process. Cracking of parts can be caused by a number of factors such as thermal stresses, hot cracking, and liquation cracking, and generally the potential for cracking increases as the hardness of the built parts increases and the toughness decreases.

Numerous industries have a great deal of interest in utilizing PBF with higher hardness materials (HV> 370) for applications such as tooling, dies, molds, cutting tools, gears, filters, and bearings. In addition to high hardness these applications typically also require high strength, toughness, and corrosion resistance, low environmental health, low safety and stewardship risk, and low cost.

Summary

An aspect of the present invention provides a method of layer-by-layer construction of a metallic part comprising supplying an iron-based alloy in particle form including the elements Cr and Mo wherein Cr is present at 10.0 wt. % to 19.0 wt. %, Mo is present at 0.5 wt. % to 3.0 wt. % and at least three elements from C, Ni, Cu, Nb, Si and N, wherein C is present at 0.1 to 0.35 wt. %, Ni is present at 0 to 5.0 wt. %, Cu is present at 0 to 5.0 wt. %, Nb is present at 0 to 1.0 wt. %, Si is present at 0 to 1.0 wt. % and N is present at 0 to 0.25 wt. %;

the balance of said alloy composition containing Fe; and

forming one or more layers of the alloy at least in part by powder bed fusing comprising melting the alloy into a molten state and cooling and forming a solidified layer of the elements wherein each of the solid layers has a thickness as formed of 2.0 microns to 200.0 microns. The metallic part comprising one or more layers has the following properties: tensile strength of at least 1000 MPa, yield strength of at least 640 MPa, elongation of at least 3.0%, hardness (HV) of at least 375.

Another aspect of the present invention provides a 3D printed metallic part comprising one or more iron based metallic alloy layers including the elements Cr and Mo wherein Cr is present at 10.0 wt. % to 19.0 wt. %, Mo is present at 0.5 wt. % to 3.0 wt. % and at least three elements from C, Ni, Cu, Nb, Si and N, wherein C is present at 0.1 to 0.35 wt. %, Ni is present at 0 to 5.0 wt. %, Cu is present at 0 to 5.0 wt. %, Nb is present at 0 to 1.0 wt. %, Si is present at 0 to 1.0 wt. % and N is present at 0 to 0.25 wt. % and the balance of said alloy composition contains Fe;

said layers having thickness in the range of 2.0 microns to 200.0 microns; and

said printed metallic part indicates a tensile strength of at least 1000 MPa, yield strength of at least 640 MPa, elongation of at least 3.0%, and hardness (HV) of at least 375.

Brief Description of the Figures

FIG. 1 is an optical image of alloy 1 (A10) built on a SLM 280 HL machine.

FIG. 2 is an optical image of alloy 1 (A10) built on a Trumpf TRUMAFORM LF 250 PBF machine.

FIG. 3 is an optical image of alloy 1 (A10) built on an EOS machine with a density >99.5 %.

FIG. 4 shows a 10,000x SEM micrograph of as-built alloy 1 (A10).

FIG. 5 shows the alloy 1 equilibrium phase diagram produced with Thermo-Calc.

FIG. 6 shows microstructures at the surface of a part made of alloy 5 (Table 1) at two different magnifications after carburization.

FIG. 7 shows hardness as a function of depth in a carburized case hardened alloy 5 and alloy 8 (Table 1).

FIG. 8 shows microstructures at the surface of a part of alloy 9 (Table 1) at two different magnifications after nitriding.

FIG. 9 shows hardness as a function of depth in a nitrided case hardened alloy 8 and 9 (Table 1).

Detailed Description

A new class of steel alloys have been developed that combine excellent printability with, in both the “as built” and in the “heat treated” state, high hardness (> 375 HV), high yield and tensile strength, and high elongation as well as low safety (EH&S) and stewardship risk and relatively low cost.

Claims:

1. A method of layer-by-layer construction of a metallic part comprising:

supplying an iron-based alloy in particle form including the elements Cr and Mo wherein Cr is present at 10.0 wt. % to 19.0 wt. %, Mo is present at 0.5 wt. % to 3.0 wt. % and at least three elements from C, Ni, Cu, Nb, Si and N, wherein C is present at 0.1 to 0.35 wt. %, Ni is present at 0 to 5.0 wt. %, Cu is present at 0 to 5.0 wt. %, Nb is present at 0 to 1.0 wt. %, Si is present at 0 to 1.0 wt. % and N is present at 0 to 0.25 wt. %;

the balance of said alloy composition containing Fe; and

forming one or more layers of the alloy at least in part by powder bed fusing comprising melting the alloy into a molten state and cooling and forming a solidified layer of the elements wherein each of the solid layers has a thickness as formed of 2.0 microns to 200.0 microns;

said metallic part having the following properties: tensile strength of at least 1000 MPa, yield strength of at least 640 MPa, elongation of at least 3.0%, hardness (HV) of at least 375.

2. The method of claim 1 wherein Cr is present at 10.0 wt. % to 18.3 wt. %, Mo is present at 0.89 wt. % to 2.5 wt. %, C is present at 0.1 to 0.30 wt. %, Ni is present at 0 to 2.5 wt. %, Cu is present at 0 to 2.56 wt. %, Nb is present at 0 to 0.7 wt. %, Si is present at 0 to 0.7 wt. % and N is present at 0 to 0.25 wt. %, the balance Fe.

3. The method of claim 1 wherein said alloy comprises Fe at 82.0 wt. % to 86.0 wt. %; Cr at 10.5 wt. % to 12.0 wt. %; Ni at 0 to 2.5 wt. %; Cu at 0.4 wt. % to 0.7 wt. %; Mo at 1.2 wt. % to 1.8 wt. %; C at 0.14 wt. % to 0.18 wt. %; Nb at 0.02 wt. % to 0.05 wt. %; N at 0.04 to 0.07 wt. % and Si at 0 to 1.0 wt. %.

4. The method of claim 1 wherein said metallic part has the following properties: a tensile strength of 1000 MPa to 1900 MPa, a yield strength of 640 MPa to 1500 MPa, an elongation of 3.0% to 25.0%, and a hardness (HV) of 375 to 600.

5. The method of claim 1 wherein said layers have a thickness of 2.0 microns to 200 microns.

6. The method of claim 1 wherein the melting is achieved by laser or electron beams with an energy density in the range of 30 J/mm3 to 500 J/mm3.

7. The method of claim 1 wherein the metallic part is built in a nitrogen and/or argon atmosphere.

8. The method of claim 1 wherein said metallic part is built on a substrate that is preheated to a temperature of less than or equal to 300°C.

9. The method of claim 1 wherein the metallic part undergoes solutionizing at a temperature of greater than 900 °C followed by a gas quench and cooling.

10. The method of claim 9 wherein said metallic part after cooling is tempered at temperature at or above 150 °C.

11. The method of claim 9 wherein said metallic part indicates a tensile strength of at least 1000 MPa, a yield strength of at least 900 MPa, an elongation of at least 1.0 % and a hardness (HV) of at least 475.

12. The method of claim 1 wherein said metallic part is carburized to increase the level of carbon from the surface down to a depth of 4.0 mm.

13. The method of claim 1 wherein said metallic part is nitrided to increase the level of nitrogen from the surface down to a depth of 400 μm.

14. The method of claim 1 wherein alloy includes at least four elements selected from C, Ni, Cu, Nb, Si and N.

15. The method of claim 1 wherein said alloy includes at least five elements selected from C, Ni, Cu, Nb, Si and N.

16. The method of claim 1 wherein said alloy includes C, Ni, Cu, Nb, Si and N.

17. A 3D printed metallic part comprising:

one or more iron based metallic alloy layers including the elements Cr and Mo wherein Cr is present at 10.0 wt. % to 19.0 wt. %, Mo is present at 0.5 wt. % to 3.0 wt. % and at least three elements from C, Ni, Cu, Nb, Si and N, wherein C is present at 0.1 to 0.35 wt. %, Ni is

present at 0 to 5.0 wt. %, Cu is present at 0 to 5.0 wt. %, Nb is present at 0 to 1.0 wt. %, Si is present at 0 to 1.0 wt. % and N is present at 0 to 0.25 wt. % and the balance of said alloy composition contains Fe;

said layers having thickness in the range of 2.0 microns to 200.0 microns; and

said printed metallic part indicates a tensile strength of at least 1000 MPa, yield strength of at least 640 MPa, elongation of at least 3.0%, and hardness (HV) of at least 375.

18. The printed metallic part of claim 17 wherein Cr is present at 10.0 wt. % to 18.3 wt. %, Mo is present at 0.89 wt. % to 2.5 wt. %, C is present at 0.1 to 0.30 wt. %, Ni is present at 0 to 2.5 wt. %, Cu is present at 0 to 2.56 wt. %, Nb is present at 0 to 0.7 wt. %, Si is present at 0 to 0.7 wt. % and N is present at 0 to 0.25 wt. %, the balance Fe.

19. The printed metallic part of claim 17 wherein said alloy includes at least four elements selected from C, Ni, Cu, Nb, Si and N.

20. The printed metallic part of claim 17 wherein said alloy includes at least five elements selected from C, Ni, Cu, Nb, Si and N.

21. The printed metallic part of claim 17 wherein said alloy includes C, Ni, Cu, Nb, Si and N.

22. The printed metallic part of claim 17 wherein said part indicates a tensile strength of 1000 MPa to 1900 MPa, a yield strength of 640 MPa to 1500 MPa, an elongation of 3.0% to 25.0%, and a hardness (HV) of 375 to 600.