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(54) Title: METHOD OF MANUFACTURING AN AIRFOIL

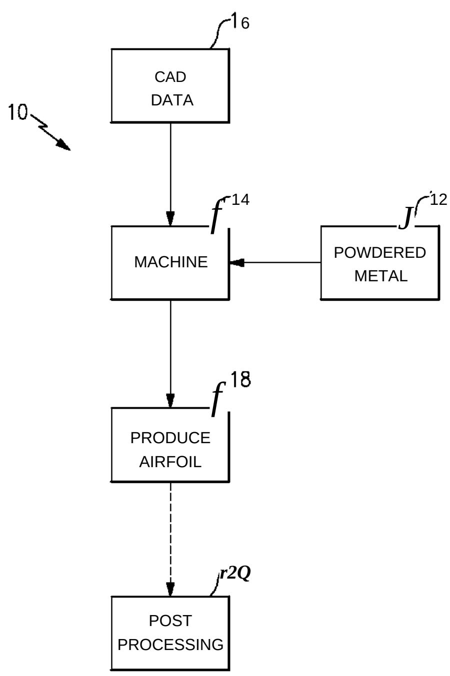

FIG.1

(57) Abstract: Disclosed is a method of manufacturing an airfoil. The method includes establishing an Argon (Ar)-free environment, providing a bed within the Argon free environment, providing a set of data instructions for manufacturing the airfoil, and providing a powdered Nickel (Ni)-based alloy on the bed. In one example, the powdered Nickel (Ni)-based alloy consists essentially of about 4.8 wt. % Iron (Fe), about 21 wt. % Chromium (Cr), about 8.6 wt. % Molybdenum (Mo), about 0.07 wt. % Titanium (Ti), about 0.40 % Aluminum (Al), about 5.01 wt. % Niobium (Nb), about 0.03 wt. % Carbon (C), about 0.14 wt. % Silicon (Si), and a balance Nickel (Ni). The method further includes fusing the powdered Nickel (Ni)-based alloy with an electron beam with reference to the data instructions to form the airfoil.

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METHOD OF MANUFACTURING AN AIRFOIL

RELATED APPLICATIONS

[0001] This application claims priority to U.S. Application No. 13/477,787, filed May 22, 2012 and claims priority to U.S. Provisional Application No. 61/596,830, filed February 9, 2012.

BACKGROUND

[0002] Processes for manufacturing airfoils from powdered metals are known and used. Some processes, known generally as additive manufacturing processes, fuse particles of a powdered metal together, and create objects by fusing successive layers of the powdered metal on top of one another. In one known method, a powdered Nickel (Ni)-based alloy is laser melted in an environment containing Argon (Ar).

SUMMARY

[0003] Disclosed is a method of manufacturing an airfoil. The method includes forming an airfoil using a powdered Nickel (Ni)-based alloy in an additive manufacturing process. The powdered Nickel (Ni)-based alloy includes Molybdenum (Mo) within a range of 7.7 to 9.5 wt. %, Titanium (Ti) within a range of 0.06 to 0.08 wt. %, Aluminum (Al) within a range of 0.3 to 0.5 wt. %, Niobium (Nb) within a range of 4.5 to 5.5 wt. %, Carbon (C) within a range of 0.02 to 0.04 wt. %, and a balance Nickel (Ni) and alloy elements.

[0004] In a further non-limiting embodiment of the foregoing method of manufacturing an airfoil, the method may further include establishing an Argon (Ar)-free environment, providing a bed within the Argon free environment, and positioning the powdered Nickel (Ni)-based alloy on the bed.

[0005] In a further non-limiting embodiment of either of the foregoing methods of manufacturing an airfoil, the method may further include providing data instructions for manufacturing the airfoil, and fusing the powdered Nickel (Ni)-based alloy using an electron beam with reference to the data instructions.

[0006] In a further non-limiting embodiment of any of the foregoing methods of manufacturing an airfoil, the method may further include that the airfoil is a turbine airfoil.

[0007] In a further non-limiting embodiment of any of the foregoing methods of manufacturing an airfoil, the method may further include that the airfoil is one of a rotor blade and a stator vane.

[0008] In a further non-limiting embodiment of any of the foregoing methods of manufacturing an airfoil, the method may further include that the alloy elements include about 4.9 wt. % Iron (Fe), about 21 wt. % Chromium (Cr), and about 0.14 wt. % Silicon (Si).

[0009] In a further non-limiting embodiment of any of the foregoing methods of manufacturing an airfoil, the method may further include that the powdered Nickel (Ni)-based alloy consists of about 4.8 wt. % Iron (Fe), about 21 wt. % Chromium (Cr), about 8.6 wt. % Molybdenum (Mo), about 0.07 wt. % Titanium (Ti), about 0.40 wt. % Aluminum (Al), about 5.01 wt. % Niobium (Nb), about 0.03 wt. % Carbon (C), about 0.14 wt. % Silicon (Si), and a balance Nickel (Ni).

[0010] In a further non-limiting embodiment of any of the foregoing methods of manufacturing an airfoil, the method may further include that the powdered Nickel (Ni)-based alloy consists essentially of about 4.8 wt. % Iron (Fe), about 21 wt. % Chromium (Cr), about 8.6 wt. % Molybdenum (Mo), about 0.07 wt. % Titanium (Ti), about 0.40 wt. % Aluminum (Al), about 5.01 wt. % Niobium (Nb), about 0.03 wt. % Carbon (C), about 0.14 wt. % Silicon (Si), and a balance Nickel (Ni).

[0011] In a further non-limiting embodiment of any of the foregoing methods of manufacturing an airfoil, the method may further include that the airfoil exhibits a tensile ductility within a range of 33% to 38% at 1400 °F.

[0012] In a further non-limiting embodiment of any of the foregoing methods of manufacturing an airfoil, the method may further include that the powdered Nickel (Ni)-based alloy is substantially free of Aluminum (Al)-based oxides.

[0013] Further disclosed is a method of manufacturing an airfoil including establishing an Argon (Ar)-free environment, providing a bed within the Argon free environment, providing a set of data instructions for manufacturing the airfoil, and providing a powdered Nickel (Ni)-based alloy on the bed. The powdered Nickel (Ni)-based alloy consists essentially of about 4.8 wt. % Iron (Fe), about 21 wt. % Chromium (Cr), about 8.6 wt. % Molybdenum (Mo), about 0.07 wt. % Titanium (Ti), about 0.40 % Aluminum (Al), about 5.01 wt. % Niobium (Nb), about 0.03 wt. % Carbon (C), about 0.14 wt. % Silicon (Si), and a balance Nickel (Ni). The method further includes fusing the powdered Nickel (Ni)-based alloy with an electron beam with reference to the data instructions to form the airfoil.

[0014] In a further non-limiting embodiment of any of the foregoing methods of manufacturing an airfoil, the method may further include that the powdered Nickel-based alloy consists of about 4.8 wt. % Iron (Fe), about 21 wt. % Chromium (Cr), about 8.6 wt. % Molybdenum (Mo), about 0.07 wt. % Titanium (Ti), about 0.40 % Aluminum (Al), about 5.01 wt. % Niobium (Nb), about 0.03 wt. % Carbon (C), about 0.14 wt. % Silicon (Si), and a balance Nickel (Ni).

[0015] In a further non-limiting embodiment of any of the foregoing methods of manufacturing an airfoil, the method may further include removing excess, unfused powdered Nickel (Ni)-based alloy from the bed.

[0016] Further disclosed is a turbine airfoil including an electron beam formed component with a chemical composition consisting essentially of approximately 4.9 wt. % Iron (Fe), approximately 21 wt. % Chromium (Cr), approximately 8.6 wt. % Molybdenum (Mo), approximately 0.07 wt. % Titanium (Ti), approximately 0.4 wt. % Aluminum (Al), approximately 5.01 wt. % Niobium (Nb), approximately 0.03 wt. % Carbon (C), approximately 0.14 wt. % Silicon (Si), and a balance Nickel (Ni).

[0017] In a further non-limiting embodiment of the turbine airfoil, the component provides one of a turbine rotor blade and a turbine stator vane.

[0018] In a further non-limiting embodiment of the turbine airfoil, the component exhibits a tensile ductility within a range of 33% to 38% at 1400 °F.

[0019] These and other features of the present disclosure can be best understood from the following drawings and detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The drawings can be briefly described as follows:

[0021] Figure 1 illustrates an example process of forming an airfoil.

[0022] Figure 2 schematically illustrates an example additive manufacturing machine.

DETAILED DESCRIPTION

[0023] Figure 1 illustrates an example additive manufacturing process 10. The process 10 can be used to create airfoils including complex features, such as cooling passages, that are relatively difficult or impossible to produce using conventional processing techniques. The airfoils could be any type of rotating airfoil, including rotor blades or stator vanes a compressor, or turbine section of a gas turbine engine, for example. The airfoils could additionally be fan blades or struts within the fan section of a gas turbine engine. This application is not limited to airfoils used in gas turbine engines, however, and extends to airfoils for land-based turbines used in power plants, or in land-based turbines that drive pumps, as examples.

[0024] In the illustrated example, a powdered metal 12 used for forming an airfoil is provided within a machine 14. Using an additive manufacturing technique, the machine 14 deposits multiple layers of powdered metal onto one another. The layers are fused together with reference to computer aided drafting (CAD) data 16, which represents a particular airfoil design.

[0025] With reference to the CAD data 16, the airfoil is produced, at 18, by building up layers of the fused powdered metal. If desired, the airfoil can be post-processed, at 20, to provide desired structural characteristics. For example, the airfoil may further machined or heated to reconfigure the joined layers into a single crystalline structure. Alternatively or additionally, known coatings may be applied.

[0026] Figure 2 schematically illustrates an example additive manufacturing machine 14. In the example, powdered metal 12 is provided on a bed 22 and is fused by an additive manufacturing process. As illustrated, the additive manufacturing process is an electron beam fusing process, including an electron beam source 24 which generates an electron beam 26. In another example, the additive manufacturing process is a direct metal laser sintering process.

[0027] The powdered metal 12 is fused in a manufacturing environment 28 provided by the machine 14. In one example, the manufacturing environment 28 is a vacuum. That is, the manufacturing environment 28 provides an environment sealed off from external influences, and may have a pressure substantially less than atmospheric pressure. In a further example, the machining environment 28 is free of Argon (Ar).

[0028] Airfoils (e.g., rotor blades, stator vanes, fan blades) are required to be strong and ductile at the high temperatures commonly associated with turbines. Nickel (Ni)-based alloys have been used in the production of airfoils using laser melting processes, within Argon (Ar) rich environments, in which Argon (Ar) gas is the most abundant gas. Airfoils produced from such methods exhibit inconsistent properties at high temperatures due, at least in part, to impurities associated with the microstructure of the components.

[0029] When manufactured using additive manufacturing techniques in an Argon (Ar)-free manufacturing environment, however, airfoils formed of certain Nickel (Ni)-based alloys have enhanced ductility and strength at the elevated temperatures associated with the operation of gas turbine engines, as explained below.

[0030] A first example of such a Nickel (Ni)-based alloy includes Molybdenum (Mo) within a range of 7.7 to 9.5 wt. %, Titanium (Ti) within a range of 0.06 to 0.08 wt. %, Aluminum (Al) within a range of 0.3 to 0.5 wt. %, Niobium (Nb) within a range of 4.5 to 5.5 wt. %, Carbon (C) within a range of 0.02 to 0.04 wt. %, and a balance of Nickel (Ni) and alloying elements. The alloying elements, in a further example, include about 4.9 wt. % Iron (Fe), about 21 wt. % Chromium (Cr), and about 0.14 wt. % Silicon (Si).

[0031] A second example Nickel (Ni)-based alloy consistent with this disclosure is Alloy 625M. Alloy 625M includes about 4.8 wt. % Iron (Fe), about 21 wt. % Chromium (Cr), about 8.6 wt. % Molybdenum (Mo), about 0.07 wt. % Titanium (Ti), about 0.40 wt. % Aluminum (Al), about 5.01 wt. % Niobium (Nb), about 0.03 wt. % Carbon (C), about 0.14 wt. % Silicon (Si), and a balance of Nickel (Ni). As used herein, the terms "about" and "approximately" refer to a range of plus or minus 15%.

[0032] While these two example Nickel (Ni)-based alloys have been used in other manufacturing techniques, the properties of an airfoil cannot be predicted based on the selection of a particular manufacturing technique alone. For example, Alloys 625, 625M and 718 have inconsistent properties when formed using laser melting within an Argon (Ar) rich environment. When manufactured within an Argon (Ar)-free manufacturing environment, however, a Nickel (Ni)-based alloy having a composition consistent with the above two examples results in an airfoil with enhanced properties relative to Alloys 625 and 718.

[0033] For example, such airfoils exhibit a yield strength within a range of 133,000 psi (about 917 MPa) and 137,000 psi (about 945 MPa), and an ultimate tensile strength within a range of 178,000 psi (about 1,241 MPa) and 183,000 psi (about 1262 MPa) when at room temperature. At significantly higher temperatures such airfoils made of Alloy 625M in an Argon-free environment exhibit a tensile ductility within a range of 33% to 38% at 1400 °F (about 760 °C), while the same made in an Argon-rich environment exhibits a tensile ductility within a range of 14% and 16% at 1400 °F (about 760 °C). Further, such airfoils have reduced levels of Aluminum (Al)-based oxides (such as alumina, $AI2O_3$), thereby reducing fracture susceptibility at grain boundaries. In one example, such airfoils are free, or are substantially free, of Aluminum (Al)-based oxides. The enhanced strength, ductility, and fracture resistance of such airfoils was unexpected given what was known relative to Alloys 625, 625M and 718 in the context of laser melting within an Argon (Ar) rich environment.

[0034] Although the different examples have the specific components shown in the illustrations, embodiments of this invention are not limited to those particular combinations. It is possible to use some of the components or features from one of the examples in combination with features or components from another one of the examples.

[0035] One of ordinary skill in this art would understand that the above-described embodiments are exemplary and non-limiting. That is, modifications of this disclosure would come within the scope of the claims. Accordingly, the following claims should be studied to determine their true scope and content.

CLAIMS

What is claimed is:

1. A method of manufacturing an airfoil, the method comprising:

forming an airfoil using a powdered Nickel (Ni)-based alloy in an additive manufacturing process, wherein the powdered Nickel (Ni)-based alloy includes Molybdenum (Mo) within a range of 7.7 to 9.5 wt. %, Titanium (Ti) within a range of 0.06 to 0.08 wt. %, Aluminum (Al) within a range of 0.3 to 0.5 wt. %, Niobium (Nb) within a range of 4.5 to 5.5 wt. %, Carbon (C) within a range of 0.02 to 0.04 wt. %, and a balance Nickel (Ni) and alloy elements.

2. The method as recited in claim 1, further including establishing an Argon (Ar)-free environment, providing a bed within the Argon free environment, and positioning the powdered Nickel (Ni)-based alloy on the bed.

3. The method as recited in claim 2, further including providing data instructions for manufacturing the airfoil, and fusing the powdered Nickel (Ni)-based alloy using an electron beam with reference to the data instructions.

4. The method as recited in claim 1, wherein the airfoil is a turbine airfoil.

5. The method as recited in claim 4, wherein the airfoil is one of a rotor blade and a stator vane.

6. The method as recited in claim 1, wherein the alloy elements include about 4.9 wt. % Iron (Fe), about 21 wt. % Chromium (Cr), and about 0.14 wt. % Silicon (Si).

7. The method as recited in claim 1, wherein the powdered Nickel (Ni)-based alloy consists of about 4.8 wt. % Iron (Fe), about 21 wt. % Chromium (Cr), about 8.6 wt. % Molybdenum (Mo), about 0.07 wt. % Titanium (Ti), about 0.40 wt. % Aluminum (Al), about 5.01 wt. % Niobium (Nb), about 0.03 wt. % Carbon (C), about 0.14 wt. % Silicon (Si), and a balance Nickel (Ni).

8. The method as recited in claim 1, wherein the powdered Nickel (Ni)-based alloy consists essentially of about 4.8 wt. % Iron (Fe), about 21 wt. % Chromium (Cr), about 8.6 wt. % Molybdenum (Mo), about 0.07 wt. % Titanium (Ti), about 0.40 wt. % Aluminum (Al), about 5.01 wt. % Niobium (Nb), about 0.03 wt. % Carbon (C), about 0.14 wt. % Silicon (Si), and a balance Nickel (Ni).

9. The method as recited in claim 1, wherein the airfoil exhibits a tensile ductility within a range of 33% to 38% at 1400 °F.

10. The method as recited in claim 1, wherein the powdered Nickel (Ni)-based alloy is substantially free of Aluminum (Al)-based oxides.

11. A method of manufacturing an airfoil, the method comprising:

establishing an Argon (Ar)-free environment;

providing a bed within the Argon free environment;

providing a set of data instructions for manufacturing the airfoil;

providing a powdered Nickel (Ni)-based alloy on the bed, wherein the powdered Nickel (Ni)-based alloy consists essentially of about 4.8 wt. % Iron (Fe), about 21 wt. % Chromium (Cr), about 8.6 wt. % Molybdenum (Mo), about 0.07 wt. % Titanium (Ti), about 0.40 % Aluminum (Al), about 5.01 wt. % Niobium (Nb), about 0.03 wt. % Carbon (C), about 0.14 wt. % Silicon (Si), and a balance Nickel (Ni); and

fusing the powdered Nickel (Ni)-based alloy with an electron beam with reference to the data instructions to form the airfoil.

12. The method as recited in claim 11, wherein the powdered Nickel-based alloy consists of about 4.8 wt. % Iron (Fe), about 21 wt. % Chromium (Cr), about 8.6 wt. % Molybdenum (Mo), about 0.07 wt. % Titanium (Ti), about 0.40 % Aluminum (Al), about 5.01 wt. % Niobium (Nb), about 0.03 wt. % Carbon (C), about 0.14 wt. % Silicon (Si), and a balance Nickel (Ni).

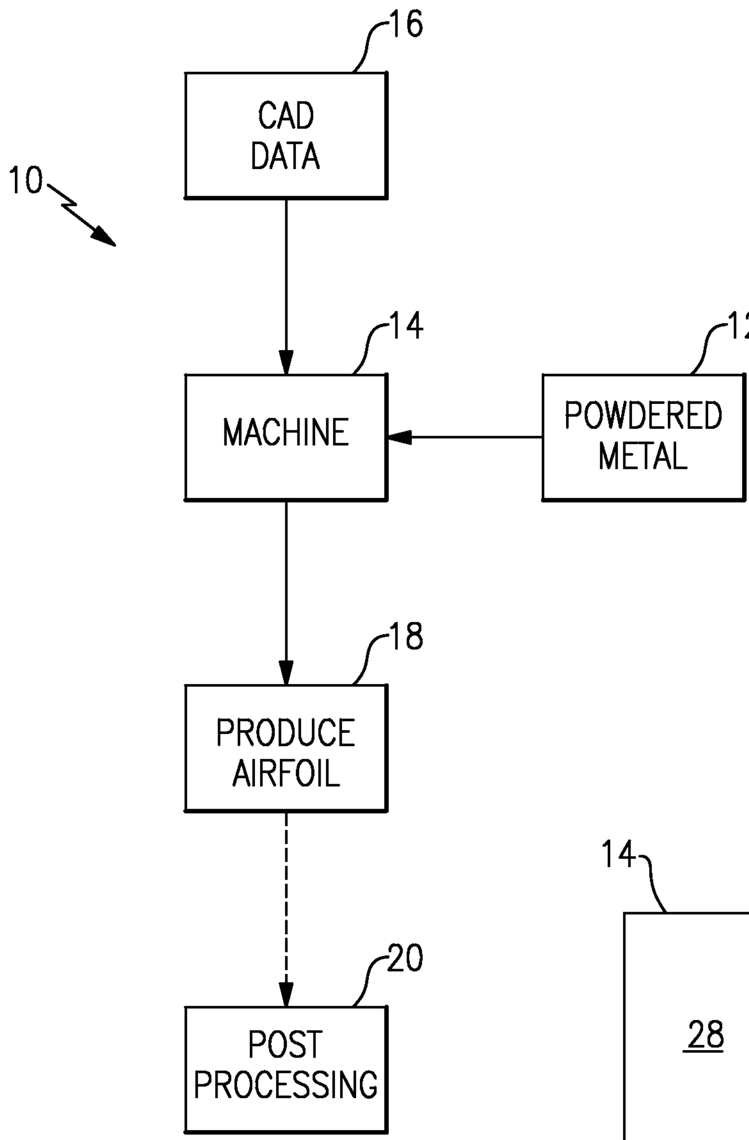
13. The method as recited in claim 11, further including removing excess, unfused powdered Nickel (Ni)-based alloy from the bed.

14. A turbine airfoil comprising:

an electron beam formed component with a chemical composition consisting essentially of approximately 4.9 wt. % Iron (Fe), approximately 21 wt. % Chromium (Cr), approximately 8.6 wt. % Molybdenum (Mo), approximately 0.07 wt. % Titanium (Ti), approximately 0.4 wt. % Aluminum (Al), approximately 5.01 wt. % Niobium (Nb), approximately 0.03 wt. % Carbon (C), approximately 0.14 wt. % Silicon (Si), and a balance Nickel (Ni).

15. The turbine airfoil as recited in claim 14, wherein the component provides one of a turbine rotor blade and a turbine stator vane.

16. The turbine airfoil as recited in claim 14, wherein the component exhibits a tensile ductility within a range of 33% to 38% at 1400 °F.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14
MACHINE
12
POWDERED METAL
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PRODUCE AIRFOIL
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POST PROCESSING

FIG.1

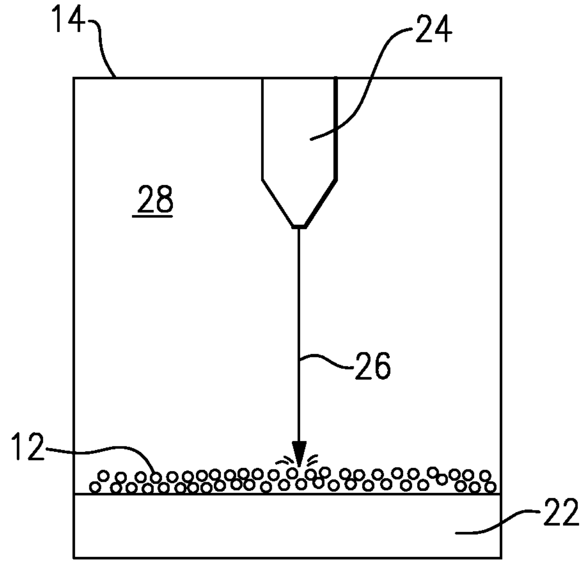
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FIG.2