US 20150118060A1

(19) United States

(12) Patent Application Publication

(10) Pub. No.: US 2015/0118060 A1

(43) Pub. Date: Apr. 30, 2015

Kumar et al.

(54) TURBINE ENGINE BLADES, RELATED ARTICLES, AND METHODS

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

(72) Inventors: **Sundeep Kumar**, Bangalore (IN); **Warren Arthur Nelson**, Clifton Park, NY (US); **Ronald Ralph Cairo**, Simpsonville, SC (US); **Anand Krishnamurthy**, Bangalore (IN)

(73) Assignee: **General Electric Company**, Schenectady, NY (US)

(21) Appl. No.: **14/063,355**

(22) Filed: **Oct. 25, 2013**

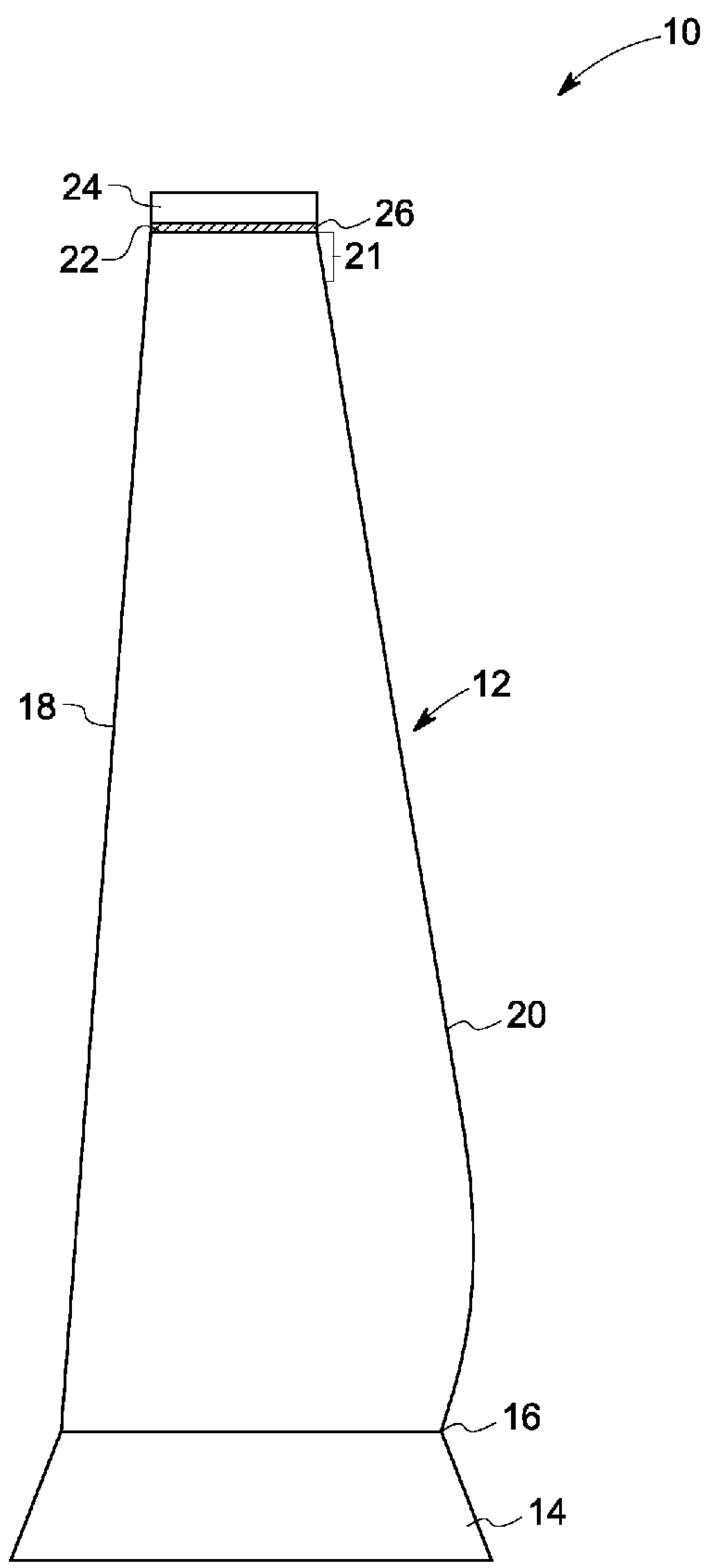
Publication Classification

(51) **Int. Cl.**
F01D 5/14 (2006.01)

(52) **U.S. Cl.**
CPC ***F01D 5/147*** (2013.01)

(57) **ABSTRACT**

A compressor blade generally used in turbine engines is presented. The compressor blade includes a protective covering bonded to a tip portion of the blade with a braze material. The braze material includes from about 1 weight percent to about 10 weight percent of an active metal element, based on the total amount of the braze material. A compressor rotor is also provided that includes a plurality of the compressor blades. A method for joining a protective covering to a tip portion of a compressor blade, and a method for repair of a compressor blade, are also provided.



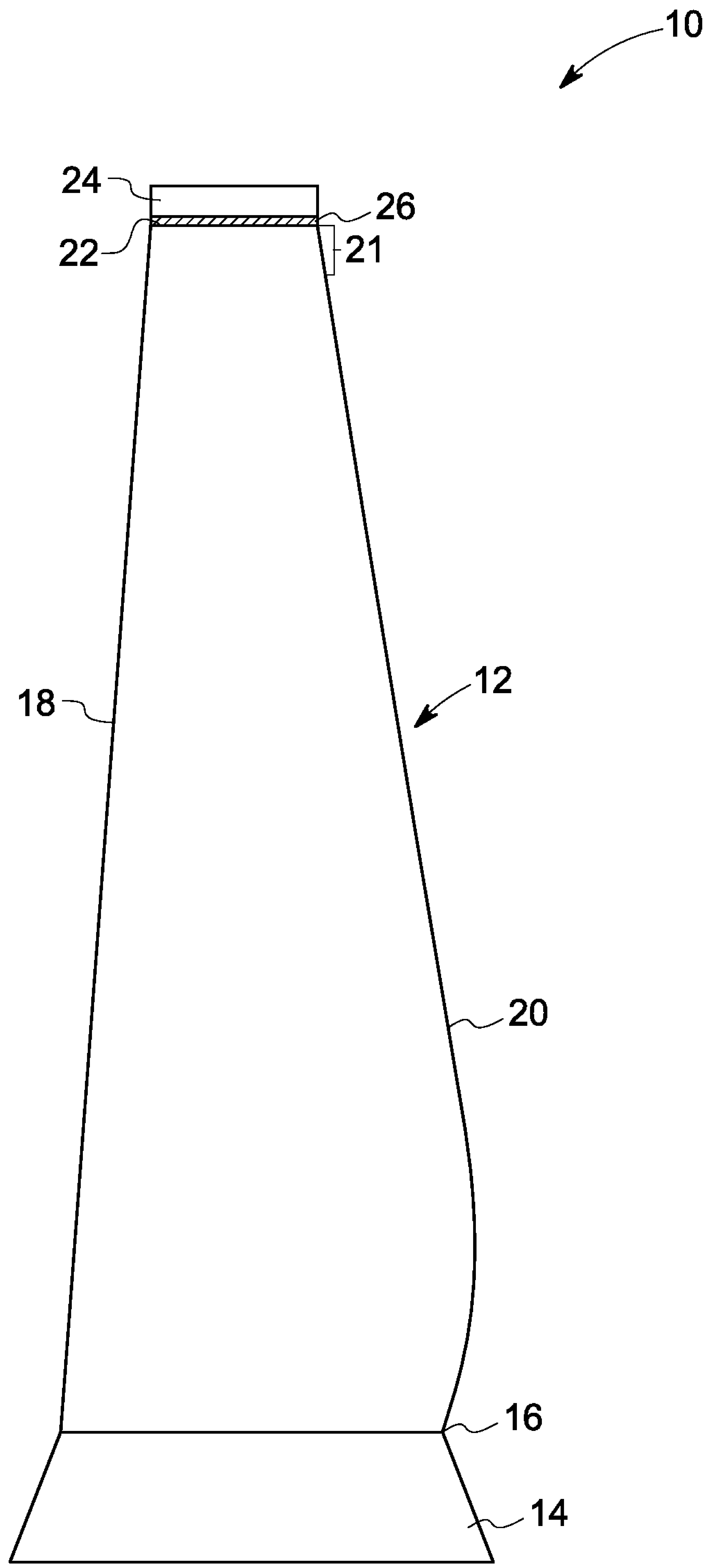


FIG. 1

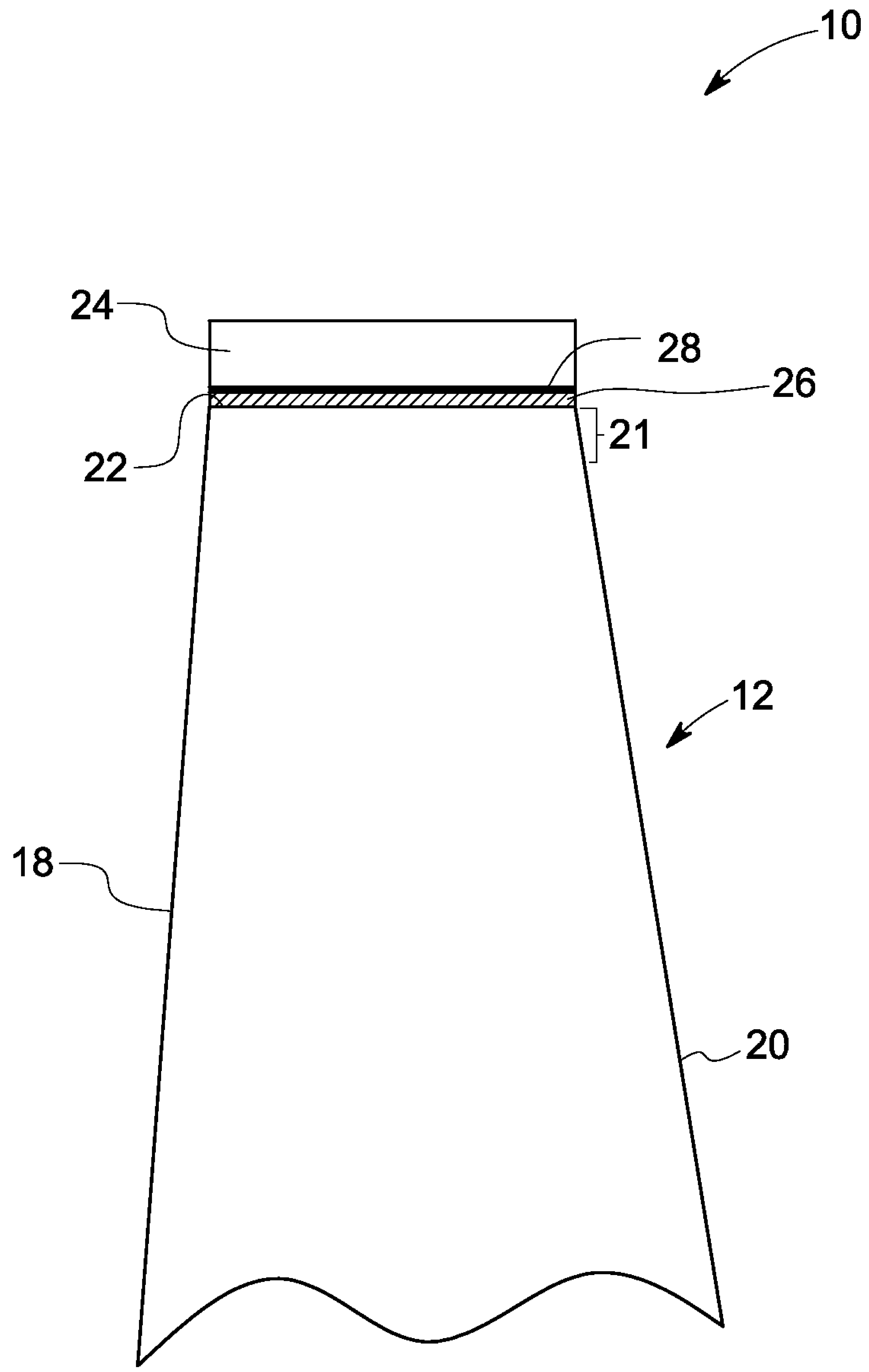


FIG. 2

TURBINE ENGINE BLADES, RELATED ARTICLES, AND METHODS

BACKGROUND OF THE INVENTION

[0001] This invention relates generally to turbine blades, and more particularly to compressor blades of a turbine engine. In some specific embodiments, the invention relates to hard tips for compressor blades, related articles, and methods for joining the hard tips to tip portions of the compressor blades.

[0002] Typically, gas turbine engines are comprised of three major sections or components which function together to produce thrust for propulsion, or energy for generating power. The compressed air from the compressor section is delivered to a combustion section where fuel is added to the air and ignited, and thereafter delivered to the turbine section of the engine, where a portion of the energy generated by the combustion process is extracted by a turbine to drive the engine compressor.

[0003] Each turbine section includes a rotor assembly comprising a plurality of rotor blades, each extending radially outward from a disk across the airflow path. More specifically, each rotor blade has a dovetail which engages with the disk, and an airfoil extending radially from the disk to a blade tip at the opposite end. In the initial sections of the engine, the compressor blades are generally made of titanium alloys, or a martensitic stainless steel, and in the later sections, the high pressure turbine blades are generally made of ferrous or nickel base alloys.

[0004] A shroud encompasses the blade tips with as little radial gap (clearance) as possible, in order to minimize bypass flow of air or other gases past the tips of the blades. The purpose of the narrow gap is to minimize gas leakage and to allow the pressure of the air to increase from one section or stage to the next. A narrower gap (or reduced clearance) between the tips and the adjacent shroud usually increases the engine efficiency and power output of the engine. For example, every 10 mil decrease in the clearance in the hot gas path can significantly improve the power output of the turbine engines.

[0005] The minimization of the gap is often limited by several factors, for example, manufacturing tolerances, differing rates of thermal expansion, mass inertia effect, and dynamic effects. If the gap is too narrow, there is the possibility of undesirable contact (e.g., rubbing) between the tip and the shroud. In these cases, the blade can heat up faster than the surrounding shroud, and thus come into contact with the shroud, due to thermal expansion and mass inertia differentials. There are likely other mechanisms (e.g., deformation, oxidation) that also cause this contact (e.g., rubbing), and in turn, damage or unduly wear the blade tips. For example, the inner diameter of the shroud is not usually concentric with the axis of rotation of the blades, and the blade tips can rub the surrounding shroud. Damage to the blade tips leads to widening the gap between the blade tip and the surrounding shroud, and allowing the air to leak through, which can, in turn, degrade the efficiency of the turbine. Severe damage can even lead to cracking of the blade and possible blade failure.

[0006] Several approaches have been proposed to address the problem of the blade tip damage and air leakage within the airflow path. One approach is to apply a clearance sealing layer on the inner diameter of the shroud, so that the sealing layer can be abraded away by the blade tip, as disclosed in U.S. Pat. Nos. 4,540,336 and 4,280,975. Another approach is to incorporate a coating on the tip of the blade. The coating may act as a cutting edge ("squealer tip") at the blade tip.

[0007] The coatings have been provided on the blade tips by a variety of methods, such as spraying, soldering, brazing, electroplating etc. Some commonly used compressor coatings include alumina, cubic boron nitride, and chromium oxide coatings. One example is a coating containing titanium carbide, applied onto a titanium alloy blade by means of a silver braze or a copper braze, as disclosed in EP-B1-0249092. Another example involves sprayed carbide and boride coatings on a blade (U.S. Pat. No. 5,683,226).

[0008] However, currently used methods have several issues. For example, sprayed coatings can sometimes exhibit fatigue or other defects; and electroplating may cause hydrogen embrittlement of the tips. Furthermore, conventionally available braze alloys have sometimes been unable to meet the demand for low brazing temperature, high ductility, and low cost—characteristics that are necessary for several applications, such as aviation engines and industrial gas turbine engines.

[0009] Therefore, there is a need for a blade having a tip with improved characteristics to meet performance requirements for turbine applications. In some preferred embodiments, manufacturing the tip should be less complicated and less expensive than existing tip coating methods.

BRIEF DESCRIPTION OF THE INVENTION

[0010] One embodiment of the invention is directed to a blade, e.g., a turbine engine blade. The blade may be a compressor blade generally used in the engines. The compressor blade includes a protective covering bonded to a tip portion of the blade with a braze material. The braze material includes from about 1 weight percent to about 10 weight percent of an active metal element, based on the total amount of the braze material. In one embodiment, a compressor rotor is provided that includes a plurality of the compressor blades.

[0011] Another embodiment of the invention is directed to a method for joining a protective covering to a tip portion of the compressor blade. The method includes the steps of disposing a braze material between a surface of a protective covering and a tip portion of the compressor blade, and joining the protective covering to the tip portion by heating the braze material to form a braze joint between the protective covering and the tip portion. The braze material includes an active metal element in an amount from about 1 weight percent to about 10 weight percent based on the total amount of the braze material.

[0012] Yet another embodiment is directed to a method for repair of a compressor blade. The method includes the steps of removing a portion of a worn or damaged tip of the blade, and providing a protective covering on a tip portion of the blade, such that the protective covering replaces at least the removed portion of the tip of the blade. The protective covering is joined to the tip portion of the blade with a braze material, wherein the braze material comprises an active metal element in an amount from about 1 weight percent to about 10 weight percent based on the total amount of the braze material. The braze material is disposed between a surface of the protective covering and a tip portion of a compressor blade, and heated to form a braze joint.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0014] FIG. **1** is a schematic, cross-sectional view of a blade, in accordance with some embodiments of the invention.

[0015] FIG. **2** is a schematic, cross-sectional exploded view of a portion of a blade, in accordance with some embodiments of the invention.

DETAILED DESCRIPTION

[0016] The present invention provides an improved blade tip for blades used in gas turbine engines, and particularly blades used in the compressor section. As discussed in detail below, some of the embodiments of the present invention provide a blade incorporating a braze material (or a braze alloy) for joining a protective covering (which may also be referred to as "protective cap") to a tip portion of the blade, and a method for the same. The invention further includes embodiments that relate to a method for repair of the blades. During service of the blade, a worn or damaged tip of the blade can be replaced by a new protective covering. These embodiments advantageously provide an improved blade tip to address problems of tip damage and leakage from the gas flow path. Though the present discussion provides examples in the context of blade tips for the compressor rotor, these processes can be applied to any other component, for example, blades in other sections of the turbine.

[0017] Quite generally, in the interest of brevity of the discussions herein, a protective coating or a protective covering or a protective cap applied/disposed on a tip portion of a blade may be referred to as a "tip" or "hard tip" of the blade.

[0018] Approximating language, as used herein throughout the specification and claims, may be applied to modify any quantitative representation that could permissibly vary, without resulting in a change in the basic function to which it is related. Accordingly, a value modified by a term or terms, such as "about," is not limited to the precise value specified. In some instances, the approximating language may correspond to the precision of an instrument for measuring the value.

[0019] In the following specification and claims, the singular forms "a", "an" and "the" include plural referents unless the context clearly dictates otherwise. As used herein, the terms "may" and "may be" indicate a possibility of an occurrence within a set of circumstances; a possession of a specified property, characteristic or function; and/or qualify another verb by expressing one or more of an ability, capability, or possibility associated with the qualified verb. Accordingly, usage of "may" and "may be" indicates that a modified term is apparently appropriate, capable, or suitable for an indicated capacity, function, or usage, while taking into account that in some circumstances, the modified term may sometimes not be appropriate, capable, or suitable.

[0020] The terms "comprising," "including," and "having" are intended to be inclusive, and mean that there may be additional elements other than the listed elements. As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items. Unless otherwise indicated herein, the terms "disposed on", or "disposed between" refer to both direct contact between components, objects, layers, and the like, or indirect contact, e.g., having intervening layers therebetween.

[0021] In some embodiments, a blade includes a protective covering bonded to a tip portion of the blade with a braze material. The blade may be a compressor blade, for example. The braze material includes from about 1 weight percent to about 10 weight percent of an active metal element, based on the total amount of the braze material.

[0022] FIG. **1** schematically represents a blade **10**. The blade **10** is exemplary of the type of compressor blades that are used in an industrial or aircraft turbine engine. The blade **10** includes a blade portion or an airfoil **12** that acts against the incoming flow of air into the turbine engine, and axially compresses the air flow. The blade **10** is usually mounted on a disk in a rotor (not shown) by a dovetail **14** which extends downwardly from the airfoil **12**, and engages a slot on the disk. The rotor may be an integral bladed disk, or a disk with inserted blades. A platform **16** extends longitudinally outwardly from the area where the airfoil **12** is joined to the dovetail **14**. The airfoil **12** includes a leading edge **18** and a trailing edge **20**. The airfoil further includes a tip portion **21**, having a tip edge **22** remote from the platform **16**.

[0023] The airfoil **12** is relatively thin, as measured in a transverse direction (i.e. perpendicular to the platform). The dovetail **14** is relatively thick, as measured perpendicular to its direction of elongation.

[0024] A single blade **10** of the compressor section (not shown) of an engine is depicted, though it should be understood that the blade **10** is one of a number of blades in a compressor rotor. The number of blades may have a substantially different shape and size, depending on many gas turbine engine models or applications. Typically, multiple blades are attached to the rotor disk in adjacent circumferential positions. As mentioned previously, these blades are often circumscribed by a case (e.g., a shroud), which is positioned in close proximity to the radially outermost tip portions (e.g., tip edges **22**) of the blades (U.S. Publication 2012/0134786 and U.S. Pat. No. 5,059,095). The case serves to channel the air flowing through the compressor, so as to ensure that the bulk of the air entering the engine will be compressed within the compressor section. A small gap is usually present between the blade tip and the case. Minimizing the gap promotes the efficiency of the compressor section and the engine thereof.

[0025] A variety of materials may be used to form the blade **10**. In one embodiment, the compressor blade **10** includes an iron-based alloy. Suitable examples of such alloys include GTD 450, AISI 403, and Sermetel coated AISI 403, which are described in a report entitled "Gas Turbine Compressor Operating Environment and Material Evaluation" by R. W. Haskell, which is incorporated herein, by reference.

[0026] In one embodiment, the compressor blade **10** includes titanium. A titanium-base alloy having more titanium than any other element is usually desirable. One particular titanium-base alloy is known as Ti-442, having a nominal composition, in weight percent, of about 4 percent aluminum, about 4 percent molybdenum, about 2 percent tin, about 0.5 percent silicon, and balance titanium. Another titanium-base alloy is known as Ti-811, having a nominal composition, in weight percent, of about 8 percent aluminum, about 1 percent molybdenum, about 1 percent vanadium, balance titanium. Another exemplary titanium-base alloy is known as Ti 64, having a nominal composition, in weight percent, of about 6 percent aluminum, about 4 percent vanadium, balance titanium. Yet another exemplary titanium-base alloy is Ti62222, having a nominal composition, in weight percent, of about 6 percent aluminum; about 2 percent tin, about 2 percent chromium, about 2 percent molybdenum; about 2 percent zirconium; and balance titanium. Other suitable materials for the blade 10 may include aluminum-based alloys, and nickel-based superalloys such as M350 and IN718.

[0027] Referring to FIG. **1** again, the blade **10** includes a protective covering **24** at the edge **22** of the tip portion **21**. The protective covering **24** forms the outer radial extremity of the blade **10**. The protective covering **24** incorporates a hard material that can assist in preventing or at least minimizing abrasion between the tip **22** and the compressor case (as discussed previously), and thus prevents/reduces degradation of the blade. Furthermore, the protective covering **24** may also serve to promote flow path sealing with the case, by creating a more tortuous flow path between the blade tip edge **22** and the case.

[0028] The protective covering **24**, as used herein, is depicted in very general form in the figures, for simplicity. The coating is meant to comprise a preform, a sheet, a wire, or a wafer that is capable of covering the tip edge **22** of the blade, in order to protect the edge from rubbing. The covering includes the hard material as discussed above, and may be joined/bonded to the tip portion at the edge **22**. In one embodiment, the protective covering **24** includes a monolith of a suitable hard material. The material for the protective covering **24** may be prepared by compacting the powder by mechanical means, casting, extrusion, molding, or additive manufacturing, followed by sintering (heat treatment). The sintered protective covering can sometimes be machined into desired shape and/or size.

[0029] A "hard material", as used herein, usually refers to a material with a hardness value of at least about 15 GPa when measured by the Vickers hardness test. These materials are highly resistive to various kinds of permanent shape change when a force is applied. The hardness of these materials generally depends on several factors, including ductility, elastic stiffness, plasticity, strain, strength, toughness, and viscosity. In some instances, the hardness of the material ranges between about 15 GPa and about 50 GPa, and in some specific instances, between about 20 GPa and about 40 GPa.

[0030] Suitable hard materials may include oxides, borides, carbides, nitrides, or a combination thereof. In some specific embodiments, the protective covering **24** includes alumina. In some embodiments, the protective covering **24** includes titanium boride, titanium carbide, or titanium nitride. Other materials may include zirconium oxide, titanium carbonitride, titanium boronitride, chrome carbide, chrome nitride, chrome boride, molycarbide, or a combination thereof.

[0031] In some embodiments, abrasive particles may be added to the hard material. One particular example of the abrasive material may be cubic boron nitride (CBN). The CBN may have an average particle diameter ranging between about 25 microns and about 100 microns. Other abrasive materials may include silicon carbide, cubic zirconia, and yttrium aluminum garnet.

[0032] The geometric profile of the protective covering **24** may be in conformance with the blade on which it needs to be adhered to. In other words, the protective covering **24** may be of a desired shape and size to cover the tip edge **22** of the blade, to prevent damage of the tip portion. In specific instances, the length and width of the protective covering **24** may be substantially equal to the length and width of the tip edge **22** of the blade **10**. The covering **24** may be plane or curved in shape, with or without angles or rounding, in order to fit the shape of the tip edge **22**. The thickness of the covering **24** (or height of the hard tip) may range from about 50 microns to about 1000 microns. In some specific embodiments, the thickness of the covering **24** may range between about 200 microns to about 500 microns.

[0033] The shape and size of several components discussed above with reference to FIG. **1** are only illustrative for the understanding of the blade structure; and are not meant to limit the scope of the invention. The exact shape, size, and position of components (e.g., the protective covering **24**) can vary to some degree.

[0034] As alluded previously, the protective covering **24** may be bonded to the tip portion **21** at the edge **22** by a braze joint or bond **26**. The braze joint **26** is formed by using a braze material that includes an active metal element. An "active metal element", as used herein, refers to a reactive metal that has a high affinity to oxygen, and thereby reacts with the ceramic. A braze material or alloy containing an active metal element can also be referred to as an "active braze alloy", and the corresponding technique may be referred to as "active brazing." Active brazing is a technique used to join a ceramic to a metal, or a ceramic to a ceramic. The active metal element undergoes a reaction with the ceramic, when the braze alloy is in a molten state, and leads to the formation of a thin reaction layer on the interface of the ceramic and the braze alloy. The thin reaction layer allows the braze alloy to wet the ceramic surface, resulting in the formation of a ceramic-ceramic or a ceramic-metal joint/bond, which may also be referred to as "active braze joint or seal."

[0035] In some embodiments, the braze material includes a silver-based alloy, a copper-based alloy, or a gold-based alloy. In general, the amount of silver, copper, or gold balances the alloy based on the amounts of the other constituents. As discussed previously, the braze alloy includes an active metal element. A variety of suitable active metal elements may be used to form the active braze alloy. The selection of a suitable active metal element mainly depends on the chemical reaction with the ceramic (e.g., alumina) to form a uniform and continuous reaction layer, and the capability of the active metal element of forming an alloy with a base element (e.g. nickel). The active metal element for embodiments herein is often titanium. Other suitable examples of the active metal element include, but are not limited to, zirconium, hafnium, and vanadium. A combination of two or more active metal elements may also be used.

[0036] The presence and the amount of the active metal may influence the thickness and the quality of the thin reaction layer, which contributes to the wettability or flowability of the braze alloy, and therefore, the bond strength of the resulting joint. A high amount (for example, greater than about 20 weight percent) of the active metal element like titanium in a braze alloy has been thought to be technically undesirable, due to the formation of brittle compounds with several alloying elements present in the blade alloy. The formation of these brittle compounds may initiate cracks at the braze joint. However, it was observed that a small amount (for example, less than about 10 weight percent) of the active metal element is generally suitable for improving the wetting of the ceramic surface (e.g., the protective covering **24**), and forming the thin reaction layer (e.g., less than about 10 microns) to form a bond with the ceramic covering (e.g., alumina). In some embodiments, the active metal element is present in an amount ranging from about 0.1 weight percent to about 10 weight percent, based on the total weight of the braze alloy. A suitable range is often from about 1 weight percent to about 6 weight percent.

[0037] The braze alloy composition may further include at least one additional element. The additional element may provide adjustments in several required properties of the braze alloy, for example, the coefficient of thermal expansion, liquidus temperature, brazing temperature, corrosion resistance, and the strength of the braze alloy. In one embodiment, the additional element can include, but is not limited to, chromium, cobalt, nickel, aluminum, tin, zinc, molybdenum, germanium, silicon, or a combination thereof. With respect to the amount, the braze alloy includes up to about 10 weight percent (e.g., about 0.1%-20%) of the additional elements, based on the total weight of the braze alloy. In some embodiments, the braze alloy includes from about 0.1 weight percent to about 2 weight percent of molybdenum, based on the total weight of the braze alloy. Some examples of the braze alloy may include Copper ABA® (92.75Cu-2Al-3Si-2.25Ti), 63Ag-35.25Cu-1.75Ti, and 82Au-15.5Ni-1.75V-0.75Mo.

[0038] Some embodiments provide a method for joining a protective covering to a blade tip. The method includes the steps of introducing the braze alloy between the protective covering and the blade tip to form a brazing structure. (The braze alloy could be deposited on one or both of the mating surfaces, for example, as also described below). The brazing structure can then be heated to form an active braze joint or seal between the protective covering and the blade tip. In one embodiment, the protective covering includes a ceramic; and the blade includes a metal. The braze alloy composition includes copper, gold, or silver, and an active metal element. At least one additional alloying element, such as chromium, cobalt, nickel, aluminum, tin, zinc, molybdenum, germanium, silicon, or a combination thereof, may further be added. The constituents of the braze alloy and their respective amounts (and proportions) are described above.

[0039] For joining the protective covering **24** to the blade tip **22**, the braze alloy may be introduced between them. For example, referring to FIG. **1**, the braze alloy may be disposed between the blade tip edge **22** and the covering **24**. In some instances, a facing layer of the braze alloy may be applied on the tip edge **22**, a surface of the covering **24**, or both of the surfaces being joined. The thickness of the alloy layer may be in a range between about 5 microns and about 100 microns, and in some specific embodiments, between about 15 microns and about 50 microns. The layer may be deposited or applied on one or both of the surfaces to be joined, by any suitable technique, e.g. by a printing process or other dispensing processes. In some instances, a foil, a sheet, wire, or a preform may be suitably positioned for bonding the surfaces to be joined.

[0040] The method further includes the step of heating the brazing structure. The entire assembly (or a brazing structure) is usually heated at a suitable brazing temperature (for example, about 1100 degrees Celsius); and the braze alloy melts and flows over the surfaces. The brazing temperature is generally less than the melting temperatures of the components to be joined, and higher than the liquidus temperature of the braze alloy. The heating can be undertaken in a controlled atmosphere, such as ultra-high pure argon, hydrogen and argon, ultra-high pure helium; or in a vacuum. To achieve good flow and wetting of the surfaces, the assembly is often held at the brazing temperature for a few minutes after melting of the braze alloy. This period may be referred to as the "brazing time". During the process, a load can also be applied.

[0041] During brazing, the alloy melts and the active metal element (or elements) present in the melt reacts with the ceramic and forms a thin reaction layer **28** at the interface of the protective covering **24** and the braze alloy (described previously), as illustrated in FIG. **2**. The thickness of the reaction layer may range from about 0.1 micron to about 2 microns, depending on the amount of the active metal element available to react with the ceramic, and depending on the surface properties of the ceramic protective covering. In a typical sequence, the brazing structure is then subsequently cooled to room temperature; with the resulting active braze hermetic joint **26** situated between the two components. In some instances, rapid cooling of the brazing structure is permitted.

[0042] When articles such as several components of gas turbines are serviced, the protective coatings, and tip coverings or tip caps (or hard tips) are usually removed to permit inspection and possible repair of the tip caps and the underlying substrate, followed by re-coating the blade and the tip of the blade. Removal of the coatings and tip caps is typically carried out by immersing the component in a stripping solution. A variety of stripping techniques are currently available for removing different types of coatings from metal substrates. The techniques usually must exhibit a considerable amount of selectivity. In other words, they must remove only intended materials, while generally preserving the article's desired structures.

[0043] Some embodiments of this invention relate to a method for repair of a compressor blade. During repair, a worn or damaged tip of the blade can be removed, and replaced by a protective covering or cap applied over a tip portion of a blade (e.g, a compressor blade). The term, "replace" as used herein means that the protective covering occupies the region on the tip edge of the blade formally occupied by the removed portion, or at least a desired portion of the region, if full coverage is not needed in the repair. The first step of the method includes the removal of a portion of the worn or damaged tip of the blade. Any suitable method can be employed to remove the damaged tip. In some embodiments, an electrochemical method can be used for the removal of the damaged tip. The electrochemical treatment is usually followed by de-smutting and rinsing steps. The replacement (or new) protective covering can then be applied to the tip portion of the blade by the active brazing method, as previously discussed in detail. In one embodiment, a sintered protective covering may be joined to the tip portion of the blade.

[0044] Embodiments of the present invention provide advantages to leverage a relatively inexpensive, simple, and rapid process to hermetically join and manufacture the blade tip, as compared to currently available methods. The resulting blade tips are very strong, reliable, and chemically stable in the corrosive environment. For example, the tensile strength of the active braze joint often ranges between about 100 Mpa and about 200 MPa for a ceramic to metal butt joint. Moreover, an additional advantage provided by active brazing is the ability to achieve the joint in single step, and thus to manufacture the blade tip in fewer steps, and simpler steps, as compared to known multi-step, cumbersome manufacturing processes. In brief, active brazing simplifies the joining process, and improves the reliability and performance of the blade tip.

[0045] In some embodiments, a compressor rotor comprises a plurality of blades. The plurality of blades is arranged circumferentially on the rotor. In some embodiments, every blade of the rotor includes the protective covering **24** (e.g., hard tip) (as discussed above). In some embodiments, a few (not all) blades include the hard tip, which are usually referred to as "cutter blades." The purpose of the cutter blade is to engage shroud material located on the inner surface of the casing, to further minimize any leakage around the blade tip. The cutter blade including the hard tip cuts the shroud material as the blade rotates, providing an incursion into the shroud material. The hard tip serves to wear-form a seal track in the shroud, resulting in a virtual seal between the blades and the shroud which prevents gases from bypassing the rotor assembly. The advantage of the cutter blade is that only a small number of the compressor blades need to be given the hard protective covering, while the rest can be left bare. Thus, for some embodiments, the cost of disposing protective coverings on every blade, and related processing (tip grinding to the precise height and profile) can be avoided. Further, the cutter blades can be made deliberately taller than the rest of the compressor blades, so that only the covered or capped cutter blades make substantial contact with the shroud material. By cutting into the shroud and creating a trench, the cutter blades protect the rest of the blades from rubbing, and reduce overall damage.

[0046] While only certain features of the invention have been illustrated and described herein, many modifications and changes will occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention. Furthermore, all of the patents, patent applications, articles, and texts which are mentioned above are incorporated herein by reference.

1. A compressor blade, comprising a protective covering bonded to a tip portion by a braze material, wherein the braze material comprises from about 1 weight percent to about 10 weight percent of an active element, based on the total amount of the braze material.

2. The compressor blade of claim **1**, formed of a material comprising titanium, iron, or an alloy containing one or more thereof.

3. The compressor blade of claim **1**, formed of a titanium-based alloy.

4. The compressor blade of claim **1**, formed of stainless steel.

5. The compressor blade of claim **1**, wherein the protective covering comprises a hard ceramic material.

6. The compressor blade of claim **5**, wherein the protective covering comprises aluminum oxide, zirconium oxide, titanium boride, titanium carbide, titanium nitride, titanium carbo-nitride, titanium boro nitride, chrome carbide, chrome nitride, chrome boride, molycarbide, or a combination thereof.

7. The compressor blade of claim **1**, wherein the protective covering is present in the form of a preform, a sheet, a wafer, or a wire.

8. The compressor blade of claim **1**, wherein the protective covering has a thickness in a range from about 50 microns to about 1000 microns.

9. The compressor blade of claim **1**, wherein the braze material comprises copper, silver, gold, zinc, manganese, tin, nickel, molybdenum, or an alloy containing one or more thereof.

10. The compressor blade of claim **1**, wherein the amount of the active metal element is in a range from about 2 weight percent to about 6 weight percent, based on the total weight of the braze material.

11. The compressor blade of claim **1**, wherein the active metal element comprises titanium, hafnium, vanadium, or zirconium.

12. A compressor rotor, comprising a plurality of blades in accordance with claim **1**.

13. A method, comprising:

disposing a braze material between a surface of a protective covering and a tip portion of a compressor blade, wherein the braze material comprises an active metal element in an amount from about 1 weight percent to about 10 weight percent, based on the total amount of the braze material; and

joining the protective covering to the tip portion by heating the braze material to form a braze joint between the tip portion and the protective covering.

14. The method of claim **13**, wherein the protective covering comprises a hard ceramic material.

15. The method of claim **14**, wherein the protective covering comprises aluminum oxide, zirconium oxide, titanium boride, titanium carbide, titanium nitride, titanium carbonitride, titanium boro nitride, chrome carbide, chrome nitride, chrome boride, molycarbide, or a combination thereof.

16. The method of claim **13**, wherein the protective covering is present in the form of a preform, a sheet, a wafer, or a wire.

17. A method for repair of a compressor blade, comprising the steps of:

(i) removing a portion of a worn or damaged tip of the blade from a tip portion of the blade; and

(ii) providing a protective covering on the tip portion of the blade such that the protective covering replaces at least a portion of the removed portion of the tip of the blade, and wherein providing the protective covering comprises the steps of:

disposing a braze material between a surface of the protective covering and a tip portion of a compressor blade, wherein the braze material comprises an active metal element in an amount from about 1 weight percent to about 10 weight percent based on the total amount of the braze material; and

joining the protective covering to the tip portion by heating the braze material, to form a braze joint between the tip portion and the protective covering.

* * * * *