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(71) **Applicant: SIEMENS ENERGY, INC.** [US/US]; 4400 Alafaya Trail, Orlando, FL 32826-2399 (US).

(72) **Inventors: OZBAYSAL, Kazim**; 3711 Surry Ridge Court, Charlotte, NC 28210 (US). **KAMEL, Ahmed**; 2439 Guiana Plum Drive, Orlando, FL 32828 (US).

(74) **Agent: OTTERLEE, Thomas, J.**; Siemens Corporation-Intellectual Property Dept., 3501 Quadrangle Blvd. Ste. 230, Orlando, FL 32817 (US).

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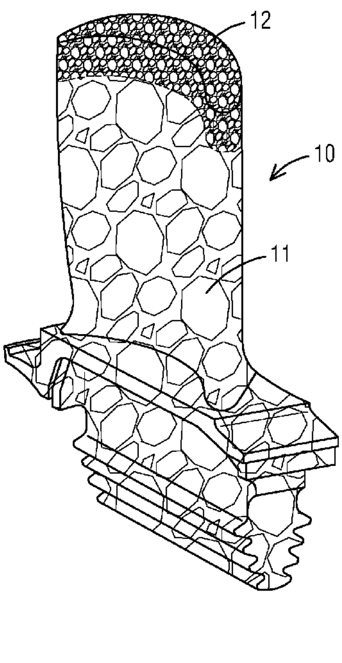
(54) **Title:** FRICTION STIR ADDITIVE MANUFACTURING AND REPAIR OF TURBINE COMPONENTS

FIG. 7



(57) **Abstract:** A turbine blade airfoil portion having a total length and fixedly attached to a base includes a first portion extending from the base to a repair line such that the first portion has a first length that is shorter than the total length, the first portion having a microstructure with a first average grain size, and a second portion extending from the repair line and having a second length equal to the difference between the total length and the first length, the second portion having a microstructure with a second average grain size, wherein the second average grain size is smaller than the first average grain size.

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FRICTION STIR ADDITIVE MANUFACTURING AND REPAIR OF TURBINE COMPONENTS

TECHNICAL FIELD

[0001] The present disclosure is directed, in general, to additive manufacturing and more specifically to additive manufacturing or repair of turbine components in the solid state.

BACKGROUND

[0002] Additive manufacturing allows for the manufacture of a component by adding material rather than removing material from a raw material, a casting, or a forging. Additive manufacturing of metallic components allows for complex structures but often requires significant heat input which can produce undesirable grain structures and material properties.

SUMMARY

[0003] A turbine blade airfoil portion having a total length and fixedly attached to a base includes a first portion extending from the base to a repair line such that the first portion has a first length that is shorter than the total length, the first portion having a microstructure with a first average grain size, and a second portion extending from the repair line and having a second length equal to the difference between the total length and the first length, the second portion having a microstructure with a second average grain size, wherein the second average grain size is smaller than the first average grain size.

[0004] In another construction, a bladed disk includes a disk portion formed from a first material and having a microstructure with a first average grain size, the disk portion having an annular shape that extends around a central axis, and a plurality of blades each extending from the disk portion substantially along a radial line with respect to the central axis, each blade including an airfoil portion formed from a second material and having a microstructure with a second average grain size, wherein the second average grain size is different than the first average grain size.

[0005] In another construction, a turbine blade includes a platform formed from a first alloy material and a airfoil portion formed onto the platform in a plurality of layers each added in the solid state, the airfoil portion formed from a second alloy.

[0006] The foregoing has outlined rather broadly the technical features of the present disclosure so that those skilled in the art may better understand the detailed description that follows. Additional features and advantages of the disclosure will be described hereinafter that form the subject of the claims. Those skilled in the art will appreciate that they may readily use the conception and the specific embodiments disclosed as a basis for modifying or designing other structures for carrying out the same purposes of the present disclosure. Those skilled in the art will also realize that such equivalent constructions do not depart from the spirit and scope of the disclosure in its broadest form.

[0007] Also, before undertaking the Detailed Description below, it should be understood that various definitions for certain words and phrases are provided throughout this specification and those of ordinary skill in the art will understand that such definitions apply in many, if not most, instances to prior as well as future uses of such defined words and phrases. While some terms may include a wide variety of embodiments, the appended claims may expressly limit these terms to specific embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Fig. 1 is a perspective view of a turbine blade including damaged portions.

[0009] Fig. 2 is a perspective view of the turbine blade of Fig. 1 with the damaged portions removed to define a platform.

[0010] Fig. 3 is a perspective view of a portion of a disk portion of a bladed disk or blisk without a blade.

[0011] Fig. 4 is a perspective view of the disk portion of Fig. 3 with a blade added.

[0012] Fig. 5 is a schematic illustration of a friction stir additive manufacturing process (FSAM).

[0013] Fig. 6 is a schematic illustration of a layer deposition pattern that can be followed using the process of Fig. 5.

[0014] Fig. 7 is an image of the microstructure between a cast first portion and a repaired portion formed using the friction stir additive manufacturing process (FSAM).

[0015] Fig. 8 illustrates a turbine blade including directionally solidified grains illustrating a potential crack location.

[0016] Fig. 9 illustrates the grain structure in the cracked portion of the blade of Fig. 8 following a repair using the FSAM process.

[0017] Fig. 10 illustrates the microstructure between a forged disk portion of a blisk and a repaired airfoil portion formed using the FSAM process.

[0018] Fig. 11 illustrates the grain microstructure of a forged blisk showing the location of potential creep damage.

[0019] Fig. 12 illustrates the grain microstructure of a blisk having a forged disk portion and FSAM formed airfoils.

[0020] Before any embodiments of the invention are explained in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the following drawings. The invention is capable of other embodiments and of being practiced or of being carried out in various ways. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting.

DETAILED DESCRIPTION

[0021] Various technologies that pertain to systems and methods will now be described with reference to the drawings, where like reference numerals represent like elements throughout. The drawings discussed below, and the various embodiments used to describe the principles of the present disclosure in this patent document are by way of illustration only and should not be construed in any way to limit the scope of the disclosure. Those skilled in the art will understand that the principles of the present disclosure may be implemented in any suitably arranged apparatus. It is to be understood that functionality that is described as being carried out by certain system elements may be performed by multiple elements. Similarly, for instance, an element may be configured to perform functionality that is described as being carried out by multiple elements. The numerous innovative teachings of the present application will be described with reference to exemplary non-limiting embodiments.

[0022] Also, it should be understood that the words or phrases used herein should be construed broadly, unless expressly limited in some examples. For example, the terms “including,” “having,” and “comprising,” as well as derivatives thereof, mean inclusion without limitation. The singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. Further, the term “and/or” as used herein refers to and encompasses any and all possible combinations of one or more of the associated listed items. The term “or” is inclusive, meaning and/or, unless the context clearly indicates otherwise. The phrases “associated with” and “associated therewith,” as well as derivatives thereof, may mean to include, be included within, interconnect with, contain, be contained within, connect to or with, couple to or with, be communicable with, cooperate with, interleave, juxtapose, be proximate to, be bound to or with, have, have a property of, or the like.

[0023] Also, although the terms "first", "second", "third" and so forth may be used herein to refer to various elements, information, functions, or acts, these elements, information, functions, or acts should not be limited by these terms. Rather these numeral adjectives are used to distinguish different elements, information, functions or acts from each other. For example, a first element, information, function, or act could be termed a second element, information, function, or act, and, similarly, a second element, information, function, or act could be termed a first element, information, function, or act, without departing from the scope of the present disclosure.

[0024] In addition, the term "adjacent to" may mean: that an element is relatively near to but not in contact with a further element; or that the element is in contact with the further portion, unless the context clearly indicates otherwise. Further, the phrase “based on” is intended to mean “based, at least in part, on” unless explicitly stated otherwise. Terms “about” or “substantially” or like terms are intended to cover variations in a value that are within normal industry manufacturing tolerances for that dimension. If no industry standard as available a variation of 20 percent would fall within the meaning of these terms unless otherwise stated.

[0025] Turbines (gas and steam) are often used in power generation applications as a prime mover that drives a generator. The drive for higher efficiencies has led to the use of different materials and higher operating temperatures. When these components are damaged, repair is often preferable to replacement from a cost standpoint. Fig. 1 illustrates an example of a damaged turbine blade 10. Damage can occur due to many factors including fatigue, erosion, or impacts from foreign objects. While repairs using welding or other high temperature techniques are known, they are sometimes not applicable to the newer materials and they often result in a grain microstructure that is sometimes undesirable.

[0026] Before proceeding, it should be noted that the terms “blade” and “airfoil” used herein are meant to be broad terms that encompass other terms for the same or similar features on both rotating and stationary components. For example, rotating blades include an aerodynamic section often referred to as an airfoil section. A similar feature on a stationary blade is often referred to as a vane or vane portion. The components and methods described herein should not be limited by the terms used to describe the features.

[0027] The method described herein allows for the repair or manufacture of turbine blades using a solid state additive manufacturing process. Fig. 2 illustrates the first step in the repair process of the turbine blade 10 of Fig. 1. To prepare the blade 10, the damaged portion is first removed to define a repair surface 15 or a platform. It is preferable that the repair surface 15 be planar and normal to a long axis 20 of the blade 10.

[0028] Fig. 5 illustrates an apparatus 25 for adding material to the repair surface 15 to rebuild the removed portion of the blade 10. The repair surface 15 defines a substrate or platform onto which layers of material will be applied. A consumable rod 30 is moved into engagement with the repair surface 15, an axial force 35 is applied along the rod, and the rod 30 is rotated 40 while also moving along a path 45 parallel to the repair surface 15. The consumable rod 30 is made from a material or alloy that matches the blade material or the desired material of the airfoil portion of the blade 10. As the consumable rod 30 moves, it mixes with the material of the repair surface 30 in the solid state with some of the material from the consumable rod 30 is deposited on the repair surface 15. In some applications powdered metal is placed between the consumable rod 30 and the repair surface 15 to enhance the quantity of material deposited. Because there is no material melting, the microstructure of the deposited material is in a form of the forged base metal of the airfoil portion. Powdered metal can be selected to chemically match the existing base material or could be selected to produce a desired alloy in the deposited material.

[0029] The process illustrated in Fig. 5 is particularly useful with materials such as titanium and titanium alloys. In one application, Ti6Al4V or TI6Al2Sn4Zr2Mo is used to repair the turbine blade 10. In other applications, nickel-based superalloys or other alloys are used as the rod 30 and the powder if employed. For example, nickel-based blades can be manufactured or repaired using a sintered consumable feed generated from the blade base material and a braze powder made of Ni-Cr-X alloy where X is either Ti, Zr, Hf, or some combination thereof.

[0030] Fig. 1 illustrates the turbine blade 10 with operational damage. In this example, portions of the leading and trailing edges and the blade tip are damaged. The first step in the process is to remove the damaged areas. Due to the axial force 35 required for the process described herein, a substantially planar surface 15 oriented in a way that will allow for the axial force 35 should first be established.

[0031] Fig. 2 illustrates the blade 10 of Fig. 1 with the damaged portions removed to define the repair surface 15 onto which repair material can be deposited. The repair surface 15 is substantially normal to the long axis 20 of the turbine blade 10 such that the downward axial force 35 is directed along the same long axis 20. The repair surface 15 is substantially normal to the axis 20 but could be angled with respect to the axis 20 if necessary. In addition, while a planar repair surface 15 is preferred, a slightly curved surface could be employed if desired.

[0032] The removed portion is then replaced using the additive process described with regard to Fig. 5. The process adds material as illustrated in Fig. 6. Specifically, rows 50 are added in a side-by-side fashion as necessary to complete a layer 55. Subsequent layers 55 are then applied on top of the prior layers 55. Once the layers 55 are completed the repaired portion can be machined or otherwise finished to return the blade to a usable condition.

[0033] Alternatively, the damaged portions could be removed to define two or more separate planar (or slightly curved) surfaces that are obliquely angled with respect to the long axis 20 of the blade 10. A fixture then supports the blade 10 with one of the planar surfaces in the desired orientation to allow for the addition of the necessary material. Once one of the surfaces is completed, the blade 10 is repositioned to allow material to be added to the other repair locations. The blade 10 is then machined or otherwise finished as required.

[0034] A repaired blade 10 that is repaired according to the aforementioned process is structurally different from the original blade. Often, blades 10 of this type are cast which produces a cast microstructure 11 with an average grain size of about 1 mm or more. Specifically, one cast blade includes a columnar grain structure with grains near 300 mm long and about 10 mm wide. Investment casting typically produces grain sizes in the range of 1-20 mm. The repaired portion will be more similar to a forged component and will have a repaired microstructure 12 that has a smaller average grain size (e.g., 0.1 mm or less) than the original material. Optimal polycrystalline grain size for blade applications is about 0.040 mm. The smaller grain size illustrated in Fig. 7 provides superior fatigue life (e.g., high-cycle fatigue) when compared to the original material which can be of benefit during future operation. In one construction, the repaired portion includes a microstructure with an average grain size that is about 50 percent the average grain size of the base material. In a preferred construction, the average grain size of the repaired microstructure is about 10 percent of the average grain size of the base material. In a more preferred construction, the average grain size of the repaired microstructure is about 1 percent of the average grain size of the base material. It should be understood that measuring an average grain size can be difficult. The term “about” as used herein is meant to include the potential errors in this process and cover the tolerances as well as the normal deviation in such measurements when performed by different individuals or using different techniques.

[0035] As one of ordinary skill understands, measuring an average grain size can be challenging. However, industry standards have developed techniques followed by most to assure consistent results. In the present application, the measurement is based on an average diameter of the various grains.

[0036] Additionally, the process described above allows for the use of dissimilar materials during the repair. For example, a turbine blade 10 that was originally made using Ti6Al4V can be repaired using a material such as TI6Al2Sn4Zr2Mo which might have superior corrosion resistance, fatigue resistance, creep resistance, or some other desirable property.

[0037] Figs. 8 and 9 illustrate another blade 56 that includes a crack 57 formed as a result of high cycle fatigue. The blade 56 is a directionally solidified blade having elongated grains 58 that extend the length of the blade 56. These grains 58 are still susceptible to high cycle fatigue in the transverse direction to elongated grains, particularly in the region where the airfoil extends from the platform as illustrated in Fig. 8.

[0038] To repair the crack 57, the damaged material is removed, and new material is added using the FSAM process described above. The newly added material includes a repaired microstructure 12 having a polycrystalline small grain size as illustrated in Fig. 9 that is much less susceptible to high cycle fatigue.

[0039] This repair technique can also be used to repair a blade 59 on a bladed disk or blisk 65 as illustrated in Fig. 10. As with the repair of the blade 10 illustrated in Figs. 1 and 2, the damaged portion of the airfoil is removed, and new material is added using the FSAM process discussed above. The result is a repaired blisk 65 wherein the microstructure of the disk portion is a forged microstructure 61 and the added material has the smaller repair microstructure 12 that exhibits superior mechanical properties.

[0040] In addition to repairing the blade 10, the process described herein can be used to form a new blade 60 on the bladed disk or blisk 65 as illustrated in Figs. 3 and 4. In this application, a disk portion 70 of the blisk 65 is first formed. Substantially planar portions 75 can be formed on an outer surface 80 of the disk portion 70 to define platforms 85 for the addition of blades 60. Alternatively, the blades 60 can simply be added to the curved surface of the disk portion 70. As with the repair, blades 60 are formed using the process described with regard to Fig. 5 using the pattern illustrated in Fig. 6. Once sufficient material is added, the blades 60 can be finish machined as may be required to complete the blisk 65.

[0041] The disk portion 70 of the blisk 65 of Figs. 3 and 4 is typically a forged component and as such has a forged microstructure 61 with an average grain size smaller than that of a cast component. As illustrated in Fig. 11, the microstructure of the forged airfoils is still susceptible to creep damage 62. Each of the blades 60 could be added using the aforementioned process and would have the repair microstructure 12, shown in Fig. 12 that includes an average grain size that is still smaller than that of the disk portion 70. The smaller repair microstructure 12 would give the blades 60 different mechanical properties than the disk portion 70 including superior creep resistance if a creep resistant composition is selected for the build-up. Like the repaired blades 60 illustrated in Fig. 7, the blades 60 could also be added to the disk portion 70 using a dissimilar material that provides other advantages over the disk material (e.g. superior corrosion resistance, fatigue resistance, creep resistance, etc.).

[0042] The process described herein could also be used to manufacture a new blade. In this application, a blade root 90 and platform 95 (shown in Figs. 1 and 2) are manufactured using any desired technique. The platform 95 defines a substantially planar surface on which the airfoil portion of the blade can be formed. The airfoil portion is formed using the process described with regard to Fig. 5 by adding layers as illustrated in Fig. 6. The airfoil portion is then machined, or further process as required to complete the airfoil portion of the blade. The new blade could include dissimilar materials throughout its construction that provide the desired mechanical properties for the different areas of the blade.

[0043] While the examples have been described as using the layer-by-layer application illustrated in Fig. 6, this pattern is not strictly necessary and other patterns may be employed depending on the application.

[0044] The process described herein, sometimes referred to as friction stir additive manufacturing (FSAM) produces material that is more similar to wrought material than welded or cast material including larger grain structures then would typically be produced using prior repair techniques.

[0045] Although an exemplary embodiment of the present disclosure has been described in detail, those skilled in the art will understand that various changes, substitutions, variations, and improvements disclosed herein may be made without departing from the spirit and scope of the disclosure in its broadest form.

[0046] None of the description in the present application should be read as implying that any particular element, step, act, or function is an essential element, which must be included in the claim scope: the scope of patented subject matter is defined only by the allowed claims. Moreover, none of these claims are intended to invoke a means plus function claim construction unless the exact words "means for" are followed by a participle.

CLAIMS

What is claimed is:

1. A turbine blade airfoil portion having a total length and fixedly attached to a base, the airfoil portion comprising:

a first portion extending from the base to a repair line such that the first portion has a first length that is shorter than the total length, the first portion having a microstructure with a first average grain size; and

a second portion extending from the repair line and having a second length equal to the difference between the total length and the first length, the second portion having a microstructure with a second average grain size, wherein the second average grain size is smaller than the first average grain size.

2. The turbine blade airfoil portion of claim 1, wherein the repair line is positioned between a damaged portion of airfoil portion and the base.

3. The turbine blade airfoil portion of claim 1, wherein the first portion is formed using a casting process and the first average grain size is greater than 1 mm.

4. The turbine blade airfoil portion of claim 1, wherein the second portion is formed using a Friction Stir Additive Manufacturing (FSAM) process and the second average grain size is less than 0.1 mm.

5. The turbine blade airfoil portion of claim 1, wherein the first portion is formed using a casting process and the first average grain size is columnar having an average length of at least 300 mm and an average width of at least 10 mm.

6. The turbine blade airfoil portion of claim 1, wherein the second average grain size is about 0.040 mm.

7. The turbine blade airfoil portion of claim 1, wherein the second average grain size is less than 1 percent of the first average grain size.

8. The turbine blade airfoil portion of claim 1, wherein the first portion is formed from a first material and the second portion is formed from a second material different than the first material.

9. The turbine blade airfoil portion of claim 8, wherein the first material includes one of a titanium alloy and a nickel-based superalloy.

10. A bladed disk comprising:

a disk portion formed from a first material and having a microstructure with a first average grain size, the disk portion having an annular shape that extends around a central axis;

a plurality of blades each extending from the disk portion substantially along a radial line with respect to the central axis, each blade including an airfoil portion formed from a second material and having a microstructure with a second average grain size, wherein the second average grain size is different than the first average grain size.

11. The bladed disk of claim 10, wherein the disk portion is formed using a forging process and the first average grain size is greater than 1 mm.

12. The bladed disk of claim 10, wherein each airfoil portion is formed using a Friction Stir Additive Manufacturing (FSAM) process and the second average grain size is less than 0.1 mm.

13. The turbine blade airfoil portion of claim 10, wherein the second average grain size is about 0.040 mm.

14. The turbine blade airfoil portion of claim 1, wherein the second average grain size is less than 10 percent of the first average grain size.

15. The bladed disk of claim 10, wherein the disk portion is formed from a first material and the airfoil portions are formed from a second material different than the first material.

16. The bladed disk of claim 10, wherein the first material includes one of a titanium alloy and a nickel-based superalloy.

17. A turbine blade comprising:

a platform formed from a first alloy material; and

an airfoil portion formed onto the platform in a plurality of layers each added in the solid state, the airfoil portion formed from a second alloy.

18. The turbine blade of claim 17, wherein the first alloy and the second alloy are the same.

19. The turbine blade of claim 17, wherein the first alloy and the second alloy are different titanium alloys.

20. The turbine blade of claim 17, wherein the first alloy and the second alloy are different nickel-based alloys.

21. The turbine blade of claim 17, wherein the platform is one of a plurality of platforms formed on a one-piece disk.

FIG. 1

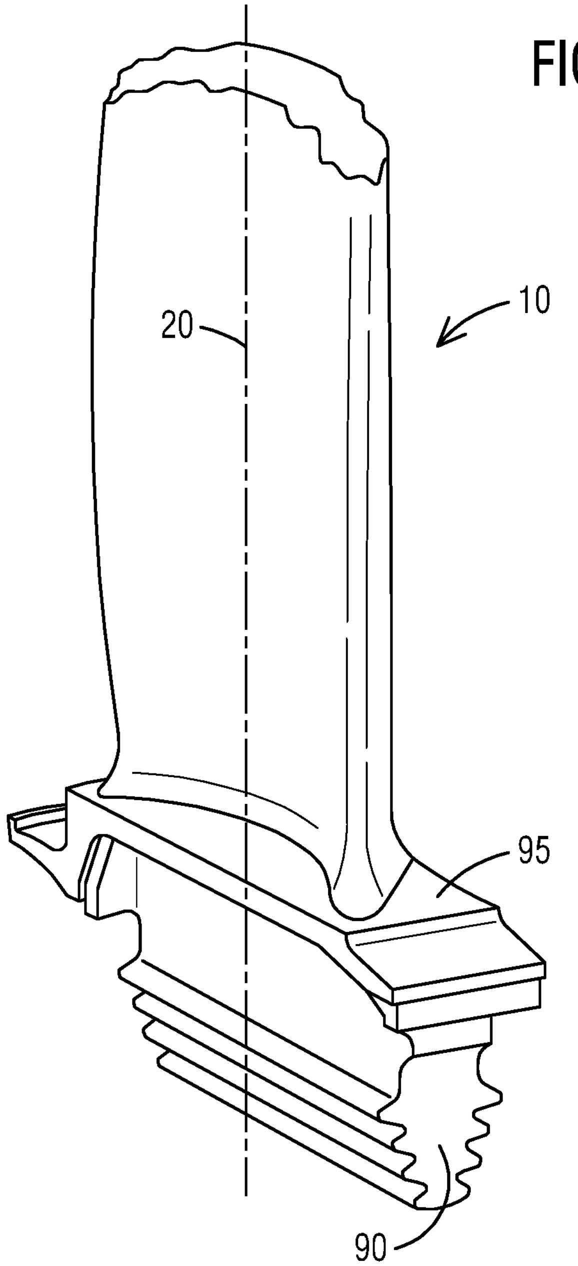


FIG. 2

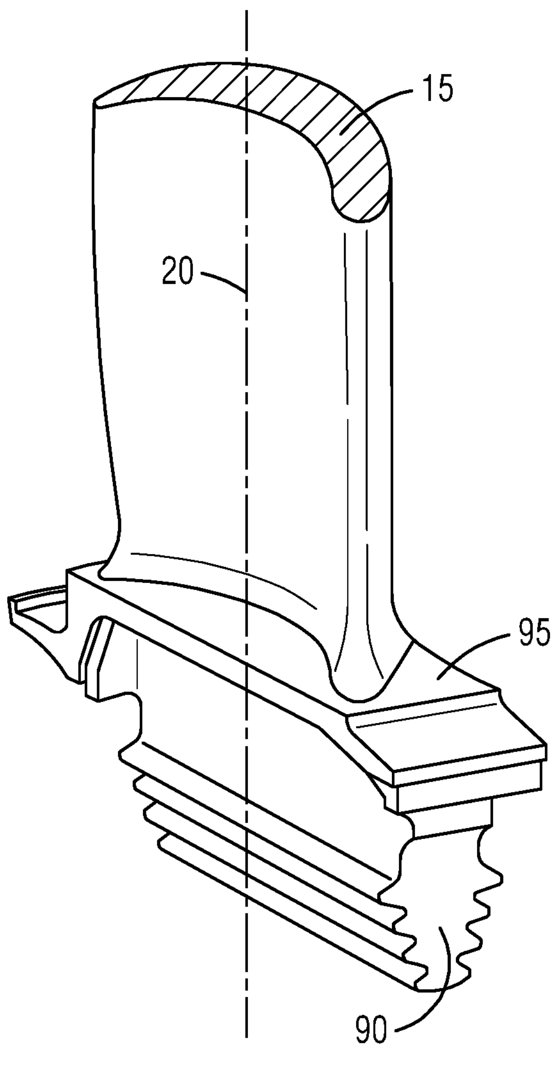


FIG. 3

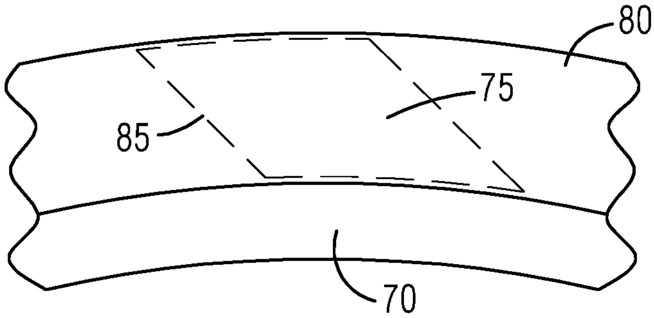


FIG. 4

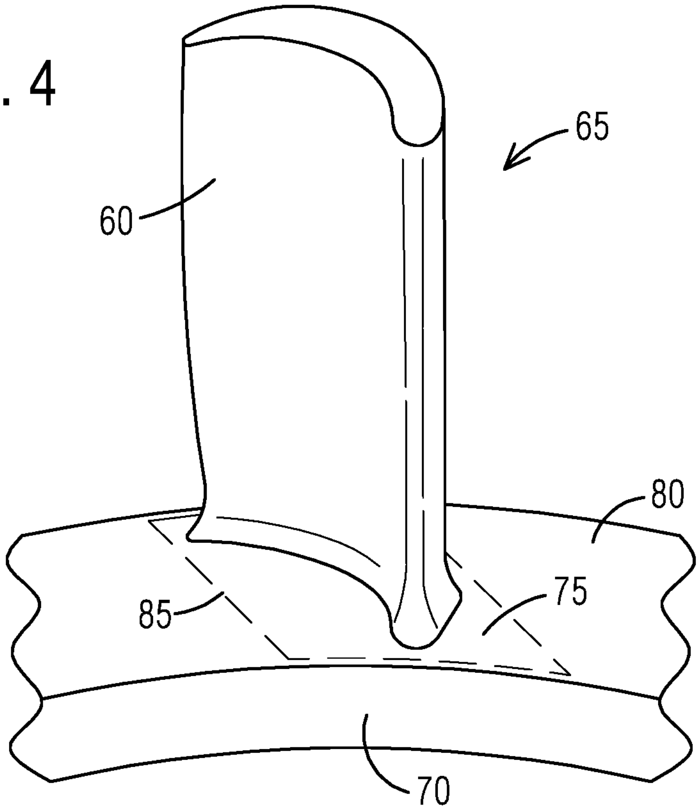


FIG. 5

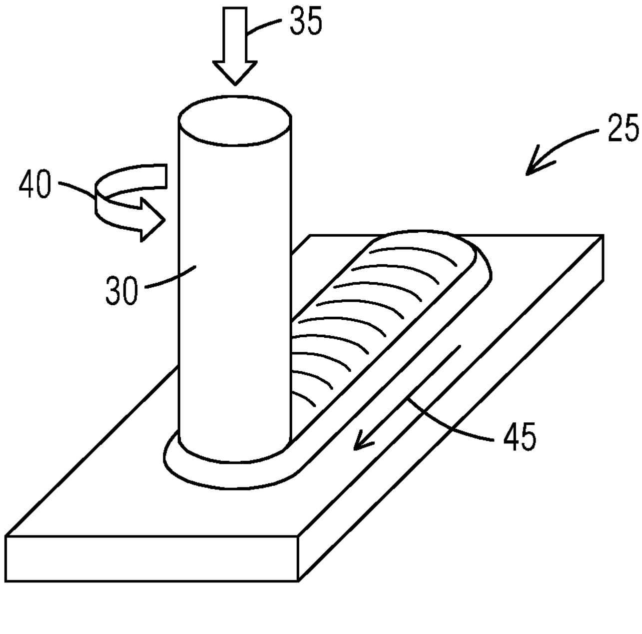


FIG. 6

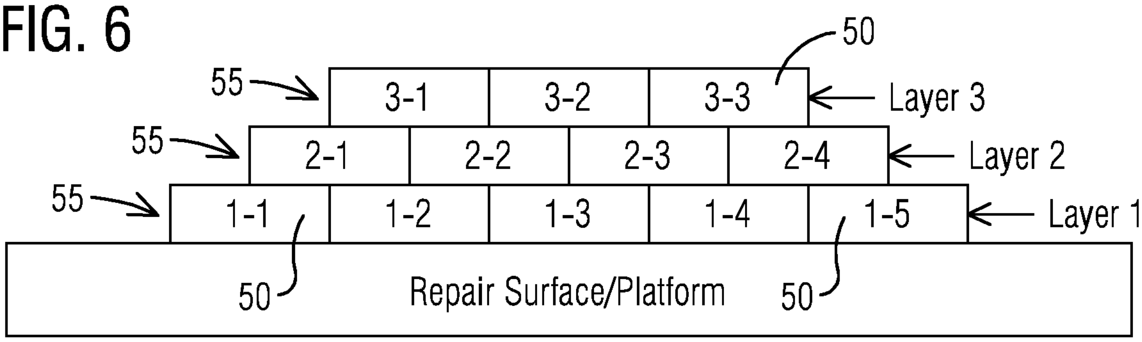


FIG. 7

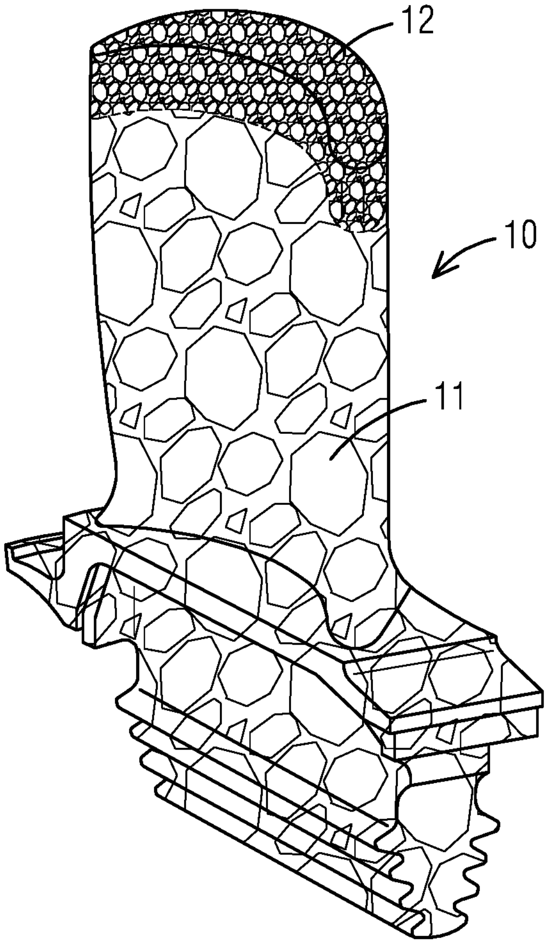


FIG. 8

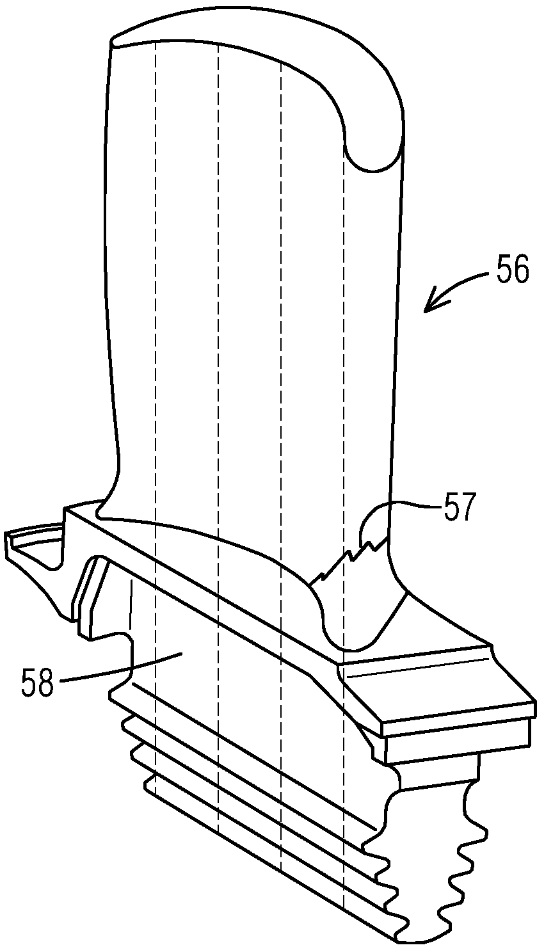


FIG. 9

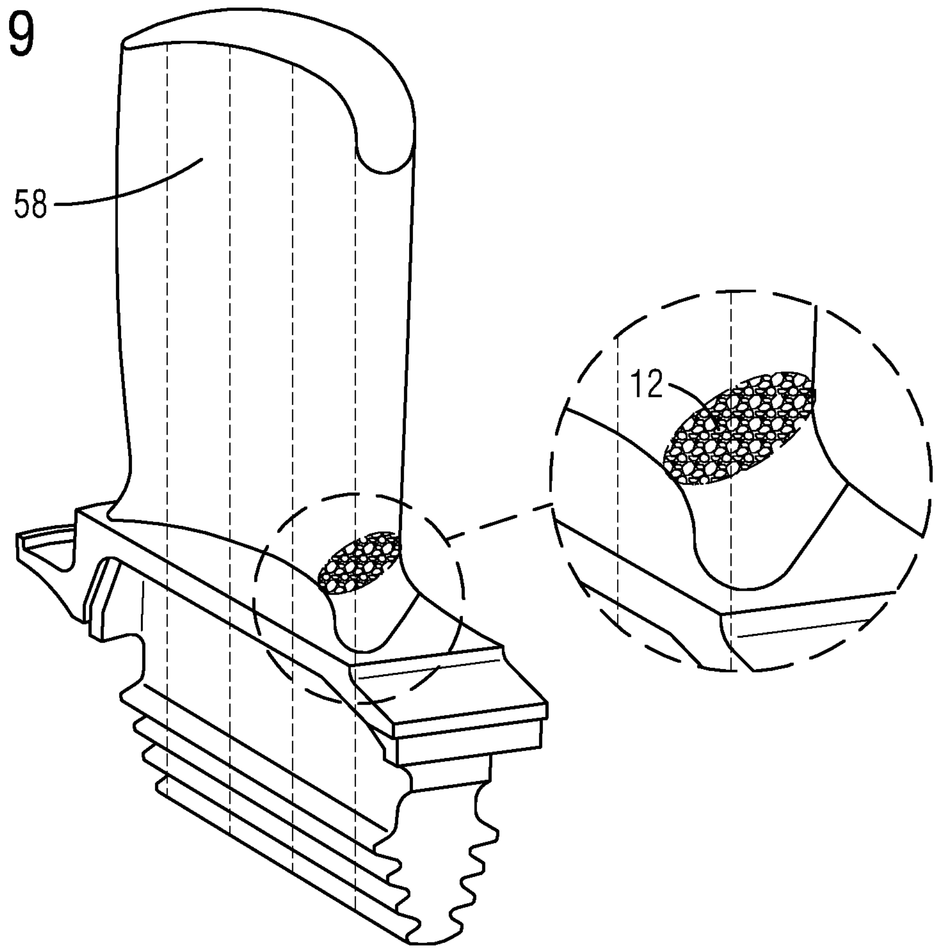


FIG. 10

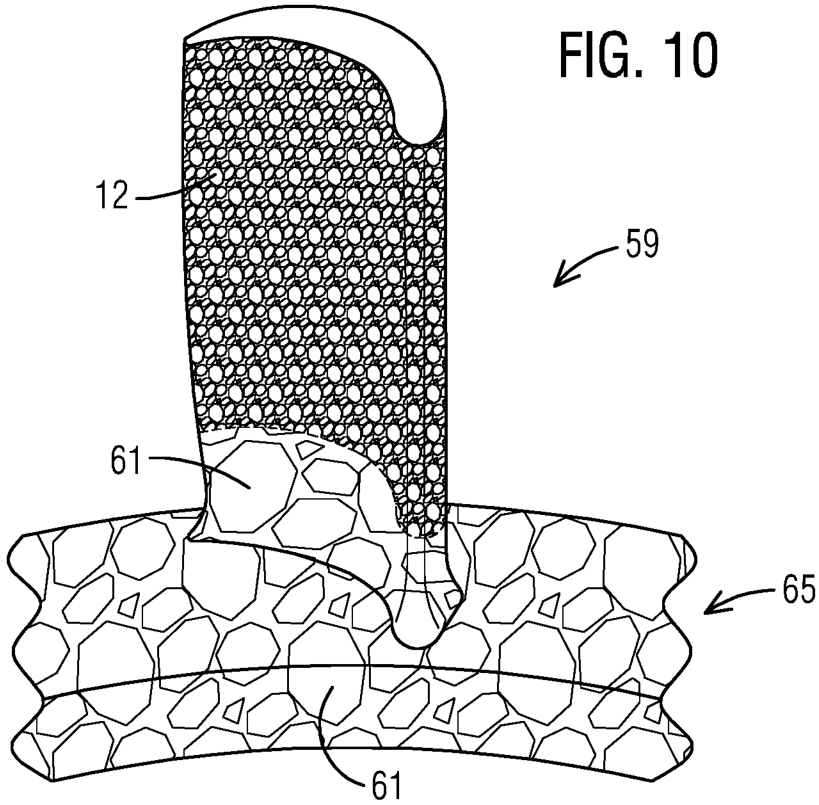


FIG. 11

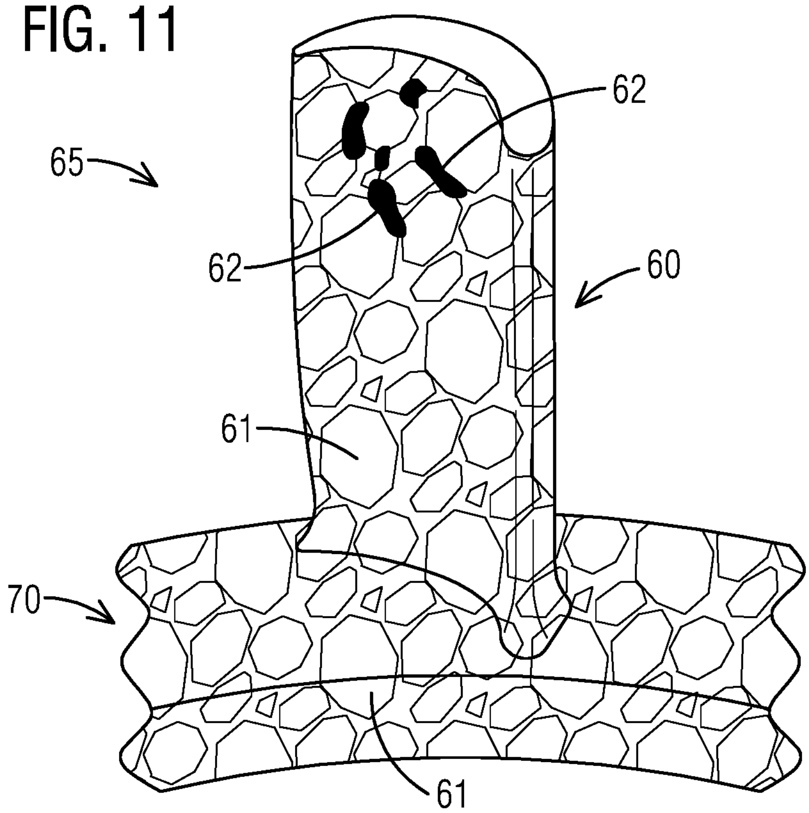
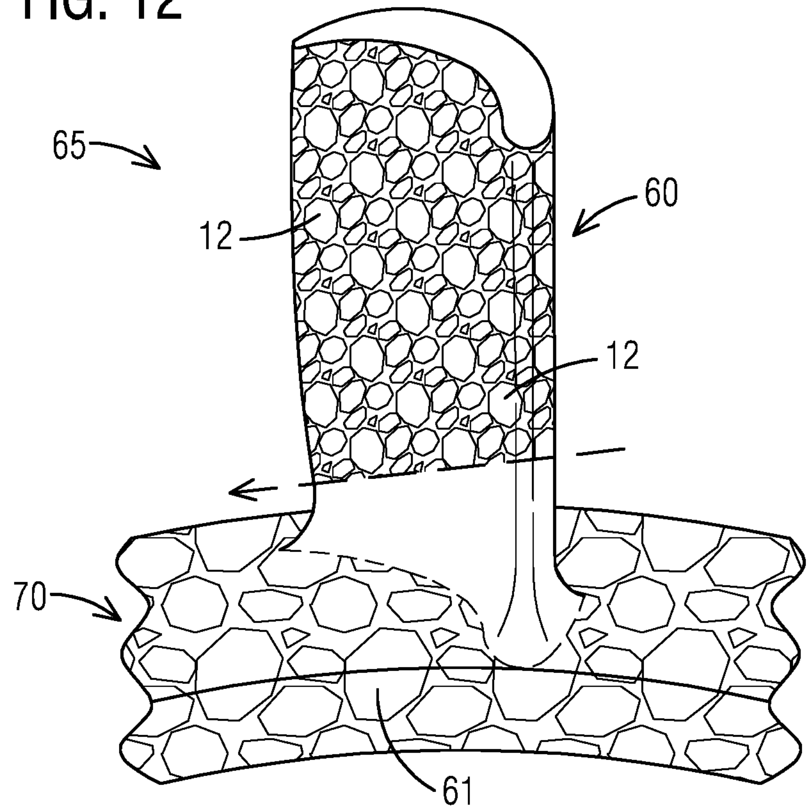


FIG. 12



INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/046155

A. CLASSIFICATION OF SUBJECT MATTER
INV. F01D5/00 F01D5/28 B23K35/28
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F01D B23K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2 920 007 A (BUCKLAND BRUCE O) 5 January 1960 (1960-01-05) abstract figures 1-3 column 3, lines 8-42 column 4, lines 3-18	1-21
X	EP 0 575 685 A1 (SULZER AG [CH]) 29 December 1993 (1993-12-29) abstract figure 12 column 4, lines 16-54	1,10,17
A	DE 10 2008 056741 A1 (MTU AERO ENGINES GMBH [DE]) 12 May 2010 (2010-05-12) abstract paragraphs [0041] - [0044]; figures 1,2	1-21

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

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Date of the actual completion of the international search	Date of mailing of the international search report
16 October 2018	24/10/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Giorgini, Gabriele

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INTERNATIONAL SEARCH REPORT

International application No
PCT/US2018/046155

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Information on patent family members

International application No
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