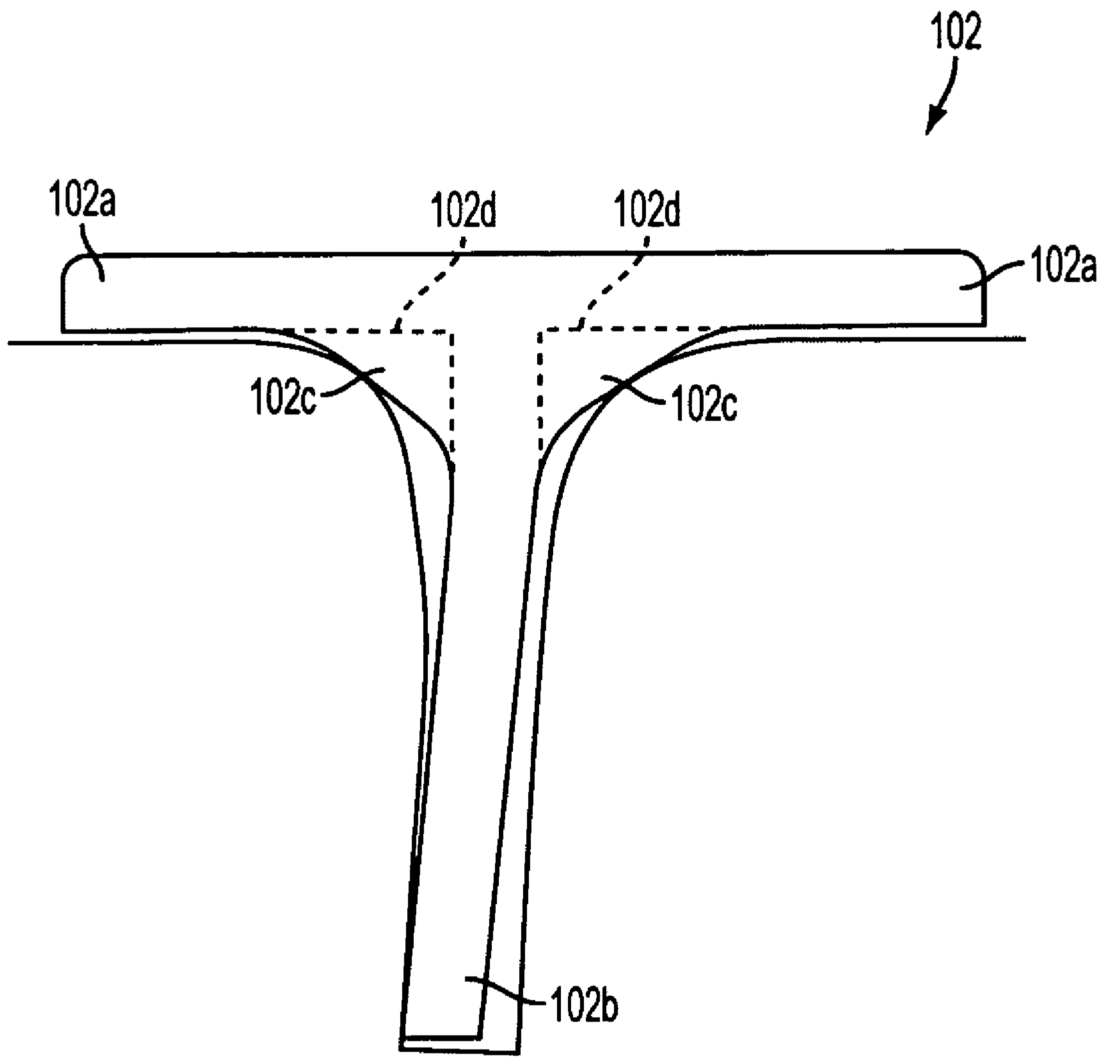


FIG. 1C
PRIOR ART

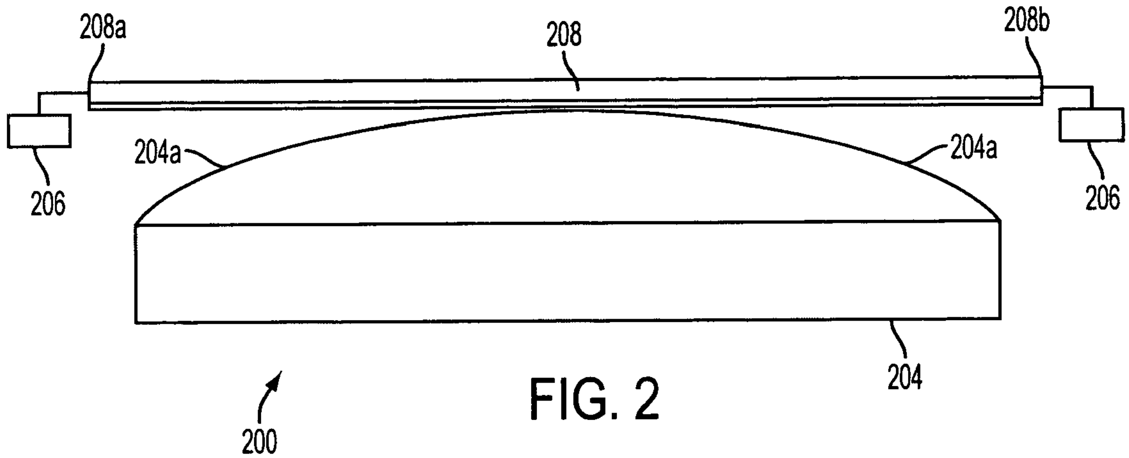


FIG. 2

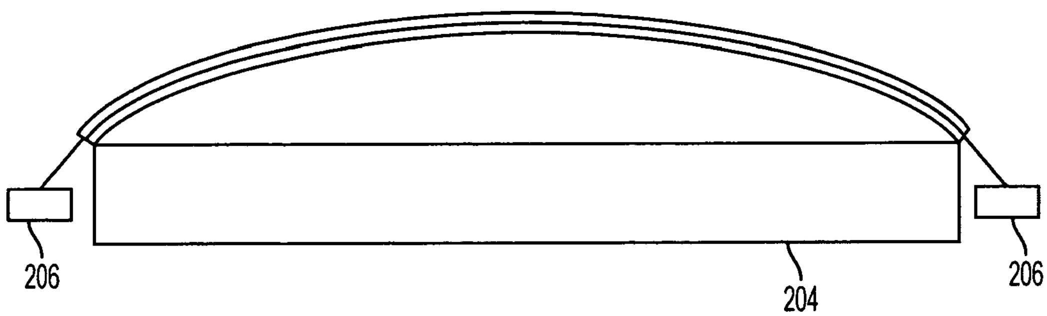


FIG. 3

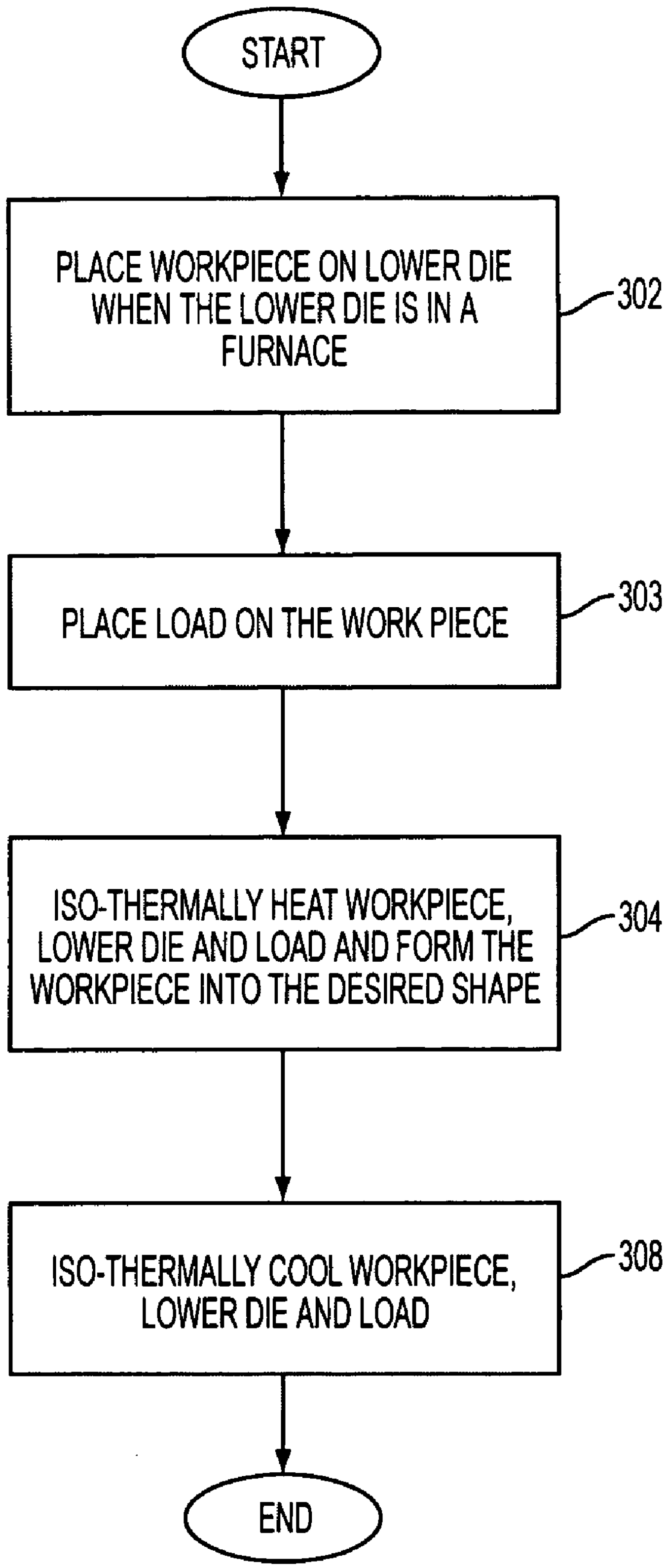

START
PLACE WORKPIECE ON LOWER DIE WHEN THE LOWER DIE IS IN A FURNACE
302
PLACE LOAD ON THE WORK PIECE
303
ISO-THERMALLY HEAT WORKPIECE, LOWER DIE AND LOAD AND FORM THE WORKPIECE INTO THE DESIRED SHAPE
304
ISO-THERMALLY COOL WORKPIECE, LOWER DIE AND LOAD
308
END

FIG. 4

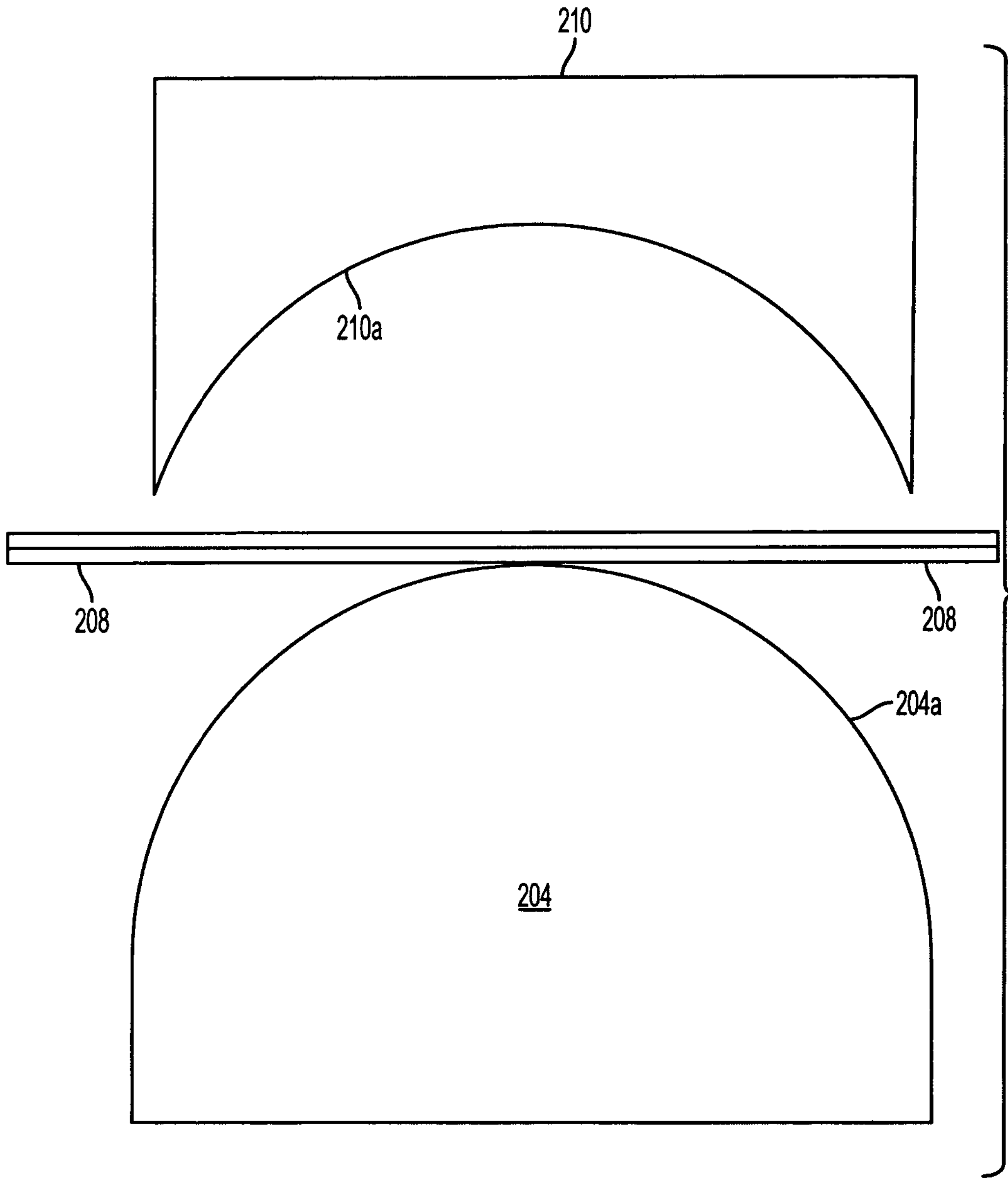


FIG. 5

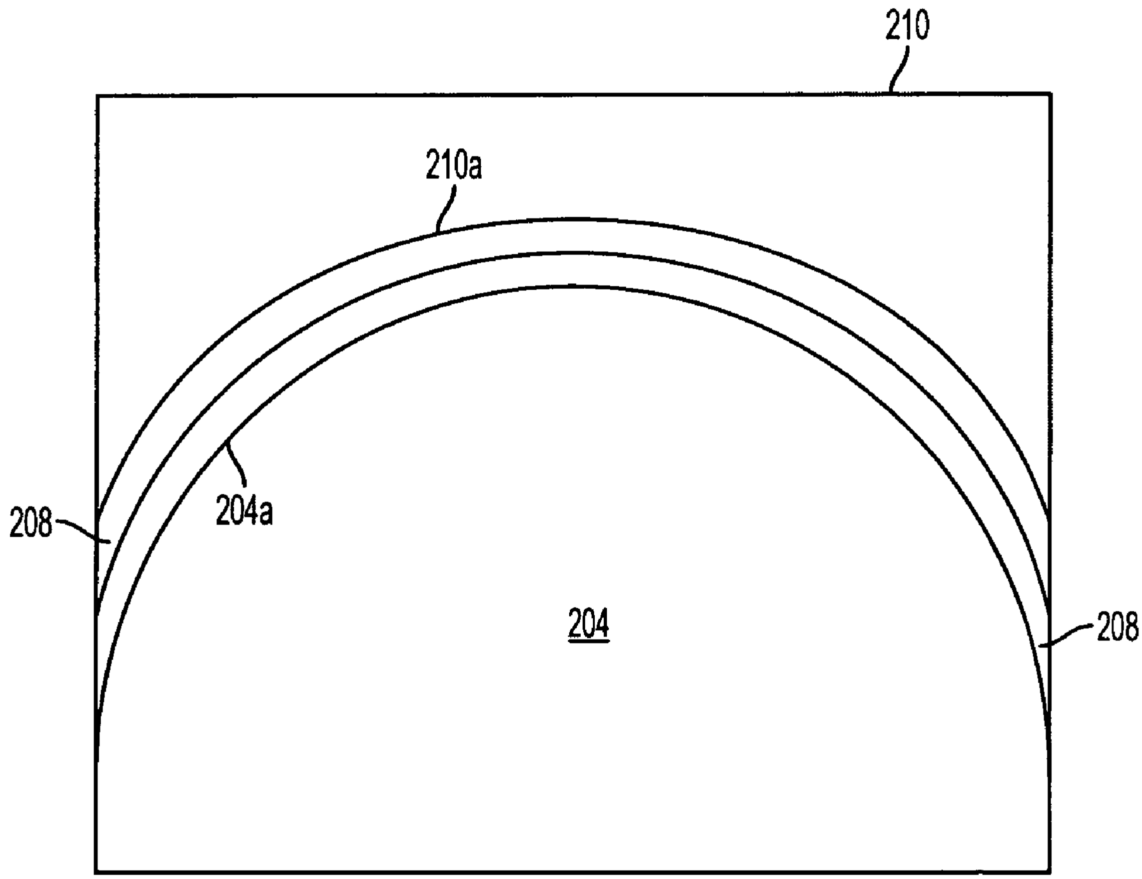


FIG. 6

CREEP FORMING A WORK PIECE

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to forming a work piece, and more particularly, to a method of forming a work piece using a creep forming technique.

[0003] 2. Discussion of the Related Art

[0004] Today, many industries, such as the aerospace industry, employ metal structures that have complex, predefined shapes. These structures are used, for example, in constructing airplanes, including fuselages, wings and support structures. The shapes associated with these structures are typically complex and they have considerably tight tolerances in order to minimize the possibility of structural failure.

[0005] Various processes are used in forming these structures. **FIG. 1A** illustrates one example in accordance with the prior art. As shown, this process uses a die having a lower die **100** and an upper die **106**. A work piece **102**, such as one made from titanium, is placed between the lower die **100** and the upper die **106**. The lower die **100** and the upper die **106** come together and, in doing so, exert a great deal of pressure on the work piece **102**.

[0006] Generally, the work piece **102** is heated in a furnace to about 1700° F. before it is placed on the lower die **100**. While the lower die **100** and the upper die **106** are outside of the furnace, they are both heated to about 200° F. After placing the work piece **102** onto the lower die **100**, the upper die **106** is lowered onto both the work piece **102** and the lower die **100**, thereby placing a load on the work piece **102**. This, in turn, shapes the work piece **102**, where the shape is defined by the upper and lower die. After the work piece **102** is shaped, the work piece **102** is removed from the lower and upper dies and annealed. The work piece **102** is then permitted to cool.

[0007] The above-described process causes a variety of problems. **FIG. 1B** illustrates one of these problems. As shown, the work piece **102** includes defects **104** which may form as a result of friction between the work piece **102** and the lower and upper dies **100** and **106**. Furthermore, since the work piece **102** is at a greater temperature than the lower and upper dies **100** and **106**, substantial heat loss occurs where the lower and upper dies initially make contact with the work piece **102** (see e.g., points A, B and C in **FIG. 1A**). This significantly reduces the pliability of the work piece **102**, at points A, B and C, relative to the rest of work piece **102**. Consequently, defects such as defects **104** can occur, thereby causing the work piece **102** to be outside the very tight, required physical tolerances. Furthermore, the temperature differential between the dies **100** and **106** and the work piece **102** shown in **FIG. 1A** allows for the formation of residual stresses. The residual stresses can cause distortion during subsequent processing of the part. Moreover, cooling of the work piece **102** leads to additional stress formation.

[0008] **FIG. 1C** shows a cross section of work piece **102** and lower die **100**. Moreover, **FIG. 1C** illustrates yet another problem associated with the aforementioned prior art process. Specifically, the excessively high load applied on work piece **102** can cause the deformation of region **102***c*. As is shown in **FIG. 1C**, during processing, the work piece **102** should have the cross-section indicated by dashed lines **102***d*. Instead, the region **102***c* forms where regions **102***a* and **102***b* of work piece **102** intersect. As one skilled in the art would readily appreciate, a deformation such as the deformation of section **102***c* shown in **FIG. 1C** would cause the work piece **102** to be outside the required physical tolerances.

[0009] Another well known technique is the super plastic forming process. This process is specifically used for shaping thin sheets of material, such as titanium. In accordance with this process, a die is heated and then the thin sheet is placed onto the heated die. Pressure is then slowly applied until the thin sheet is formed into the shape defined by the die. While this process is useful for forming thin sheets into relatively simple shapes, this process is not applicable for forming work pieces other than thin sheets, nor is it applicable for forming complex shapes and/or contours, such as those required for manufacturing primary frame structures that are used in aircraft and other industries.

[0010] Thus, there is a substantial need for a process that can be used in forming work pieces that exhibit complex contours and/or shapes. And, in addition, there is a need for a process that can achieve this without the various problems associated with the prior art.

SUMMARY OF THE INVENTION

[0011] Accordingly, the present invention is directed to an assembly and process for forming a work piece that substantially obviates one or more of the problems due to limitations and disadvantages of the related art.

[0012] An advantage of the present invention is that fewer defects occur as a result of the problems discussed in the prior art. As a further advantage, the present invention eliminates residual stresses.

[0013] Another advantage of the present invention is to more effectively meet tight tolerance requirements.

[0014] An advantage of the present invention is to combine annealing and forming into a simultaneous process.

[0015] As a further advantage, the annealing process produces a work piece which is free of internal stresses and residual elastic stresses, thereby increasing strength and longevity of any structure which employs the work piece. This freedom from residual stresses also minimizes any distortion during subsequent machining.

[0016] Another advantage is that the present invention forms a work piece free of wrinkles, kinks, and other non-linear distortions.

[0017] Additional features and advantages of the invention will be set forth in the description which follows, and in part will be apparent from the description, or may be learned by practice of the invention. The objectives and other advantages of the invention will be realized and attained by the structure particularly pointed out in the written description and claims hereof as well as the appended drawings.

[0018] In accordance with one aspect of the present invention, the aforementioned and other advantages are achieved with a method of creep forming a work piece. The method includes placing a work piece on a first die having a predetermined contour. The predetermined contour corresponds to a shape of the work piece after the work piece has been creep formed. After placement of the work piece on the first die, a load is applied on the work piece. The work piece, the first die and the load are then heated such that the work piece, the first die and the load are iso-thermal. The work piece is creep formed during heating using the load such that the work piece has the predetermined contour. After creep formation, the work piece, the first die and the load are cooled such that the work piece, the first die and the load remain iso-thermal.

[0019] In accordance with another aspect of the present invention, the aforementioned and other advantages are achieved by a method of hot forming a work piece. The method comprises placing a work piece on a first die having a predetermined contour and placing a load on the work piece. The work piece is then annealed while the work piece is disposed on the first die and the load is placed on the work piece. During the annealing process, the work piece, the first die and the load are iso-thermal. The method also includes creep forming the work piece with the load. Creep forming the work piece under iso-thermal conditions avoids the formation of residual stresses. In this embodiment, the creep forming occurs during annealing of the work piece such that a shape of the work piece is the same as the predetermined contour. After creep formation, the work piece, the first die, and the load are cooled where the work piece, the first die and the load are iso-thermal during cooling. The iso-thermal conditions during the cooling cycle also prevent the formation of residual stresses.

[0020] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are intended to provide further explanation of the invention as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] The accompanying drawings, which are included to provide a further understanding of the invention and are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and together with the description serve to explain the principles of the invention.

[0022] In the drawings:

[0023] **FIG. 1A** illustrates the formation of a work piece in accordance with the prior art;

[0024] **FIG. 1B** illustrates the work piece shown in **FIG. 1A** after an upper die has been removed and the work piece has been shaped in accordance with the prior art;

[0025] **FIG. 1C** is a cross-sectional view of the work piece shown in **FIG. 1A** in accordance with the prior art;

[0026] **FIG. 2** illustrates a process of forming a work piece in accordance with an embodiment of the present invention;

[0027] **FIG. 3** is an embodiment of the present invention illustrating the work piece described in **FIG. 2** after the work piece has been formed;

[0028] **FIG. 4** is a flowchart illustrating a method of creep forming in accordance with an embodiment of the present invention;

[0029] **FIG. 5** shows a further embodiment of the present invention where the assembly of **FIG. 2** includes an upper die and thermocouples which monitor the temperature of the work piece during a creep formation process; and

[0030] **FIG. 6** illustrates the upper die shown in **FIG. 4** creep forming a work piece in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION OF THE ILLUSTRATED EMBODIMENTS

[0031] The present invention relates to forming a work piece using a creep formation process. As will be discussed in greater detail further on, creep formation occurs when a load, which exceeds a creep limit of a work piece, is placed on the work piece during both annealing and cooling of the work piece.

[0032] **FIG. 2** illustrates an arrangement of components **200** in accordance with an exemplary embodiment of the present invention used to form a work piece **208**. The assembly includes a lower die **204** and a load **206** where the work piece **208** is placed on the lower die **204**. The work piece **208** may be any type of metal, such as titanium or the like, and it may be formed using an extrusion process, an open or closed die forging process, or the like.

[0033] The lower die **204** may be any material such as steel, ceramic, brick, aluminum, or the like that may be cast and is capable of withstanding high temperatures associated with annealing operations. The lower die **204** has a contoured surface **204*a*** which is a predetermined contour which defines the desired contour that is imparted to the work piece **208** during the creep formation process. The contoured surface **204*a*** may exhibit a simple contour, as shown in the exemplary embodiment of **FIG. 2**, or a complex contour.

[0034] In the embodiment illustrated in **FIG. 2**, the work piece **208** has a first end **208*a*** and a second end **208*b***. The load **206** is placed at the ends **208*a*** and **208*b*** of the work piece **208**. The load **206** exceeds the creep limit of the work piece **208** such that the load **206** causes deformation of the work piece **208** such that the work piece **208** takes on a desired shape such as the contour defined by the contoured surface **204*a*** as illustrated in **FIG. 3**. It should be noted that the load **206** may also exceed a yield point of the work piece **208**. When the load **206** exceeds the yield point of the work piece **208**, the work piece also takes on the shape as illustrated in **FIG. 3**. It will be noted that the creep limit varies according to the type of metal used for the work piece **208**. Thus, the load **206** varies according to the creep limit of the type of the metal used for the work piece **208**.

[0035] **FIG. 4** illustrates a creep formation method **300** in accordance with an embodiment of the present invention. As shown in operation **302**, the work piece **208** is first placed on top of the lower die **204** when the lower die **204** is in a furnace (not shown). Next, the load **206** is placed on the work piece **208** in accordance with operation **303**. The work piece **208**, the lower die **204** and the load **206** are then heated inside the furnace in operation **304**. Operation **304** is preferably an iso-thermal process.

[0036] Accordingly, the lower die **204**, the load **206** and the work piece **208** are heated to the same temperature. The temperature within the furnace must at least reach a temperature that causes the work piece **208** to anneal. As mentioned above, the work piece **208** may be any type of metal, thus the temperature at which annealing occurs varies according to the metal. In an embodiment where the work piece **208** is titanium, the temperature of the furnace will be approximately 1200° F. to 1750° F.

[**0037**] During operation **304**, the load **206** forms the work piece **208** as illustrated in **FIG. 3**. In accordance with an embodiment of the present invention, when the work piece **208** is titanium, heating, during which creep occurs, occurs during a time period lasting between about two hours and about ten hours.

[**0038**] Once the work piece **208** acquires the desired contour, the work piece **208**, the load **206**, and the lower die **204** are slow cooled, in accordance with operation **308**. Preferably, operation **308** is an iso-thermal process whereby the lower die **204**, the load **206** and the work piece **208** slow cool. It should be noted that slow cooling is preferred in order to ensure an iso-thermal cooling process. Where the work piece **208** is titanium, the slow cooling process should last for a period of four to twenty-four hours.

[**0039**] **FIG. 5** illustrates a further embodiment of the present invention. As shown, the components include an upper die **210** along with the lower die **204** and the work piece **208**. As may be seen in **FIG. 5**, the upper die **210** includes a contoured surface **210***a* which complements the contoured surface **204***a* of the lower die **204**. The contoured surface **210***a* may be used in conjunction with the contoured surface **204***a* of the lower die **204** to impart a simple or complex contour on the work piece **208**.

[**0040**] It should be noted that a thermocouple (not shown) may be placed on the work piece **208**. The thermocouple can be used to monitor the temperature of the work piece **208** during the creep formation process.

[**0041**] The embodiment illustrated in **FIG. 5** may be used in conjunction with the creep formation method **300** discussed in **FIG. 4**. In particular, after the work piece **208** is placed on the lower die **204** in a furnace in operation **302**, the load **210** is placed on the work piece **208** in operation **303**. In operation **304**, the lower die **204**, the work piece **208** and the load **210** are iso-thermally heated. During heating, creep occurs and the work piece acquires the desired shape, as more clearly shown in **FIG. 6**. After the work piece acquires the desired shape, the lower die **204**, the work piece **208** and the load **210** are slow cooled during an iso-thermal cooling process.

[**0042**] The present invention provides an attractive option to those desiring to form a work piece so as to impart simple or complex contours or large radial contours where the requirements demand tight tolerances. Requirements such as these are necessary in many industries, including the manufacturing of aircraft and architectural applications. Although, clearly, the present invention is not limited to these industries. Furthermore, because annealing and forming are combined into a simultaneous process, time and costs are minimized.

[**0043**] It will be apparent to those skilled in the art that various modifications and variation can be made in the present invention without departing from the spirit or scope of the invention. Thus, it is intended that the present invention cover the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

What is claimed is:

1. A method of forming a work piece comprising:

placing a work piece on a first die having a predetermined contour;

applying a load on the work piece;

iso-thermally heating the work piece, the first die and the load;

forming the work piece using the load such that the work piece has the predetermined contour; and

iso-thermally cooling the work piece, the first die and the load.

2. The method of forming a work piece as recited in claim 1, wherein the work piece is titanium.

3. The method of forming a work piece as recited in claim 2, wherein the work piece, the first die and the load are heated to a temperature in a range between 1200° F. and 1750° F.

4. The method of forming a work piece as recited in claim 2, wherein the operation of iso-thermally cooling the work piece, the lower die and the load comprises:

slow-cooling the work piece, the first die and the load for up to twenty-four hours.

5. The method of forming a work piece as recited in claim 2, wherein the work piece, the first die and the load are heated for a time period lasting between two hours and eight hours.

6. The method of forming a work piece as recited in claim 1, wherein the work piece has a first end and a second end.

7. The method of forming a work piece as recited in claim 6, where the operation of applying a load on the work piece comprises:

placing a first load on the first end of the work piece; and

placing a second load on the second end of the work piece.

8. The method of forming a work piece as recited in claim 1, wherein the load exceeds a creep limit of the work piece.

9. The method of forming a work piece as recited in claim 1, wherein the load is a second die having a second predetermined contour, wherein the second predetermined contour complements the predetermined contour associated with the first die.

10. The method of forming a work piece as recited in claim 9, wherein the operation of applying a load on the work piece comprises:

placing the second die on the work piece such that the work piece is disposed between the first die and the second die.

11. The method of forming a work piece as recited in claim 1, wherein the work piece is heated to an annealing temperature.

12. The method of forming a work piece as recited in claim 11, wherein the forming operation and the heating operation are simultaneous.

13. A method of hot forming a work piece comprising:

placing a work piece on a first die having a predetermined contour;

placing a load on the work piece, wherein the load exceeds a creep limit of the work piece;

annealing the work piece while the work piece is disposed on the first die and the load is placed on the work piece wherein the work piece, the first die and the load are iso-thermal during the annealing operation;

forming the work piece with the load wherein the forming occurs during annealing of the work piece such that a shape of the work piece is the same as the predetermined contour wherein annealing the work piece and forming the work piece are simultaneous; and

iso thermally cooling the work piece, the first die, and the load.

14. The method of hot forming a work piece as recited in claim 13, wherein the work piece is titanium.

15. The method of hot forming a work piece as recited in claim 14, wherein the wherein the work piece, the first die and the load are heated to a temperature in a range between 1200° F. and 1750° F.

16. The method of hot forming a work piece as recited in claim 14, wherein the operation of iso-thermally cooling the work piece, the lower die and the load comprises:

slow cooling the work piece, the first die and the load for up to twenty-four hours.

17. The method of hot forming a work piece as recited in claim 14, wherein the work piece is annealed for a time period lasting between two hours and eight hours.

18. The method of hot forming a work piece as recited in claim 13, wherein the work piece has a first end and a second end.

19. The method of hot forming a work piece as recited in claim 18, where the operation of placing a load on the work piece further comprises:

placing a first load on the first end of the work piece; and

placing a second load on the second end of the work piece.

20. The method of hot forming a work piece as recited in claim 13, wherein the load is a second die having a second predetermined contour, wherein the second predetermined contour complements the predetermined contour associated with the first die.

21. The method of forming a work piece as recited in claim 20, wherein the operation of placing a load on the work piece comprises:

placing the second die on the work piece such that the work piece is disposed between the first die and the second die.

* * * * *