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(54) **Shape memory stainless steels with rare earth elements Ce and La**

(57) Shape memory stainless steels with rare earth elements Cerium (Ce) and Lanthanum (La) are disclosed. In one embodiment, raw materials including Manganese (Mn), Silicon (Si), Chromium (Cr), Nickel (Ni), Carbon (C), Ce, La and Iron (Fe) are melted to form a molten alloy of the shape memory stainless steels with rare earth elements Ce and La. Further, the molten alloy is solidified to form an ingot. Furthermore, the ingot is subjected to nondestructive evaluation to assess internal soundness of the ingot. In addition, the evaluated ingot is homogenized to form homogenized shape memory stainless steels with rare earth elements Ce and La.

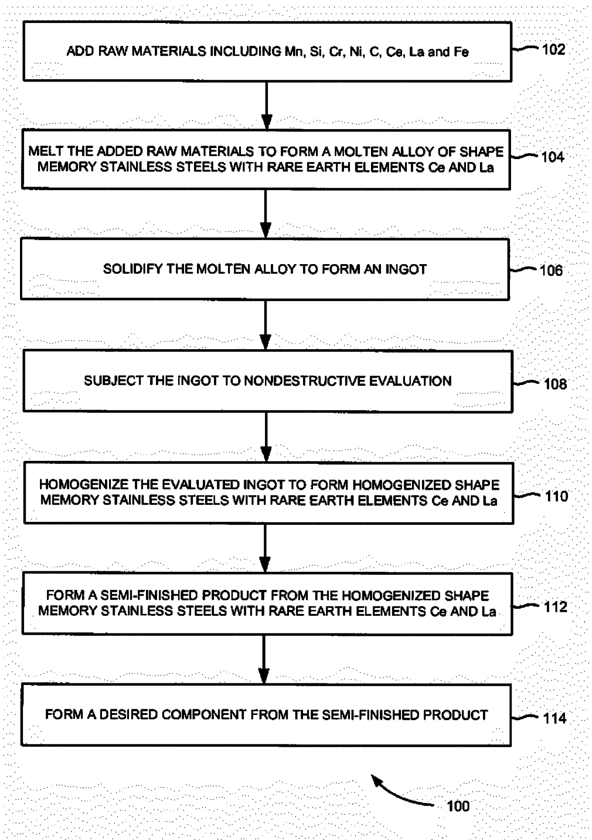

FIG. 1

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Description

FIELD OF TECHNOLOGY

[0001] The present subject matter relates to shape memory stainless steels. More particularly, the present subject matter relates to shape memory stainless steels with rare earth elements Cerium (Ce) and Lanthanum (La).

BACKGROUND

[0002] Shape memory alloys are a promising class of advanced materials used in many high technology applications, such as aerospace, electronics, and biotechnology. The shape memory alloys at a high temperature can be used as functional materials, such as actuators for aircraft engines, automobiles and pipe couplings. Further, the shape memory alloys are used to absorb wind energy. Typically, Nickel-Titanium (Ni-Ti) and Copper (Cu) based shape memory alloys have been used in such high technology applications. Even though the Nickel-Titanium (Ni-Ti) and Copper (Cu) based shape memory alloys have good shape memory effect, however their mechanical properties are lower and are significantly more expensive to produce when compared with shape memory stainless steels. Further, machinability of the Ni-Ti based shape memory alloys is relatively poor when compared with the shape memory stainless steels.

[0003] Generally, the shape memory stainless steels are cheaper alternatives to the expensive Ni-Ti and Cu based shape memory alloys. The existing shape memory stainless steels exhibit good shape memory effect, mechanical properties, machinability, weldability and corrosion resistance. However, the shape memory effect of the shape memory stainless steels is not as good as the Ni-Ti and Cu based shape memory alloys.

[0004] It is well known that the shape memory effect in Iron (Fe) based shape memory alloys is associated with the transformation of face centred cubic austenite (γ) to hexagonal dosed packed (hcp) ε - martensite. The transformation can be divided into two components, such as one involving formation of ε - martensite when cooled below a martensite start temperature (Ms) and the other involving stress induced transformation of austenite. There are different opinions on the effect of thermal martensite on recovery strain of the Fe based shape memory alloys. One technique that is used to reduce an incidence of thermal martensite is to reduce Ms by decreasing the austenite grain size, such as addition of grain refining elements, thermo-mechanical treatments and so on.

SUMMARY

[0005] Shape memory stainless steels with rare earth elements Cerium (Ce) and Lanthanum (La) are disclosed. According to one aspect of the present subject matter, the shape memory stainless steels with rare earth elements include Manganese (Mn), Silicon (Si), Chromium (Cr), Nickel (Ni), Carbon (C), Ce, La and Iron (Fe). The shape memory stainless steels with rare earth elements Ce and La include, by weight, about 15 to 17% of Mn, about 5 to 6% of Si, about 9 to 12% of Cr, about 8 to 10% of Ni, about 0.03 to 0.06% of C, about 0.10 to 0.50% of Ce, about 0.5 to 1.0% of La and the balance being Fe.

[0006] According to another aspect of the present subject matter, raw materials including Mn, Si, Cr, Ni, C, Ce, La and Fe are melted to form a molten alloy of the shape memory stainless steels with rare earth elements Ce and La. Further, the molten alloy is solidified to form an ingot. Furthermore, the ingot is subjected to nondestructive evaluation to assess internal soundness of the ingot. In addition, the evaluated ingot is homogenized to form homogenized shape memory stainless steels with rare earth elements Ce and La. Moreover, a semi-finished product is formed from the homogenized shape memory stainless steels with rare earth elements Ce and La. Also, a desired component is formed from the semi-finished product.

[0007] The method disclosed herein may be implemented in any means for achieving various aspects. Other features will be apparent from the accompanying drawings and from the detailed description that follow.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Various embodiments are described herein with reference to the drawings, wherein:

[0009] **FIG. 1** illustrates a flow diagram of an exemplary method of forming shape memory stainless steels with rare earth elements Cerium (Ce) and Lanthanum (La); and

[0010] **FIG. 2** is a table including a range, by weight, of each element in the shape memory stainless steels with rare earth elements Ce and La, according to one embodiment.

[0011] The drawings described herein are for illustration purposes only and are not intended to limit the scope of the present disclosure in any way.

DETAILED DESCRIPTION

[0012] Shape memory stainless steels with rare earth elements Cerium (Ce) and Lanthanum (La) are disclosed. In the following detailed description of the embodiments of the present subject matter, references are made to the accompanying drawings that form a part hereof, and in which are shown by way of illustration specific embodiments in which the present subject matter may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the present subject matter, and it is to be understood that other embodiments may be utilized and that changes may be made without departing from the scope of the present subject matter. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present subject matter is defined by the appended claims.

[0013] **FIG. 1** illustrates a flow diagram 100 of an exemplary method of forming shape memory stainless steels with rare earth elements Ce and La. At block 102, raw materials including Manganese (Mn), Silicon (Si), Chromium (Cr), Nickel (Ni), Carbon (C), Ce, La and Iron (Fe) are added. In one embodiment, as shown in **FIG. 2,** the shape memory stainless steels with rare earth elements Ce and La include, by weight, about 15 to 17% of Mn, about 5 to 6% of Si, about 9 to 12% of Cr, about 8 to 10% of Ni, about 0.03 to 0.06% of C, about 0.10 to 0.50% of Ce, about 0.5 to 1.0% of La and the balance being Fe. At block 104, the added raw materials are melted to form a molten alloy of the shape memory stainless steels with rare earth elements Ce and La. In one embodiment, the added raw materials are melted at a temperature of about 1600 °C to form the molten alloy. In this embodiment, the added raw materials are melted conventionally or using vacuum induction at the temperature of about 1600 °C to form the molten alloy.

[0014] At block 106, the molten alloy is solidified to form an ingot. In one embodiment, the molten alloy is solidified by cooling to form the ingot of a desired shape. At block 108, the ingot is subjected to nondestructive evaluation to assess internal soundness of the ingot based on quality parameters, such as internal defects, voids, cracks, cavities and the like. In one embodiment, the nondestructive evaluation uses gamma radiography. At block 110, the evaluated ingot is homogenized to form homogenized shape memory stainless steels with rare earth elements Ce and La. In one embodiment, the evaluated ingot is homogenized by heating the evaluated ingot at a temperature in a range of about 1050 °C to 1150 °C for about 6 hours to form the homogenized shape memory stainless steels with rare earth elements Ce and La. At block 112, a semi-finished product is formed from the homogenized shape memory stainless steels with rare earth elements Ce and La. Exemplary semi-finished product includes a rolled product, a forged product and the like. At block 114, a desired component is formed from the semi-finished product. In one embodiment, the semi-finished product is cold worked or machined to form the desired component. Exemplary desired component includes an actuator for an aircraft engine, an automobile component, a pipe coupling and the like.

[0015] In one embodiment, to measure shape memory effect of the shape memory stainless steels with rare earth elements Ce and La, thin sheets of the homogenized shape memory stainless steels with rare earth elements Ce and La are made and then small strips are extracted from the thin sheets. In one embodiment, strips with different lengths are extracted from the thin sheets to measure the shape memory effect. Further, the strips are bent into a semicircular shape on mandrels with different diameters at a room temperature with the ends of strips perpendicular to horizontal straight line. Furthermore, pre-strain (ε_p) is computed for each strip using an equation:

$$\varepsilon_p = t/d$$

where t is thickness of the strips and d is diameter of the semicircular shapes of a respective strip.

[0016] The strips are then allowed to recover at a temperature in a range about 400 °C - 450 °C. In addition, a degree of shape recovery (η_{SME}) for each strip is computed using an equation:

$$\eta_{SME} = ((90 - \theta)/90) X 100$$

where θ is a residual angle.

[0017] Also, the shape memory effect (also referred as a net reversible strain (ε_R)), in percentage, for each strip is computed using an equation:

$$\varepsilon_R = \varepsilon_P X \eta_{SME}.$$

[0018] Referring now to **FIG. 2,** a table 200 including a range, by weight, of each element in the shape memory stainless steels with rare earth elements Ce and La, according to one embodiment. In the table 200, the first row includes various elements in the shape memory stainless steels with rare earth elements Ce and La, such as Mn, Si, Cr, Ni, C, Ce, La and Fe. Further in the table 200, the second row includes the range, by weight, of each element in the shape memory stainless steels with rare earth elements Ce and La. Using the range of the elements, in the table 200, one can form multiple shape memory stainless steels with rare earth elements Ce and La.

[0019] In various embodiments, the method described in **FIGS. 1** and **2** enables to form the shape memory stainless steels with rare earth elements Ce and La. The shape memory stainless steels with rare earth elements Ce and La are cheaper compared to existing shape memory alloys. Further, the shape memory stainless steels with rare earth elements Ce and La have good mechanical properties, machinability, weldability and corrosion resistance.

[0020] Although the present embodiments have been described with reference to specific example embodiments, it will be evident that various modifications and changes may be made to these embodiments without departing from the broader spirit and scope of the various embodiments.

Claims

1. Shape memory stainless steels with rare earth elements Cerium (Ce) and Lanthanum (La), which comprise, Manganese (Mn), Silicon (Si), Chromium (Cr), Nickel (Ni), Carbon (C), Ce, La and Iron (Fe), wherein the shape memory stainless steels with rare earth elements Ce and La comprise, by weight, about 0.10 to 0.50% of Ce and about 0.5 to 1.0% of La.

2. The shape memory stainless steels of claim 1, wherein the shape memory stainless steels with rare earth elements Ce and La comprise, by weight, about 15 to 17% of Mn, about 5 to 6% of Si, about 9 to 12% of Cr, about 8 to 10% of Ni, about 0.03 to 0.06% of C and the balance being Fe.

3. The shape memory stainless steels of claim 2, wherein the shape memory stainless steels with rare earth elements Ce and La further comprise:

   unavoidable impurities.

4. A method of forming shape memory stainless steels with rare earth elements Cerium (Ce) and Lanthanum (La), comprising:

   melting raw materials including Manganese (Mn), Silicon (Si), Chromium (Cr), Nickel (Ni), Carbon (C), Ce, La and Iron (Fe) to form a molten alloy of the shape memory stainless steels with rare earth elements Ce and La, wherein the shape memory stainless steels with rare earth elements Ce and La comprise, by weight, about 0.10 to 0.50% of Ce and about 0.5 to 1.0% of La;
   solidifying the molten alloy to form an ingot;
   subjecting the ingot to nondestructive evaluation to assess internal soundness of the ingot; and
   homogenizing the evaluated ingot to form homogenized shape memory stainless steels with rare earth elements Ce and La.

5. The method of claim 4, wherein the shape memory stainless steels with rare earth elements Ce and La comprise, by weight, about 15 to 17% of Mn, about 5 to 6% of Si, about 9 to 12% of Cr, about 8 to 10% of Ni, about 0.03 to 0.06% of C and the balance being Fe.

6. The method of claim 4, wherein homogenizing the evaluated ingot to form the homogenized shape memory stainless steels with rare earth elements Ce and La comprises:

   homogenizing the evaluated ingot by heating the evaluated ingot at a temperature in a range of about 1050°C to 1150°C for about 6 hours to form the homogenized shape memory stainless steels with rare earth elements Ce and La.

7. The method of claim 4, wherein the nondestructive evaluation comprises nondestructive evaluation using gamma radiography.

8. The method of claim 4, wherein melting the raw materials to form the molten alloy comprises:

   adding the raw materials; and
   melting the added raw materials at a temperature of about 1600°C to form the molten alloy.

9. The method of claim 8, wherein melting the added raw materials at the temperature of about 1600°C comprises:

   conventional melting of the added raw materials at the temperature of about 1600°C.

10. The method of claim 8, wherein melting the added raw materials at the temperature of about 1600°C comprises:

    vacuum induction melting of the added raw materials at the temperature of about 1600°C.

11. The method of claim 4, wherein solidifying the molten alloy to form the ingot comprises:

    solidifying the molten alloy by cooling to form the ingot of a desired shape.

12. The method of claim 4, further comprising:

    forming a semi-finished product from the homogenized shape memory stainless steels with rare earth elements Ce and La.

13. The method of claim 12, wherein the semi-finished product comprises a rolled product or a forged product.

14. The method of claim12, further comprising:

    forming a desired component from the semi-finished product.

15. The method of claim 14, wherein the desired component is an actuator for an aircraft engine, an automobile component and a pipe coupling.

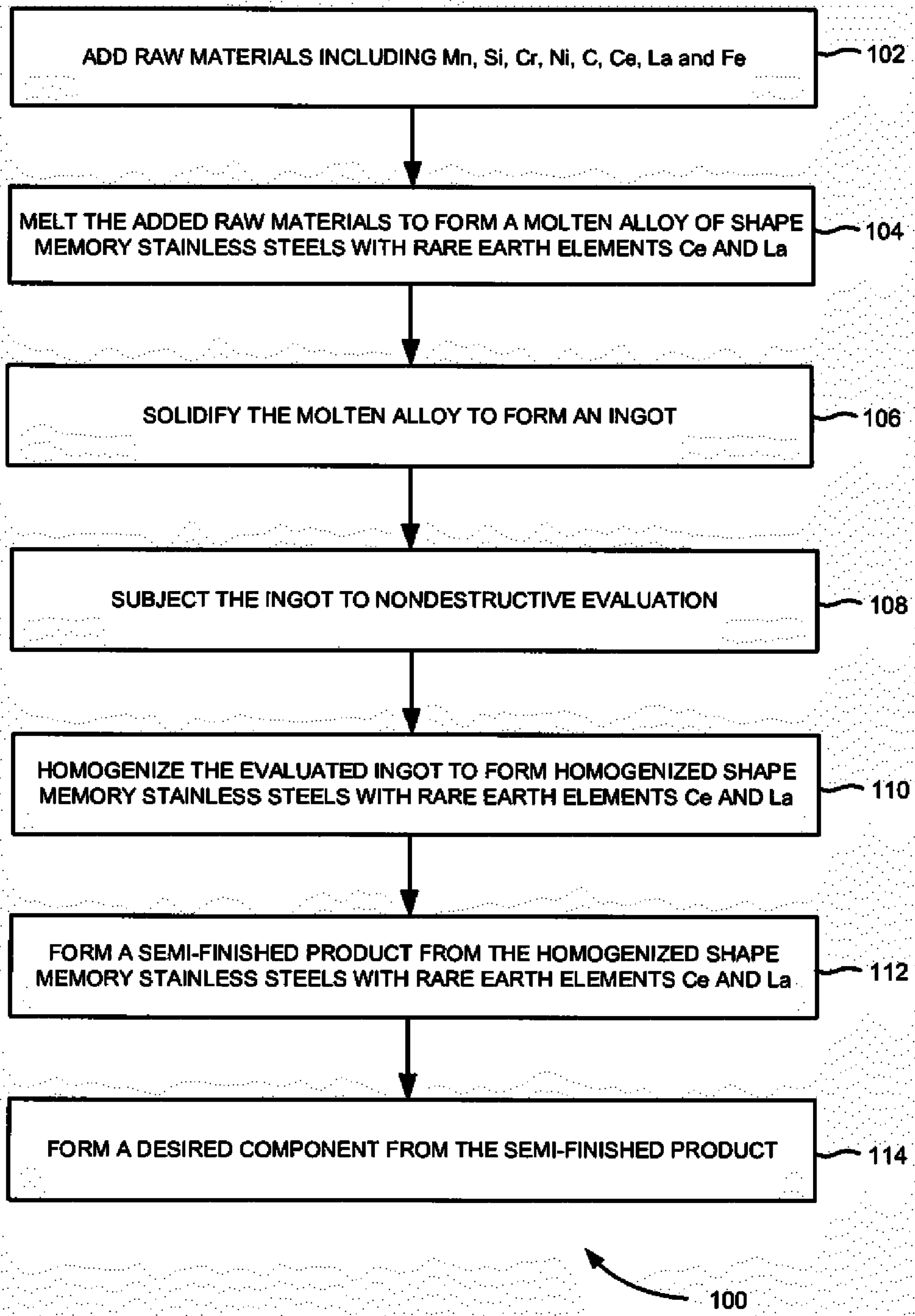
ADD RAW MATERIALS INCLUDING Mn, Si, Cr, Ni, C, Ce, La and Fe
102
MELT THE ADDED RAW MATERIALS TO FORM A MOLTEN ALLOY OF SHAPE MEMORY STAINLESS STEELS WITH RARE EARTH ELEMENTS Ce AND La
104
SOLIDIFY THE MOLTEN ALLOY TO FORM AN INGOT
106
SUBJECT THE INGOT TO NONDESTRUCTIVE EVALUATION
108
HOMOGENIZE THE EVALUATED INGOT TO FORM HOMOGENIZED SHAPE MEMORY STAINLESS STEELS WITH RARE EARTH ELEMENTS Ce AND La
110
FORM A SEMI-FINISHED PRODUCT FROM THE HOMOGENIZED SHAPE MEMORY STAINLESS STEELS WITH RARE EARTH ELEMENTS Ce AND La
112
FORM A DESIRED COMPONENT FROM THE SEMI-FINISHED PRODUCT
114
100

FIG. 1

ELEMENTS	MANGANESE	SILICON	CHROMIUM	NICKEL	CARBON	CERIUM	LANTHANUM	IRON
WEIGHT (IN PERCENTAGE)	15 - 17	5 - 6	9 - 12	8 - 10	0.03 - 0.06	0.10 - 0.50	0.5 - 1.0	BALANCE

200

FIG. 2

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EUROPEAN SEARCH REPORT

Application Number
EP 12 19 4924

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TECHNICAL FIELDS SEARCHED (IPC)

C22C

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	9 April 2013	Radeck, Stephanie

CATEGORY OF CITED DOCUMENTS

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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 12 19 4924

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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