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(71) Applicant: **General Electric Company**
Schenectady, NY 12345 (US)

(72) Inventor: **Park, Junyoung**
Greenville, SC 29615 (US)

(74) Representative: **Szary, Anne Catherine**
GE International Inc.
Global Patent Operation - Europe
15 John Adam Street
London
WC2N 6LU (GB)

(54) Cast compressor articles and methods of forming same

(57) Methods of forming a compressor article such as a cast airfoil, a stator, a blade, a gas turbine, and a gas turbine shell via casting are presented. The methods include: preparing an iron-manganese-aluminum-silicon-carbon (Fe-Mn-Al-Si-C) based alloy; casting the Fe-Mn-Al-Si-C based alloy, wherein a cast has a shape of the compressor article; and performing post-casting finishing thereby forming the compressor article.

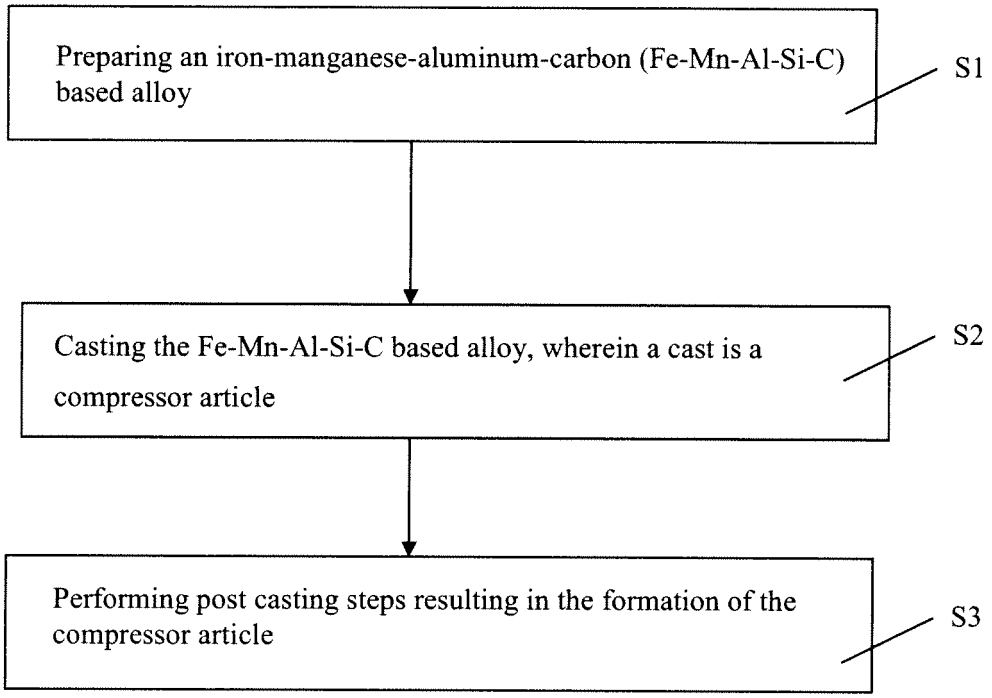

FIG. 1

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Description

BACKGROUND OF THE INVENTION

[0001] The invention relates generally to cast compressor articles. More particularly, the invention relates to cast airfoils, stators, blades, gas turbines, gas turbine shells, etc, and methods of forming the same.

[0002] Typically, current compressor articles used in various gas turbines are made of conventional and sometimes slightly modified stainless steels, and formed via a forging process with extensive post process machining to bring the articles to their final shape.

BRIEF DESCRIPTION OF THE INVENTION

[0003] A first aspect of the disclosure provides a method of forming a compressor article comprising: preparing an iron-manganese-aluminum-silicon-carbon (Fe-Mn-Al-Si-C) based alloy; casting the Fe-Mn-Al-Si-C based alloy, wherein a cast has a shape of a compressor article; and performing post-casting finishing thereby forming the compressor article.

[0004] A second aspect of the disclosure provides a method of forming a compressor article comprising: preparing an iron-manganese-aluminum-silicon-carbon (Fe-Mn-Al-Si-C) based alloy; casting the Fe-Mn-Al-Si-C based alloy, wherein a cast has a shape of a compressor article selected from the group consisting of an airfoil, a stator, a gas turbine, a blade, and a gas turbine shell, and performing post-casting finishing thereby forming the compressor article.

[0005] A third aspect of the disclosure provides a compressor including a part made of an iron-manganese-aluminum-silicon-carbon (Fe-Mn-Al-Si-C) based alloy.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] These and other features of this invention will be more readily understood from the following detailed description of the various aspects of the invention taken in conjunction with the accompanying drawings that depict various embodiments of the invention, in which:

[0007] FIG. 1 shows a flow diagram of an embodiment of a method of forming a compressor article, in accordance with the present invention; and

[0008] FIG. 2 shows a compressor blade in an embodiment of a compressor part, in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0009] Current forming processes, such as forging, for compressor articles employ heating and shaping the raw material by suitably applying of compressive forces. Due to the nature of this process, typically extensive machining is involved in post processing to bring the products to their final shapes. The whole process can be very costly, time-consuming, and environmentally unsound. It has been discovered that using a casting process and employing an iron-manganese-aluminum-silicon-carbon (Fe-Mn-Al-Si-C) based alloy, eliminates or minimizes machining, reduces lead time, and reduces the carbon foot print of the process. The cast parts can also be Hot Isostatic Pressed (HIPed) to eliminate/minimize internal voids. It also has been discovered that using the Fe-Mn-Al-Si-C based alloy affords a cost savings in raw material use as compared to materials typically used in current forming processes.

[0010] Referring to FIG. 1, an embodiment of a method of forming a compressor article is shown. The method comprises: a first step S1, preparing an iron-manganese-aluminum-silicon-carbon (Fe-Mn-Al-Si-C) based alloy; a second step S2, casting the Fe-Mn-Al-Si-C based alloy, wherein a cast has a shape of a compressor article; and a third step S3, performing post-casting finishing thereby forming the compressor article.

[0011] Referring to method step S1, preparing an Fe-Mn-Al-Si-C based alloy, in an embodiment of the present invention, the Fe-Mn-Al-Si-C based alloy comprises approximately 54.3% - 76.4% Fe, approximately 12% - 30% Mn, approximately 5% - 12% Al, approximately 0.3% - 2.5% Si, and approximately 0.3% - 1.2% C. In another embodiment, the Fe-Mn-Al-Si-C based alloy comprises approximately 59.5% Fe, approximately 29.4% Mn, approximately 8.8% Al, approximately 1.3% Si, and approximately 1% C. In another embodiment, the Fe-Mn-Al-Si-C based alloy additionally comprises approximately 0.5% - 1% Molybdenum (Mo).

[0012] The Fe-Mn-Al-Si-C based alloy may be prepared by melting the components of the alloy in an argon atmosphere to minimize oxidation and to form a molten metal Fe-Mn-Al-Si-C based alloy. The process to provide the molten Fe-Mn-Al-Si-C based alloy, as described, is well known in the art and thus, for the sake of brevity, no further description is provided.

[0013] The prepared Fe-Mn-Al-Si-C based alloy has casting characteristics similar to ductile iron with improved age hardening characteristics. The Fe-Mn-Al-Si-C based alloy possesses low density (6.5-7.2 g/cm3), tensile strength (UTS) from 600 MPa to 2000 MPa, and excellent ductility as great as over 70% strain to failure when solution treated, elongation

from 10% to 70%, and yield strength (YS) from 600 to 1000 MPa. The superior fluidity and the age-hardening ability characteristics of the Fe-Mn-Al-Si-C based alloy allow it to be used to produce compressor articles utilizing near-net shape casting processes. Examples of the casting processes are described *infra.*

[0014] The Fe-Mn-Al-Si-C based alloy has two major matrix constituents (austenite and ferrite). The two constituents increase the dampening capability of compressor articles formed having the Fe-Mn-Al-Si-C based alloy. Table I compares properties of the Fe-Mn-Al-Si-C based alloy with other alloys typically used in forming processes for compressor articles.

Table I

	59.5Fe-29.4 Mn-8.8 Al-1.33 Si-1C	59.5 Fe-29.4 Mn-8.8 Al-1.33 Si-1C	304 SS 18%-20% Cr, 8%-10.5% Ni	410 SS 11.5%-13.5% Cr	1.58% Cr-1.54% Ni-0.192 Mo	1.18 Cr-1.11 Mo-0.26% V
condition	Cast, Sol'n treated	Cast, Aged 16 hr @ 550 C	Forged, Annealed	Tempered, Hot or Cold Finished	Forged, QTed	Forged, QTed
UTS (MPa)	871	1210	515 min	825 min	840	814.2
0.2 YS (MPa)	620	884	205 min	620 min	700	694.14
% elongation	77	15	40 min	12 min	18.5	20.3
Hardness (BHN)	272	434	203 max		255	244

[0015] Referring to method step S2, casting an Fe-Mn-Al-Si-C based alloy wherein the cast has a shape of a compressor article, in an embodiment of the present invention casting is selected from the group consisting of sand casting, investment casting, permanent mold casting, and die casting. The aforementioned casting processes, as described, are well known in the art and thus, for the sake of brevity, no further description is provided. The aforementioned casting processes also are near-net shape processes requiring very little post process machining, if any. In an embodiment of the present invention, the Fe-Mn-Al-Si-C based alloy prepared in method step S1 is poured into pre-made molds (permanent molds) in the shape of a compressor article.

[0016] The molds have cavities that match the geometrical shape of the final compressor article. The molds also have a gating system that provides channels to the cavity of the mold. In an embodiment, the cast is in a mold having a geometrical shape selected from the group consisting of an airfoil, a stator, a gas turbine, a blade, and a gas turbine shell. In another embodiment, the Fe-Mn-Al-Si-C based alloy may be cast using a technique not specifically mentioned or later developed techniques appropriate for the alloy to be cast.

[0017] Referring to method step S3, performed post-casting finishing resulting in the formation of the compressor article. In an embodiment of the present invention post-casting finishing includes but is not limited to separating the article from the mold, heat treating the separated article, age hardening the separated article, and process machining. In one embodiment, the cast article is separated from the gating system with saw cuts. The separated article is then solution heat treated to meet mechanical properties pre-selected for the article. Solution heat treatment may be performed at 1,000° C or above in an atmosphere that prevents decarburization and oxidation. Age hardening may then be performed in a temperature range from approximately 500° C to 650° C at a period of time required to obtain a pre-selected mechanical property for the article. In another embodiment, the post casting steps may be performed using a technique not specifically mentioned or later developed techniques appropriate for the post casting treatment of the cast Fe-Mn-Al-Si-C based alloy.

[0018] The compressor article formed from S3 includes but is not limited to an airfoil, a stator, a gas turbine, a blade, and a gas turbine shell. The formed article has the characteristics as described in Table I *supra* as well as comparable oxidation and weldability properties to 304SS (Stainless Steel). The formed article also is 12%-18% lighter than High Strength Lightweight Aluminum (HSLA) steels. The formed article also is less expensive than conventional stainless steel articles which require high chromium additions and expensive nickel additions.

[0019] Referring to FIG. 2, a compressor blade 1 is shown, in an embodiment of a compressor part/article, according to the present invention. In one embodiment, the compressor includes a compressor blade 1 comprising an iron-manganese-aluminum-silicon-carbon (Fe-Mn-Al-Si-C) based alloy. The characteristics, methods of forming, and various embodiments of the Fe-Mn-Al-Si-C based alloy are described *supra,* and thus, for the sake of brevity, no further description is provided. In one embodiment, the compressor blade 1 is formed via casting. The characteristics, methods of forming, and various embodiments of compressor parts/articles comprising the Fe-Mn-Al-Si-C based alloy are described *supra,* and thus, for the sake of brevity, no further description is provided. In an embodiment of the present invention, the

compressor part(s) is selected from the group consisting of an airfoil, a stator, a gas turbine, a blade, and a gas turbine shell.

[0020] The terms "first," "second," and the like, herein do not denote any order, quantity, or importance, but rather are used to distinguish one element from another, and the terms "a" and "an" herein do not denote a limitation of quantity, but rather denote the presence of at least one of the referenced item. The modifier "approximately" used in connection with a quantity is inclusive of the stated value and has the meaning dictated by the context, (e.g., includes the degree of error associated with measurement of the particular quantity). The suffix "(s)" as used herein is intended to include both the singular and the plural of the term that it modifies, thereby including one or more of that term (e.g., the metal (s) includes one or more metals). Ranges disclosed herein are inclusive and independently combinable (e.g., ranges of "up to about 25 wt%, or, more specifically, about 5 wt% to about 20 wt %", is inclusive of the endpoints and all intermediate values of the ranges of "about 5 wt% to about 25 wt%," etc).

[0021] While various embodiments are described herein, it will be appreciated from the specification that various combinations of elements, variations or improvements therein may be made by those skilled in the art, and are within the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.

Claims

1. A method of forming a compressor article comprising:

   preparing an iron-manganese-aluminum-silicon-carbon (Fe-Mn-Al-Si-C) based alloy;
   casting the Fe-Mn-Al-Si-C based alloy, wherein a cast has a shape of a compressor article; and
   performing post-casting finishing thereby forming the compressor article.

2. A method of forming a compressor article according to claim 1, wherein the Fe-Mn-Al-Si-C based alloy comprises approximately 54.3% - 76.4% Fe, approximately 12% - 30% Mn, approximately 5% - 12% Al, approximately 0.3% - 2.5% Si, and approximately 0.3% - 1.2% C.

3. A method of forming a compressor article according to claim 1 or claim 2, wherein the Fe-Mn-Al-Si-C based alloy comprises approximately 59.5% Fe, approximately 29.4% Mn, approximately 8.8% Al, approximately 1.3% Si, and approximately 1% C.

4. A method of forming a compressor article according to any preceding claim, wherein the Fe-Mn-Al-Si-C based alloy additionally comprises approximately 0.5% - 1% Mo.

5. A method of forming a compressor article according to any preceding claim, wherein the preparing the Fe-Mn-Al-Si-C based alloy comprises melting the Fe-Mn-Al-Si-C based alloy components to form a molten metal Fe-Mn-Al-Si-C based alloy.

6. A method of forming a compressor article according to claim 1, wherein the casting is selected from the group consisting of sand casting, investment casting, permanent mold casting, and die casting.

7. A method of forming a compressor article according to any preceding claim, wherein the cast has a shape selected from the group consisting of an airfoil, a stator, a gas turbine, a blade, and a gas turbine shell.

8. A method of forming a compressor article according to any preceding claim, wherein the post-casting finishing comprises separating the compressor article from the cast, heat treating the separated compressor article, age hardening the separated compressor article, and performing machining on the separated compressor article.

9. A method of forming a compressor article according to any preceding claim, wherein the article is selected from the group consisting of an airfoil, a stator, a gas turbine, a blade, and a gas turbine shell.

10. A method of forming a compressor article comprising:

    preparing an iron-manganese-aluminum-silicon-carbon (Fe-Mn-Al-Si-C) based alloy;
    casting the Fe-Mn-Al-Si-C based alloy, wherein a cast has a shape of a compressor article selected from the

group consisting of an airfoil, a stator, a gas turbine, a blade, and a gas turbine shell; and performing post-casting finishing thereby forming the compressor article.

11. A method of forming a compressor article according to claim 10, wherein the Fe-Mn-Al-Si-C based alloy comprises approximately 54.3% - 76.4% Fe, approximately 12% - 30% Mn, approximately 5% - 12% Al, approximately 0.3% - 2.5% Si, and approximately 0.3% - 1.2% C.

12. A method of forming a compressor article according to claim 10 or claim 11, wherein the Fe-Mn-Al-Si-C based alloy additionally comprises approximately 0.5% - 1% Mo.

13. A method of forming a compressor article according to any one of claims 10 to 12, wherein the preparing the Fe-Mn-Al-Si-C based alloy comprises melting the Fe-Mn-Al-Si-C based alloy components to form a molten metal Fe-Mn-Al-Si-C based alloy.

14. A method of forming a compressor article according to any one of claims 10 to 13, wherein the casting is selected from the group consisting of sand casting, investment casting, permanent mold casting, and die casting.

15. A method of forming a compressor article according to any one of claims 10 to 14, wherein the post-casting finishing comprises separating the compressor article from the cast, heat treating the separated compressor article, age hardening the separated compressor article, and performing machining on the separated compressor article.

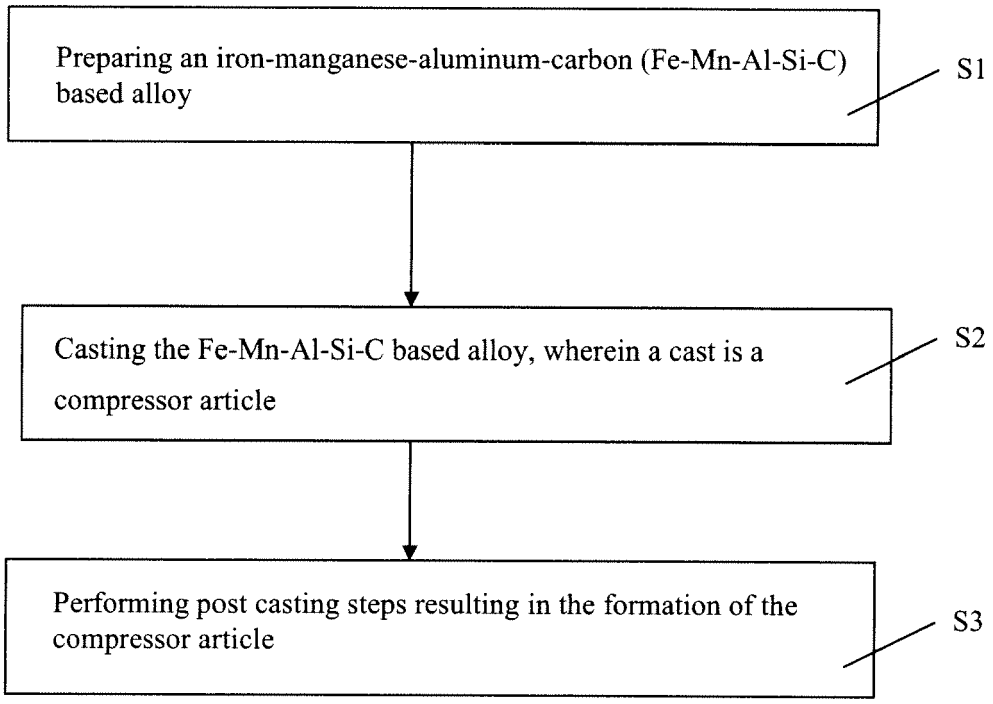
Preparing an iron-manganese-aluminum-carbon (Fe-Mn-Al-Si-C) based alloy
S1
Casting the Fe-Mn-Al-Si-C based alloy, wherein a cast is a compressor article
S2
Performing post casting steps resulting in the formation of the compressor article
S3

FIG. 1

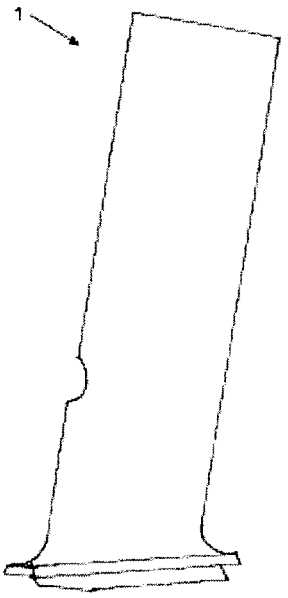

FIG. 2

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EUROPEAN SEARCH REPORT

Application Number
EP 10 17 5726

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X,P	WO 2010/052052 A1 (SIEMENS AG [DE]; BODE RALF [DE]) 14 May 2010 (2010-05-14) * claims 3,7,8-12 *	1,7-10, 13-15	
A	ALTSTETTER C J ET AL: "PROCESSING AND PROPERTIES OF Fe-Mn-Al ALLOYS", MATERIALS SCIENCE ENGINEERING, ELSEVIER SEQUOIA, LAUSANNE, CH, vol. 82, 1 September 1986 (1986-09-01), pages 13-25, XP002407487, ISSN: 0025-5416, DOI: DOI:10.1016/0025-5416(86)90091-1 * page 14 - page 16; table 1 *	1-3,5,6, 8,10-15	TECHNICAL FIELDS SEARCHED (IPC) C22C C21D
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A	US 1 892 316 A (ALTON MITCHELL H ET AL) 27 December 1932 (1932-12-27) * claim 4 *	1-4, 10-12	

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	18 January 2011	Lilimpakis, Emmanuel

CATEGORY OF CITED DOCUMENTS

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E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

1 EPO FORM 1503 03.82 (P04C01)

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EUROPEAN SEARCH REPORT

Application Number
EP 10 17 5726

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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TECHNICAL FIELDS SEARCHED (IPC)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	18 January 2011	Lilimpakis, Emmanuel

CATEGORY OF CITED DOCUMENTS

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& : member of the same patent family, corresponding document

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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 10 17 5726

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