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(54) Low porosity powder metallurgy produced components

(57) Components produced by powder metallurgy techniques are described herein. Embodiments of these components have little or no porosity therein after processing. Embodiments of these components are created by creating a preform from a powder; creating a component from the preform; heat treating the component to create a predetermined microstructure therein; and then hot isostatic pressing the heat treated component to reduce any porosity therein. The components can then be machined to their final dimensions, if necessary.

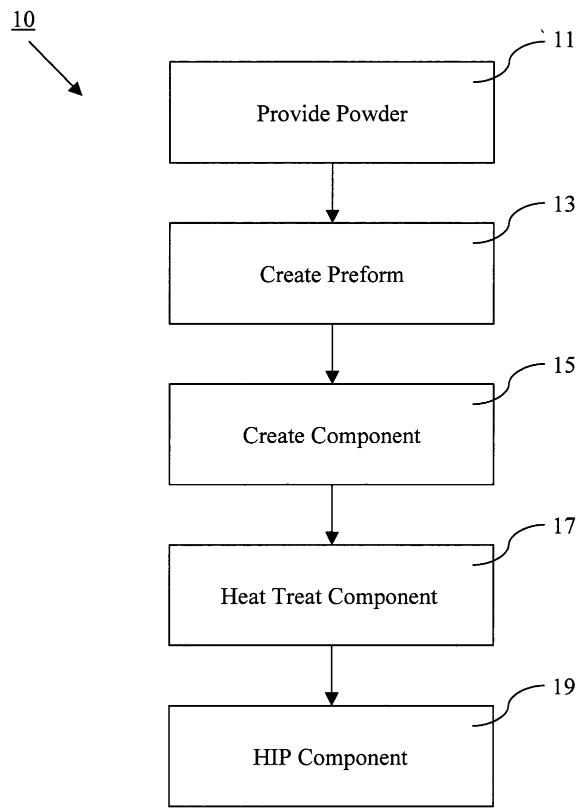


FIGURE 1

EP 1 649 954 A2

Description

[0001] The present invention relates generally to components prepared by powder metallurgy techniques. More specifically, the present invention relates to hot isostatic pressing such components after heat treating to eliminate, or at least minimize or shrink, any porosity therein.

[0002] The efficiency of high performance gas turbine engines increases with increasing operating temperatures. Therefore, there is a large incentive to raise the combustion and exhaust gas temperatures of such engines. However, while increased operating temperatures are desired, there is also a large incentive to decrease the weight of the rotating components as much as possible, to increase the thrust-to-weight ratio of the engines, particularly for aerospace applications. Thus, there is a desire to have components that are lighter than existing components.

[0003] Two-phase gamma-TiAl based intermetallic alloys have received considerable attention as potential materials for high-temperature aerospace and automotive applications, particularly as possible replacements for conventional nickel and titanium alloys in gas turbine engines. Such alloys exhibit improved high temperature mechanical properties and improved oxidation resistance as compared to conventional high temperature titanium alloys. Furthermore, such alloys have good creep resistance and strength at elevated temperatures, and have a lower density than conventional nickel and titanium alloys. Such alloys could be used to make lightweight gas turbine engine components, such as blades, vanes, disks, etc., where higher operating temperatures would allow increased efficiency to be achieved.

[0004] Powder metallurgy techniques can produce components having greater homogeneity than cast components, and higher strengthener content than conventionally wrought components. Therefore, it may be desirable to use powder metallurgy techniques to form such components.

[0005] However, the powder metallurgy techniques currently used to produce such components often create components having porosity therein that is too large or too numerous for many applications. Therefore, it would be desirable to have improved powder metallurgy techniques for producing such components. It would also be desirable to have methods for minimizing the porosity in such components, or at least reducing the porosity therein to an acceptable level. It would be further desirable to have powder metallurgy processing techniques that are useful for a variety of materials.

[0006] The above-identified shortcomings are overcome by embodiments of the present invention, which relates to improved powder metallurgy processing techniques that can be used to produce components having an acceptable level of porosity therein. These techniques may be utilized with a variety of materials to create various components, such as, but not limited to, gas turbine engine components.

[0007] Embodiments of this invention comprise components and methods for forming such components, comprising: providing a powder; creating a preform from the powder; creating a component from the preform; heat treating the component to create a predetermined microstructure therein; and hot isostatic pressing the heat treated component to reduce any porosity therein. Embodiments may further comprise machining the heat treated and hot isostatic pressed component to its final dimensions. Any porosity remaining in the heat treated and hot isostatic pressed component is generally less than about 0.005 (0.13 mm) in size. This invention may be utilized to create gas turbine engine components such as, but not limited to, compressor disks, compressor blades, low pressure turbine blades, and tangential on board injectors.

[0008] Creating the preform from the powder may comprise hot isostatic pressing the powder at a temperature sufficient to densify the preform and consolidate the powder through bonding thereof. In embodiments, this hot isostatic pressing may occur at about 925-1320°C and about 15-45 ksi (103-310 MPa) for about 2-10 hours in an argon atmosphere. More specifically, in embodiments, this hot isostatic pressing may occur at about 1260°C and about 25 ksi (172 MPa) for about 4 hours in an argon atmosphere.

[0009] The component may be created from the preform in numerous ways, such as via extrusion and/or isothermal forging, etc. In embodiments, the component may be created from the preform at a temperature below the alpha transus temperature of the powder so that a near gamma microstructure exists in the preform.

[0010] Heat treating the component occurs at a time and temperature sufficient to create the desired microstructure in the component. In embodiments, this heat treating may occur at a temperature above the alpha transus temperature of the powder, for example, at about 925-1370°C for about 2-10 hours, to create a lamellar microstructure in the component. More specifically, in embodiments, this heat treating may occur at about 1354°C for about 4 hours.

[0011] After heat treating, the component is hot isostatic pressed at a temperature low enough to prevent significant grain growth from occurring in the component. In embodiments, this temperature may preserve a lamellar microstructure in the component, and be carried out at about 925-1320° C and about 15-45 ksi (103-310 MPa) for about 2-10 hours. More specifically, in embodiments, this hot isostatic pressing may be carried out at about 1232°C and about 25 ksi (172 MPa) for about 10 hours. After this hot isostatic pressing step, the component will have less or smaller porosity than existed in the component prior to this step.

[0012] The powder utilized in this invention may comprise any suitable material, including, but not limited to, gamma-TiAl, nickel aluminides, iron aluminides, titanium alloys, and superalloys. In embodiments, the powder may comprise about 44-48 atomic percent aluminum, about 1-2 atomic percent niobium, about 1-2 atomic percent chromium, about 1-2 atomic percent molybdenum, about 0.1-0.2 atomic percent boron, and about 0.1-0.2 atomic percent carbon, the balance substantially titanium. The powder may have an average particle size of about 70μm.

[0013] Further details of this invention will be apparent to those skilled in the art during the course of the following description.

[0014] Certain preferred embodiments of the present invention are described below by way of example only, with reference to the drawings, wherein like characters of reference designate like parts throughout the drawings, in which:

Figure 1 is a flowchart showing an exemplary powder metallurgy processing technique that may be utilized in embodiments of this invention to create a component having minimal or no porosity;

Figure 2 is a SEM photomicrograph showing the near gamma microstructure of a disk utilized in embodiments of this invention;

Figure 3 is a SEM photomicrograph showing the lamellar microstructure of the disk of Figure 2 after it was heat treated;

Figure 4 is an ultrasonic C-scan showing a portion of the heat treated disk of Figure 3, showing two visible flaws;

Figures 5 (a) and (b) are ultrasonic A-scans confirming the presence of the flaws depicted in Figure 4;

Figure 6 is an ultrasonic C-scan showing the same portion of the disk of Figure 3 after the heat treated disk was hot isostatic pressed, showing no visible indication of the flaws identified in Figures 4 and 5;

Figures 7 (a) and (b) are ultrasonic A-scans confirming the elimination of the flaws identified in Figures 4 and 5; and

Figure 8 is a SEM photomicrograph showing that the lamellar microstructure of the disk of Figure 3 was maintained after the heat treated disk was hot isostatic pressed.

[0015] For the purposes of promoting an understanding of the invention, reference will now be made to some embodiments of this invention as illustrated in FIGURES 1-8 and specific language used to describe the same. The terminology used herein is for the purpose of description, not limitation. Specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a basis for teaching one skilled in the art to variously employ the present invention.

[0016] This invention relates to improved powder metallurgy processed components that have little or no porosity therein. Powder metallurgy techniques are used to make the components of this invention because such techniques provide microstructural and chemical homogeneities in the consolidated powder, and therefore, also in the final extruded and/or forged components produced therefrom. This invention may be utilized with any material formed from a rapidly solidified powder produced by powder metallurgy in insoluble gas (i.e., argon or helium), and having thermally induced porosity therein in its consolidated and heat treated form. Materials created from powders produced via powder metallurgy in argon or helium gas generally contain thermally induced porosity after heat treatment because argon and helium are both insoluble in metals, and when heat treated at elevated temperatures, these gases become mobile and precipitate as pores (i.e., as thermally induced porosity) in the material.

[0017] Embodiments of this invention comprise the general powder metallurgy technique 10 shown in Figure 1. First, a powder may be provided 11. Next, a preform may be created 13 from the powder. Thereafter, a component may be created 15 from the preform. Next, the component may be heat treated 17 to create a desired microstructure therein. Thereafter, the component may be hot isostatic pressed 19 to minimize any porosity therein that is created during heat treatment. Thereafter, if the component is not already in its final desired shape or form, the component can then be machined or otherwise formed into its final desired shape, form or dimensions.

[0018] The powders 11 utilized in this invention may comprise any rapidly solidified, insoluble gas produced powder, such as, but not limited to, gamma-TiAl powders, nickel aluminide powders, iron aluminide powders, titanium alloy powders, any other superalloy powders utilized to make gas turbine engine components, etc. In embodiments, argon gas atomized gamma-TiAl powder may be desirable because it comprises a fine grain microstructure with virtually no chemical segregation. Furthermore, such gamma-TiAl components may be used instead of the superalloy components currently used in many gas turbine engine components. As used herein and throughout, "gamma titanium aluminides" and derivations thereof (i.e., gamma-TiAl, γ-TiAl, etc.) are those compositions that are capable of forming the two-phase ($\gamma + \alpha_2$) microstructure found generally centered around about 44-48 atomic percent aluminum in the binary titanium-aluminum phase diagram. Alloying additions of X, where X may include, but is not limited to, chromium, niobium, molybdenum, boron, and/or carbon, etc., may be provided in embodiments of this invention to modify and/or improve the properties of the alloy for a given application.

[0019] The preform may be formed 13 from the powder in any suitable manner, such as, for example, by hot isostatic pressing, hot die compaction, etc. In embodiments, the powder may be canned and hot isostatic pressed at a temperature sufficient to densify the preform and consolidate the powder through bonding thereof. Hot isostatic pressing the powder in this manner allows the powder grains to connect metallically and/or to sinter together. In gamma-TiAl embodiments, the preform should have a near gamma microstructure if the hot isostatic pressing is performed below the alpha transus temperature (T_α) of the powder.

[0020] Once the preform is created, the component can be created 15 therefrom in any suitable manner, such as, for example, by forging, extrusion, and/or by a combination of extrusion and then forging, etc. In some embodiments, the preform may be isothermally forged to create a desired component, such as a disk. In gamma-TiAl embodiments, the extrusion and/or isothermal forging are typically carried out at a temperature in the ($\alpha + \gamma$) phase field of the Ti-Al phase diagram, which is well below T_α for this material. Therefore, gamma-TiAl components should have a near gamma microstructure after they are formed. In other embodiments (i.e., nickel aluminides, iron aluminides, other titanium alloys and other superalloys), the extrusion and/or isothermal forging may be carried out at temperatures as high as about 1023°C or higher.

[0021] Once the component is created, the component can be heat treated 17 to create the desired microstructure therein. Since fully lamellar microstructures are strong and crack resistant, they are desirable in many applications. A crack resistant lamellar microstructure can be achieved in gamma-TiAl components by heat treating the component at a temperature above the T_α of the component alloy. In other embodiments (i.e., nickel aluminides, iron aluminides, other titanium alloys and other superalloys), heat treating at temperatures of about 1000-1200°C for about 2-4 hours may be used to create a desirable microstructure in the components.

[0022] Such elevated temperature heat treatment often leaves behind cavities in the component, which can be confirmed in various manners, such as, for example, by ultrasonic scanning, x-ray radiography, serial sectioning, etc. In embodiments, it is believed that such porosity may be thermally induced porosity that is created by the argon or other insoluble gas that is entrapped in the powder, which agglomerates in the form of cavities/pores during heat treatment. This is an undesirable condition known as thermally induced porosity. Regardless of the mechanism of formation, this porosity may be much larger than acceptable for many components. Furthermore, depending upon how this porosity was formed, the porosity may be associated with grain boundaries, which may reduce the low cycle fatigue properties of the final component by serving as preferential sites for crack initiation. Therefore, this porosity must be eliminated, or at least be reduced to an acceptable level, in order for powder metallurgy techniques to be acceptably utilized for forming many components.

[0023] It has been discovered that hot isostatic pressing 19 the component after heat treating 17 may eliminate the porosity therein, or at least reduce the porosity therein to an acceptable level. Hot isostatic pressing can eliminate internal voids and microporosity in a component through a combination of plastic deformation, creep and diffusion, thereby producing a denser component. This hot isostatic pressing step should have minimal effect on the microstructure, other than decreasing the amount or size of porosity therein. A simple calculation may be done to show whether or not the compressive creep strain that is developed during this hot isostatic pressing step is enough to heal the porosity therein sufficiently to make the component acceptable for use for a given application. Alternatively, ultrasonic inspection may be utilized to verify that any porosity remaining in the component is acceptable.

[0024] Once the component is heat treated and hot isostatic pressed, it may be machined or otherwise formed to its desired final dimensions, if necessary. The fully lamellar microstructure of the gamma-TiAl components should be maintained if this additional processing step is carried out at a temperature below the T_α of the component alloy.

[0025] The powder metallurgy processing techniques of this invention may be utilized to make a variety of components, such as, for example, gas turbine engine components (i.e., compressor disks, compressor blades, low pressure turbine blades, tangential on board injectors, etc.) or any other components that may be exposed to high mechanical loads at high temperatures.

EXAMPLE

[0026] An exemplary non-limiting sample gamma-TiAl disk was made and evaluated to verify this invention. This sample was prepared utilizing argon gas atomized gamma-TiAl powder 11 having a nominal composition, in atomic percent, of Ti-46Al-3.7(Nb,Cr,Mo)-0.4(B,C) and having an average particle size of about 70μm. A preform was created 13 by canning and hot isostatic pressing this powder at about 1260°C and about 25 ksi (172 MPa) for about 4 hours in an argon atmosphere. Once the preform was consolidated, the preform was isothermally forged 15 into a disk in a two-step operation in the ($\alpha + \gamma$) phase field at about 1177°C using about an 85% reduction. At this point, the disk had a near gamma microstructure, as shown in Figure 2. The disk was then heat treated 17 at about 1354°C for about 4 hours under vacuum to create a fully lamellar microstructure comprising alternating platelets of γ-TiAl phase and α_2-Ti_3Al with an average lamellar grain size of about 250μm, as shown in Figure 3. In general, gamma-TiAl having a duplex microstructure provides better elongation and strength properties, whereas gamma-TiAl having a lamellar microstructure provides better creep resistance, toughness, and crack resistance. Ultrasonic scans and serial sectioning indicated that a small amount of cavities/pores 50, 55 existed in this heat treated disk, as shown in Figure 4. As shown in Figures 5 (a) and (b), ultrasonic scans confirmed the presence of this porosity 50, 55. This porosity 50, 55, which had diameters of about 0.013" (0.33 mm) and 0.019" (0.48 mm) respectively, was much larger than acceptable for many components, such as for rotating compressor disks used in gas turbine engines. Therefore, further processing was undertaken in an attempt to eliminate this porosity 50, 55. In that regard, the heat treated disk was hot isostatic pressed 19 at about 1232°C and about 25 ksi (172 MPa) for about 10 hours in an argon atmosphere in an attempt to minimize the porosity 50, 55 therein. As shown in Figures 6 and 7 (a) and (b), ultrasonic scanning confirmed that, after hot isostatic pressing, the porosity 50, 55 that had previously existed in the heat treated disk was eliminated. Furthermore, as can be seen in Figures 3 and 8, no significant changes were detected in the microstructure of the heat treated disk after hot isostatic pressing (Figure 8) as compared to before hot isostatic pressing (Figure 3).

[0027] As described above, this invention provides improved powder metallurgy processing techniques for producing components having little or no porosity therein. Advantageously, these techniques can be used with a variety of materials to produce components that have good mechanical properties at elevated temperatures. These techniques may be utilized to make gas turbine engine components and other components that are subjected to high mechanical loads at high temperatures. Many other embodiments and advantages will be apparent to those skilled in the relevant art.

[0028] Various embodiments of this invention have been described in fulfillment of the various needs that the invention meets. It should be recognized that these embodiments are merely illustrative of the principles of various embodiments of the present invention. Numerous modifications and adaptations thereof will be apparent to those skilled in the art without departing from the scope of the present invention. For example, while gamma-TiAl powders were described herein in one non-limiting exemplary embodiment, this invention is not limited to use with such powders. This invention may be used with any rapidly solidified, insoluble gas produced powder that creates thermally induced porosity in a component during heat treatment thereof. Thus, it is intended that the present invention cover all suitable modifications and variations as come within the scope of the appended claims and their equivalents.

Claims

1. A method for forming a component comprising:

providing a powder;
creating a preform from the powder;
creating a component from the preform;
heat treating the component to create a predetermined microstructure therein; and
hot isostatic pressing the heat treated component to reduce any porosity therein.

2. The method of claim 1, wherein the powder comprises at least one of: a gamma-TiAl powder, a nickel aluminide powder, an iron aluminide powder, a titanium alloy powder, and a superalloy powder.

3. The method of claim 1, wherein the powder comprises about 44-48 atomic percent aluminum, about 1-2 atomic percent niobium, about 1-2 atomic percent chromium, about 1-2 atomic percent molybdenum, about 0.1-0.2 atomic percent boron, and about 0.1-0.2 atomic percent carbon, the balance substantially titanium.

4. The method of claim 1, 2 or 3, wherein the powder has an average particle size of about 70 μm.

5. The method of any preceding claim, wherein creating the preform from the powder comprises hot isostatic pressing the powder at a temperature sufficient to densify the preform and consolidate the powder through bonding thereof.

6. The method of claim 5, wherein hot isostatic pressing the powder occurs at about 925-1320°C and about 15-45 ksi (103-310 MPa) for about 2-10 hours.

7. The method of claim 5 or 6, wherein hot isostatic pressing the powder occurs in an argon atmosphere.

8. The method of any preceding claim, wherein the component is created from the preform via at least one of: extrusion and isothermal forging.

9. The method of any preceding claim, wherein the component is created from the preform at a temperature below the alpha transus temperature of the powder.

10. The method of any preceding claim, wherein after the component is created, and prior to heat treating the component, the component comprises a near gamma microstructure.

11. The method of any preceding claim, wherein heat treating the component occurs at a temperature above the alpha transus temperature of the powder.

12. The method of any preceding claim, wherein heat treating the component occurs at about 925-1370°C for about 2-10 hours.

13. The method of any preceding claim, wherein the predetermined microstructure is a lamellar microstructure.

14. The method of any preceding claim, wherein hot isostatic pressing the heat treated component occurs at a temperature low enough to prevent significant grain growth from occurring in the component.

15. The method of any preceding claim, wherein hot isostatic pressing the heat treated component occurs at a temperature sufficient to preserve a lamellar microstructure in the component.

16. The method of claim 1, wherein hot isostatic pressing the heat treated component occurs at about 925-1320°C and about 15-45 ksi (103-310MPa) for about 2-10 hours.

17. The method of any preceding claim, wherein any porosity in the heat treated and hot isostatic pressed component is less than about 0.005 inches (0.13mm) in size.

18. The method of any preceding claim, further comprising:

machining the heat treated and hot isostatic pressed component to its final dimensions.

19. The method of any preceding claim, wherein the component comprises a gas turbine engine component.

20. The method of claim 19, wherein the gas turbine engine component comprises at least one of: a compressor disk, a compressor blade, a low pressure turbine blade, and a tangential on board injector.

21. A method for forming a component compri sing:

providing a gamma-TiAl powder;
consolidating the gamma-TiAl powder into a preform;
creating a component from the preform;
heat treating the component to create a predetermined microstructure therein; and
hot isostatic pressing the heat treated component to reduce any porosity therein.

22. The method of claim 21, wherein the gamma-TiAl powder comprises about 44-48 atomic percent aluminum, about 1-2 atomic percent niobium, about 1-2 atomic percent chromium, about 1-2 atomic percent molybdenum, about 0.1-0.2 atomic percent boron, and about 0.1-0.2 atomic percent carbon, the balance substantially titanium.

23. The method of claim 21 or 22, wherein the gamma-TiAl powder has an average particle size of about 70 μm.

24. The method of claim 21, wherein consolidating the gamma- TiAl powder into a preform comprises hot isostatic pressing the gamma-TiAl powder at about 1260°C and about 25 ksi (172 MPa) for about 4 hours in an argon atmosphere.

25. The method of any of claims 21 to 24, wherein the component is created from the preform via at least one of: extrusion and isothermal forging.

26. The method of any of claims 21 to 25, wherein after the component is created, and prior to heat treating the component, the component comprises a near gamma microstructure.

27. The method of any of claims 21 to 26, wherein heat treating the component to create a predetermined microstructure therein comprises heat treating the component at about 1354°C for about 4 hours.

28. The method of any of claims 21 to 27, wherein the predetermined microstructure is a lamellar microstructure.

29. The method of any of claims 21 to 28, wherein hot isostatic pressing the heat treated component occurs at about 1232°C and about 25 ksi (172 MPa) for about 10 hours.

30. The method of any of claims 21 to 29, wherein the microstructure of the heat treated and hot isostatic pressed component comprises a lamellar microstructure substantially similar to the lamellar microstructure that existed in the heat treated component prior to being hot isostatic pressed.

31. The method of any of claims 21 to 30, wherein the heat treated and hot isostatic pressed component has less porosity than the heat treated component prior to being hot isostatic pressed.

32. The method of any of claims 21 to 31, wherein any porosity in the heat treated and hot isostatic pressed component is less than about 0.005 inches.

33. The method of any of claims 21 to 32, further comprising:

machining the heat treated and hot isostatic pressed component to its final dimensions.

34. The method of any of claims 21 to 33, wherein the component comprises a gas turbine engine component.

35. The method of claim 34, wherein the gas turbine engine component comprises at least one of: a compressor disk, a compressor blade, a low pressure turbine blade, and a tangential on board injector.

36. A component formed by the method of any preceding claim.

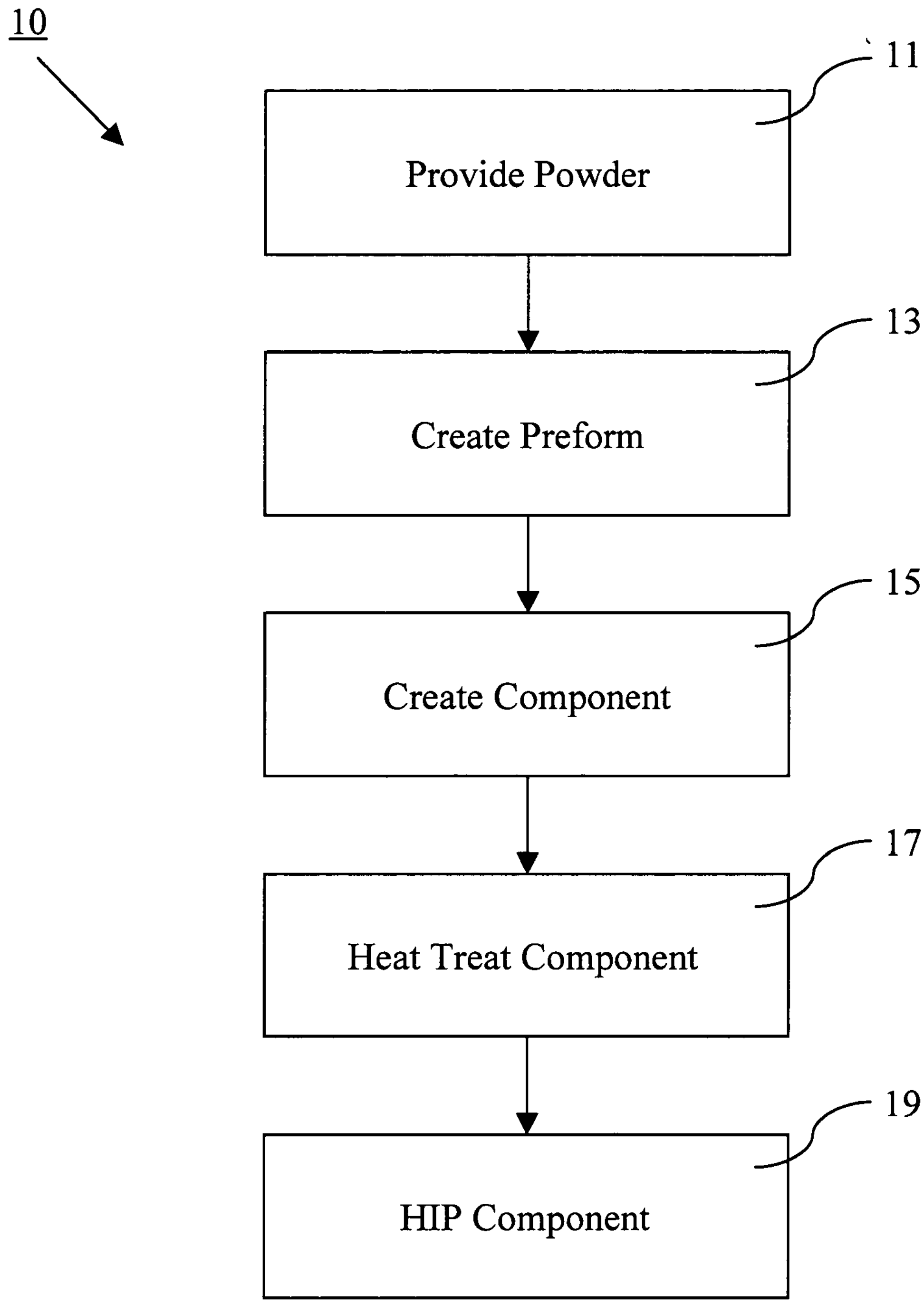

10
11
Provide Powder
13
Create Preform
15
Create Component
17
Heat Treat Component
19
HIP Component

FIGURE 1

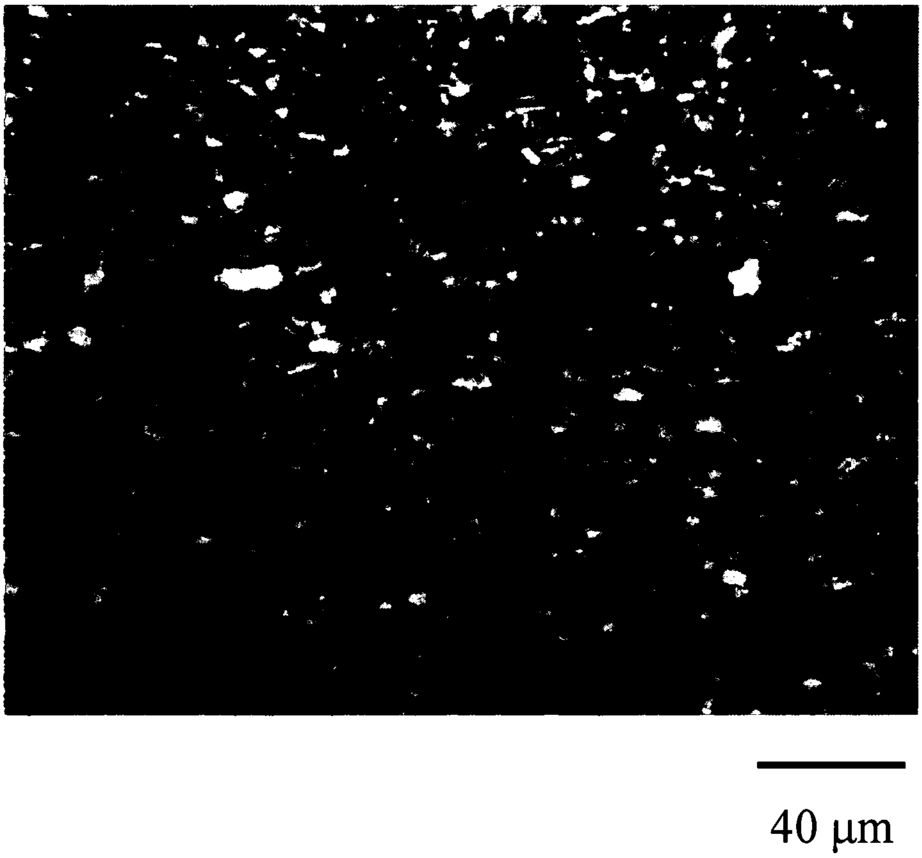


FIGURE 2

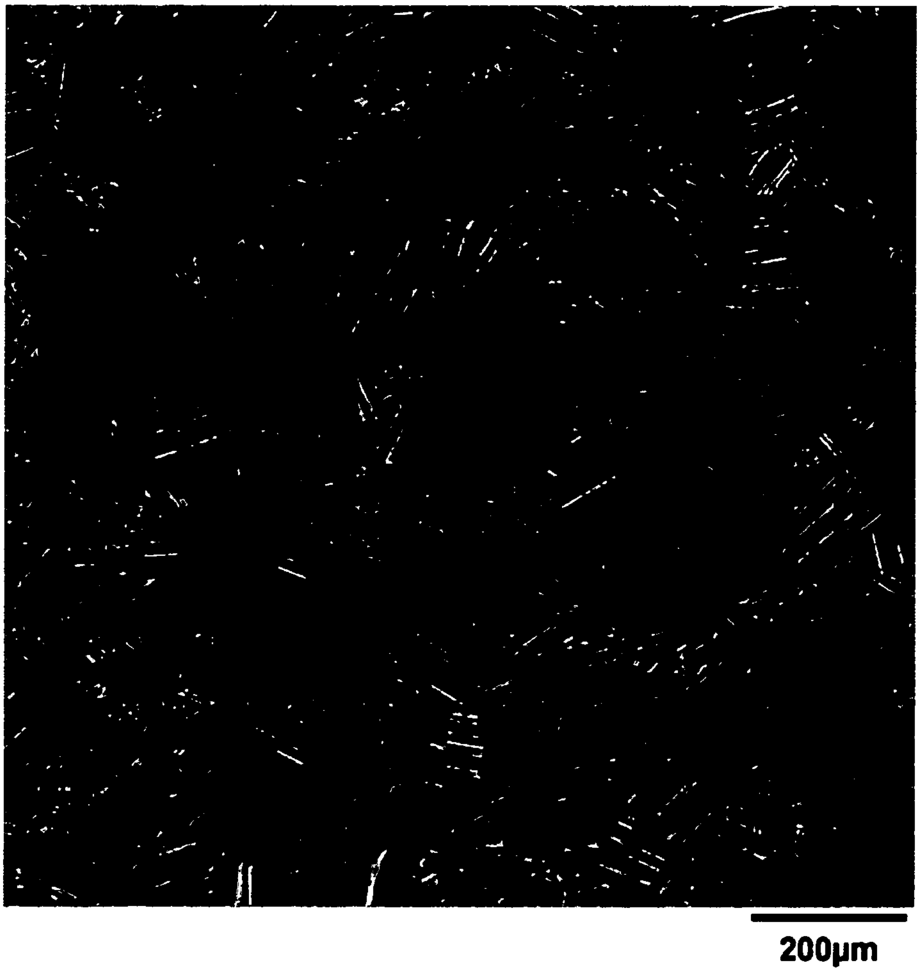


FIGURE 3

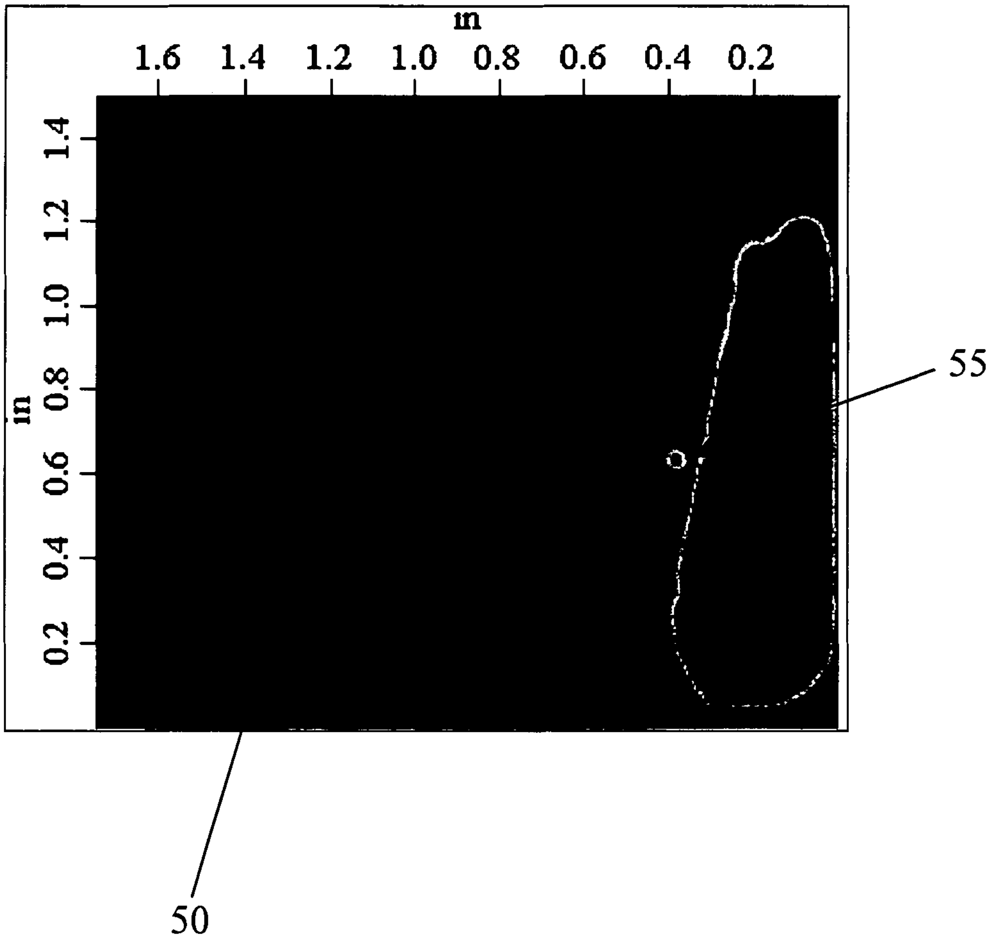
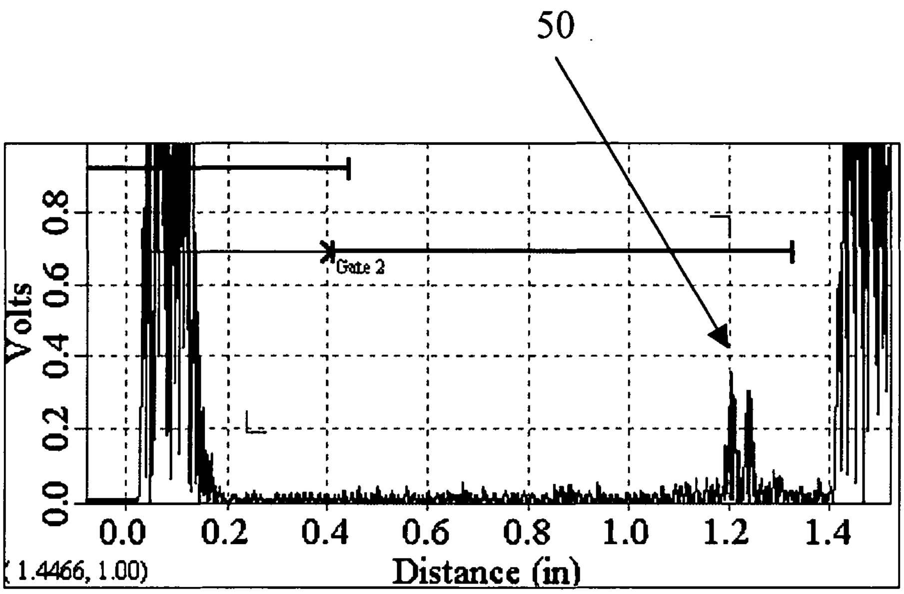


FIGURE 4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0.6
0.8
Gate 2
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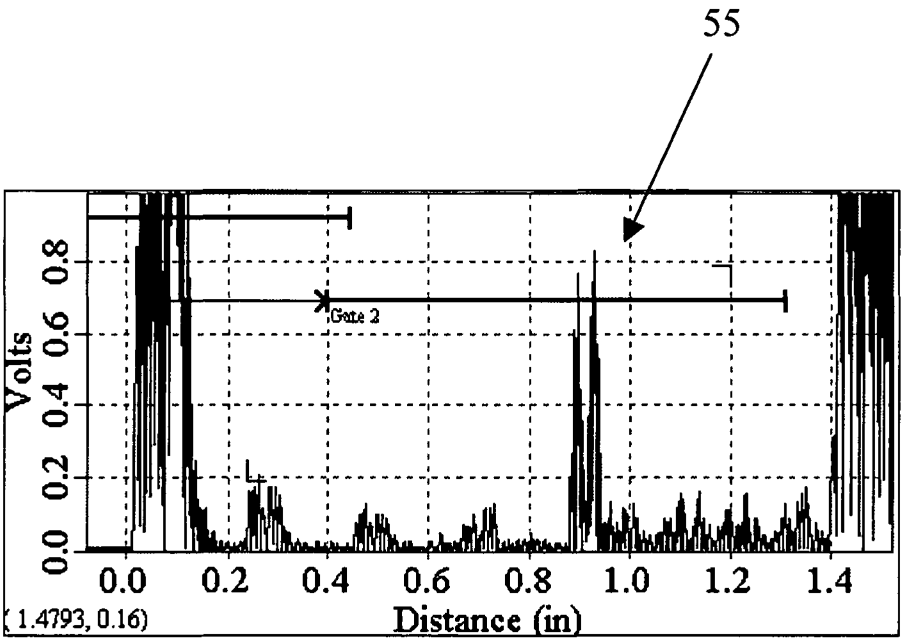
(a)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(b)

FIGURE 5

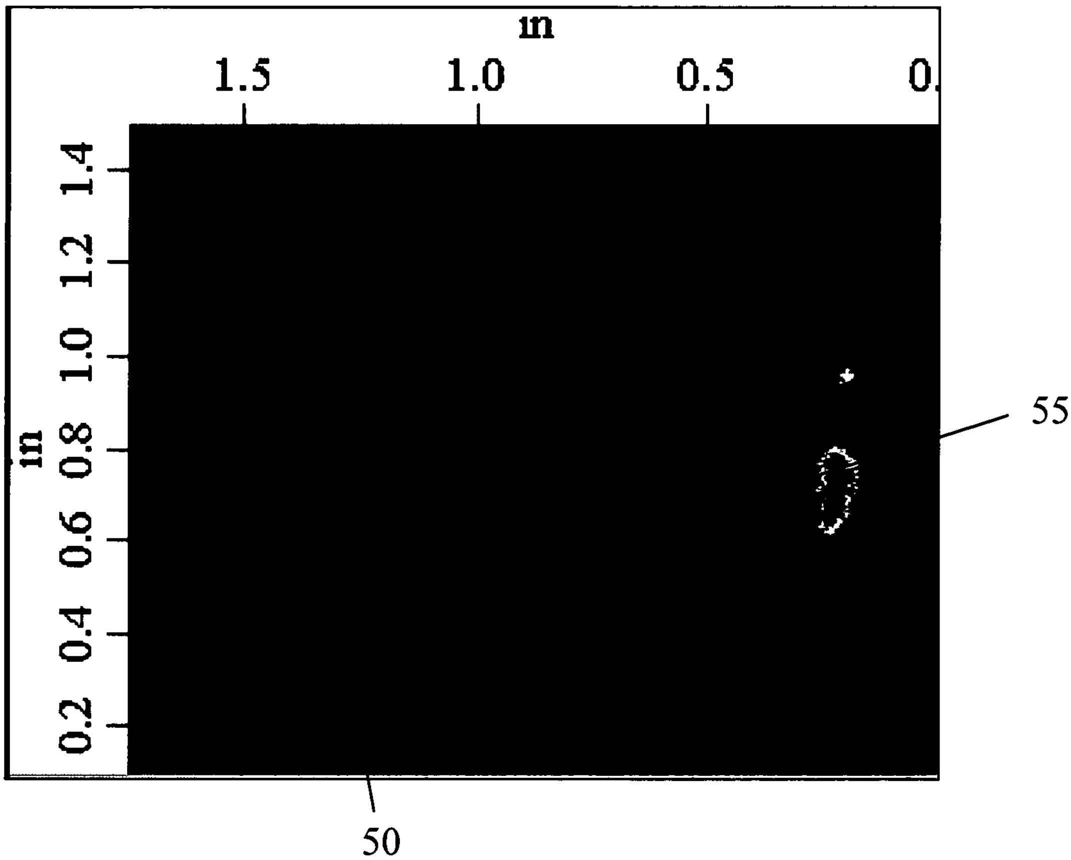
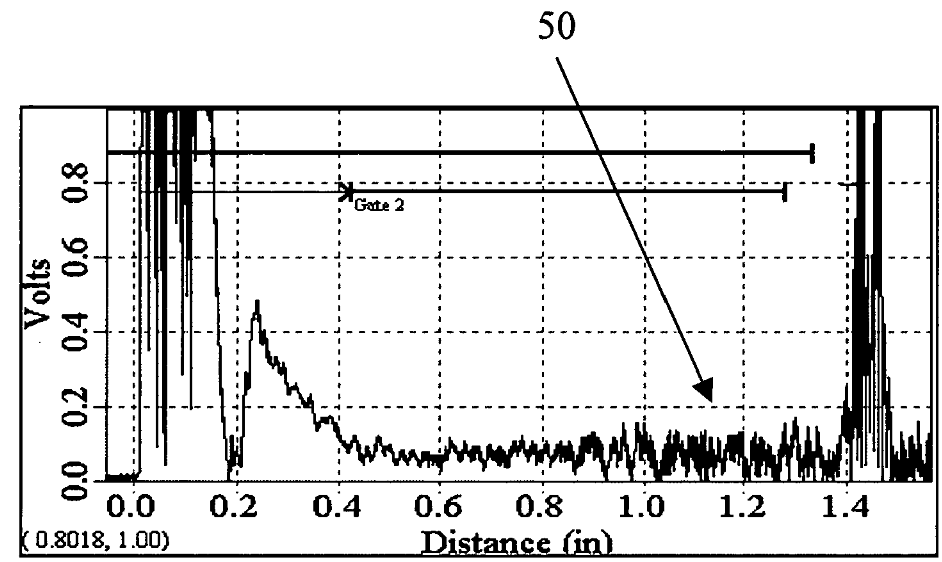


FIGURE 6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Distance (in)
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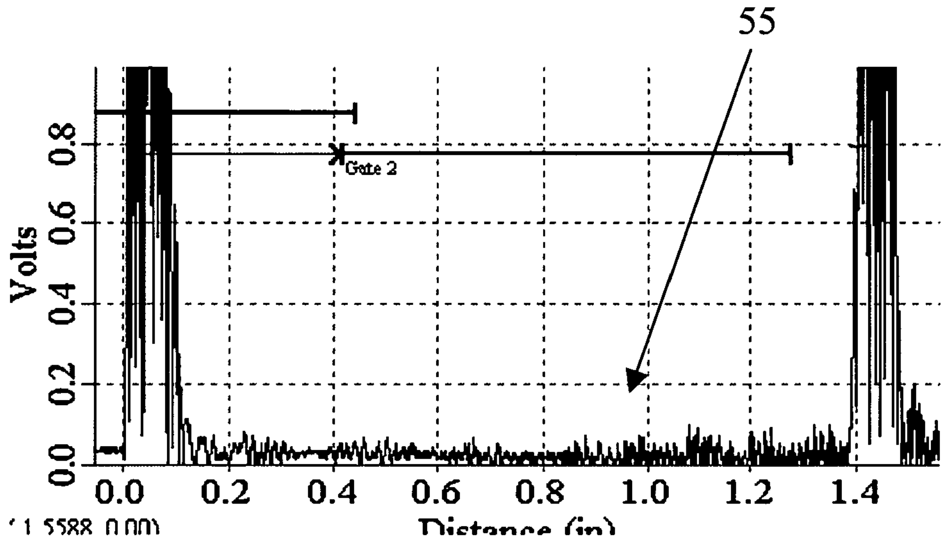
(a)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0.8
Gate 2
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(b)

FIGURE 7

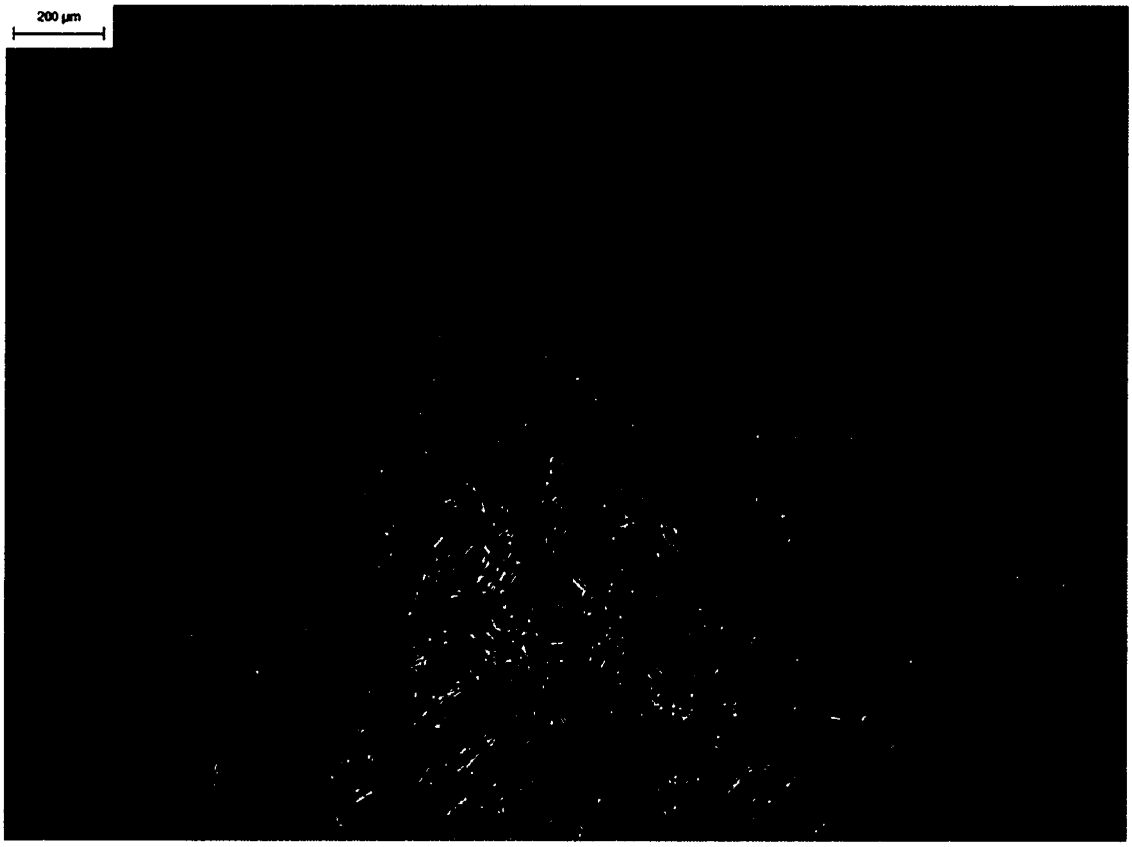

FIGURE 8