

METHODS OF FURNACE-LESS BRAZING

FIELD

[0001] The present subject matter relates generally to methods of furnace-less brazing. More particularly, the present subject matter relates to a braze material capable of sustaining an exothermic reaction for braze joining and/or repair of a substrate.

BACKGROUND

[0002] Superalloys are used in the manufacture of components that must operate at high temperatures, such as blades, nozzles, combustors, and shrouds of aerospace or industrial gas turbines. During the operation of such components under strenuous high temperature conditions, various types of damage or deterioration can occur, including oxidation, wear and cracking. Accordingly, improved brazing methods are required for repairing components of turbine engines.

BRIEF DESCRIPTION

[0003] Aspects and advantages of the invention will be set forth in part in the following description, or may be obvious from the description, or may be learned through practice of the invention.

[0004] In one exemplary embodiment of the present subject matter, a method of furnace-less brazing of a substrate is provided. The method includes providing a substrate having a braze region thereon; disposing braze precursor material containing a nickel powder, an aluminum powder, and a platinum group metal powder on the braze region; and initiating an exothermic reaction of the braze precursor material such that the exothermic reaction produces a braze material that reaches a temperature above the solidus temperature for the braze material.

[0005] In a further exemplary embodiment of the present subject matter, a braze precursor material is provided. The braze precursor material comprises a nickel powder, an aluminum powder, and a platinum-group metal powder, the braze precursor material capable of producing a braze material having a braze temperature to propagate and sustain an exothermic reaction, wherein after the exothermic reaction a solidified braze

material is formed, the solidified braze material includes a nickel alloy having at least 5 vol.% gamma (FCC) phase.

[0006] These and other features, aspects and advantages of the present invention will become better understood with reference to the following description and appended claims. The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] A full and enabling disclosure of the present invention, including the best mode thereof, directed to one of ordinary skill in the art, is set forth in the specification, which makes reference to the appended figures, in which:

[0008] FIG. 1 provides a schematic cross-section view of an exemplary gas turbine engine according to various embodiments of the present disclosure;

[0009] FIG. 2 illustrates a portion of a component having a braze region thereon repaired according to exemplary embodiments of the present disclosure;

[0010] FIG. 3 illustrates a portion of a component having a braze region thereon repaired according to exemplary embodiments of the present disclosure;

[0011] FIG. 4 illustrates a portion of a component having a braze region thereon repaired according to exemplary embodiments of the present disclosure;

[0012] FIG. 5 illustrates a portion of a component having a braze region thereon repaired according to exemplary embodiments of the present disclosure;

[0013] FIG. 6 illustrates a flowchart of an example method according to exemplary embodiments of the present disclosure;

[0014] FIG. 7 illustrates a composition range of a Ni-Al-Pd ternary alloy composition according exemplary embodiments of the present disclosure;

[0015] FIG. 8 illustrates an SEM microphotograph of a braze region according to exemplary embodiments of the present disclosure;

[0016] FIG. 9 illustrates an SEM microphotograph of a braze region according to exemplary embodiments of the present disclosure; and

[0017] FIG. 10 illustrates an SEM microphotograph of a braze region according to exemplary embodiments of the present disclosure.

DETAILED DESCRIPTION

[0018] Reference will now be made in detail to present embodiments of the invention, one or more examples of which are illustrated in the accompanying drawings. The detailed description uses numerical and letter designations to refer to features in the drawings. Like or similar designations in the drawings and description have been used to refer to like or similar parts of the invention.

[0019] As used herein, the terms “first,” “second,” and “third” may be used interchangeably to distinguish one component from another and are not intended to signify location, order, or importance of the individual components.

[0020] The terms “coupled,” “fixed,” “attached to,” and the like refer to both direct coupling, fixing, or attaching, as well as indirect coupling, fixing, or attaching through one or more intermediate components or features, unless otherwise specified herein.

[0021] The singular forms “a,” “an,” and “the” include plural references unless the context clearly dictates otherwise.

[0022] Approximating language, as used herein throughout the specification and claims, is 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,” “approximately,” and “substantially,” are not to be limited to the precise value specified. In at least some instances, the approximating language may correspond to the precision of an instrument for measuring the value, or the precision of the methods or machines for constructing or manufacturing the components and/or systems. For example, the approximating language may refer to being within a 10 percent relative margin.

[0023] As used herein the term “powder” or the like refers to a collection of particles. The particles may be of any configuration, shape or size as long as they are suitable for the flowability, dispersion and/or compaction thereof. In some embodiments, a median particle size of the powder is less than about 100 micrometers.

[0024] As used herein the term “median particle size” refers to median value of the particle size distribution, also known as d₅₀.

[0025] Here and throughout the specification and claims, range limitations are combined and interchanged, such ranges are identified and include all the sub-ranges

contained therein unless context or language indicates otherwise. For example, all ranges disclosed herein are inclusive of the endpoints, and the endpoints are independently combinable with each other.

[0026] Because the cost of components formed from superalloys is relatively high, it is often more desirable to repair these components than to replace them. For the same reason, new-make components that require repair due to manufacturing flaws are also preferably repaired instead of being scrapped. Furthermore, in some manufacturing operations that require braze joining, it is preferable not to subject the entire part to the brazing temperature, as would be the case in isothermal furnace, such as conventional vacuum, brazing.

[0027] Generally, the present subject matter provides a method of furnace-less brazing of a substrate, including joining for manufacturing and repair. The method includes providing a substrate having a braze region thereon; disposing braze precursor material containing a nickel powder, an aluminum powder, and a platinum group metal powder on the braze region; and initiating an exothermic reaction of the braze precursor material such that the braze precursor material reaches a temperature above the melting temperature for the braze precursor material; wherein after the exothermic reaction of the braze precursor material a solidified braze material is formed. For instance, the braze precursor material is capable of heating up to a braze temperature at which the resulting braze alloy is at least partially melted, so as to form a metallurgical bond between the substrate and the solidified braze material. Braze precursor materials and methods for in-situ repair of gas turbine engine components are also provided. The brazing methods and materials disclosed herein are suitable for brazing components without the use of a furnace. Thus, the brazing methods and materials disclosed herein can be used for a variety of repairs where furnace brazing is not feasible or desired.

[0028] Referring now to the drawings, wherein identical numerals indicate the same elements throughout the figures, FIG. 1 is a schematic cross-sectional view of a gas turbine engine in accordance with an exemplary embodiment of the present disclosure. More particularly, for the embodiment of FIG. 1, the gas turbine engine is a turbofan jet engine 10. As shown in FIG. 1, the turbofan engine 10 defines an axial direction A (extending parallel to a longitudinal centerline 12) and a radial direction R.

In general, the turbofan engine 10 includes a fan section 14 and a core turbine engine 16 disposed downstream from the fan section 14.

[0029] The exemplary core turbine engine 16 depicted generally includes a substantially tubular outer casing 18 that defines an annular inlet 20. The outer casing 18 encases, in serial flow relationship, a compressor section including a booster or low pressure (LP) compressor 22 and a high pressure (HP) compressor 24; a combustion section 26; a turbine section including a high pressure (HP) turbine 28 and a low pressure (LP) turbine 30; and a jet exhaust nozzle section 32. A high pressure (HP) shaft or spool 34 drivingly connects the HP turbine 28 to the HP compressor 24. A low pressure (LP) shaft or spool 36 drivingly connects the LP turbine 30 to the fan 38 and LP compressor 22.

[0030] For the depicted embodiment, fan section 14 includes a fan 38 having a plurality of fan blades 40 coupled to a fan disk 42 in a spaced apart manner. As depicted, fan blades 40 extend outward from fan disk 42 generally along the radial direction R. The fan blades 40 and fan disk 42 are together rotatable about the longitudinal centerline 12 by LP shaft 36. In some embodiments, a power gear box having a plurality of gears may be included for stepping down the rotational speed of the LP shaft 36 to a more efficient rotational fan speed.

[0031] Referring still to the exemplary embodiment of FIG. 1, fan disk 42 is covered by rotatable front nacelle 48 aerodynamically contoured to promote an airflow through the plurality of fan blades 40. Additionally, the exemplary fan section 14 includes an annular fan casing or outer nacelle 50 that circumferentially surrounds the fan 38 and/or at least a portion of the core turbine engine 16. It should be appreciated that fan case (nacelle) 50 may be configured to be supported relative to the core turbine engine 16 by a plurality of circumferentially-spaced outlet guide vanes 52. Moreover, a downstream section 54 of the fan case 50 may extend over an outer portion of the core turbine engine 16 so as to define a bypass airflow passage 56 therebetween.

[0032] During operation of the turbofan engine 10, a volume of air 58 enters turbofan engine 10 through an associated inlet 60 of the fan case 50. As the volume of air 58 passes across fan blades 40, a first portion of the air 58 as indicated by arrows 62 is directed or routed into the bypass airflow passage 56 and a second portion of the air 58 as indicated by arrows 64 is directed or routed into the LP compressor 22. The ratio

between the first portion of air indicated by arrows 62 and the second portion of air as indicated by arrows 64 is commonly known as a bypass ratio. The pressure of the second portion of air as indicated by arrows 64 is then increased as it is routed through the high pressure (HP) compressor 24 and into the combustion section 26, where it is mixed with fuel and burned to provide combustion gases 66.

[0033] The combustion gases 66 are routed through the HP turbine 28 where a portion of thermal and/or kinetic energy from the combustion gases 66 is extracted via sequential stages of HP turbine stator vanes 68 that are coupled to the outer casing 18 and HP turbine rotor blades 70 that are coupled to the HP shaft or spool 34, thus causing the HP shaft or spool 34 to rotate, thereby supporting operation of the HP compressor 24. The combustion gases 66 are then routed through the LP turbine 30 where a second portion of thermal and kinetic energy is extracted from the combustion gases 66 via sequential stages of LP turbine stator vanes 72 that are coupled to the outer casing 18 and LP turbine rotor blades 74 that are coupled to the LP shaft or spool 36, thus causing the LP shaft or spool 36 to rotate, thereby supporting operation of the LP compressor 22 and/or rotation of the fan 38.

[0034] The combustion gases 66 are subsequently routed through the jet exhaust nozzle section 32 of the core turbine engine 16 to provide propulsive thrust. Simultaneously, the first portion of air indicated by arrows 62 is routed through the bypass airflow passage 56 before it is exhausted from a fan nozzle exhaust section 76 of the turbofan engine 10, also providing propulsive thrust. The combustion section 26, the HP turbine 28, the LP turbine 30, and the jet exhaust nozzle section 32 at least partially define a hot gas path 78 for routing the combustion gases 66 through the core turbine engine 16.

[0035] As noted above, certain components of the turbine engine can be fabricated from metallic materials, such as metal alloys, including superalloys. After continued use, one or more components of the engine 10 may become damaged. For example, certain metallic components of the engine may develop one or more cracks or pits due to oxidation, corrosion, or thermo-mechanical stresses.

[0036] Referring now to FIG. 2, a cross section view of a component 100 including a braze region 104 is shown. In FIG. 2, the braze region 104 can be a repair region including a damaged area in need of repair. For instance, the damaged area can

include a crack or pit in the substrate 106 of the component 100. At 200 a braze precursor material 108 is disposed on or about the repair region 104. At 202 the braze precursor material 108 is ignited such that an exothermic reaction of the braze precursor material 108 takes place, forming molten braze material. Once cooled, the molten braze material solidifies, creating a solidified braze material 109 in braze region 104 of the substrate 106.

[0037] In other embodiments, as shown in FIG. 3, a heat source material 110 is disposed over or around the braze precursor material 108. The braze precursor material 108 is disposed on the braze region 104 of the substrate 106. For example, at 200a a heat source material 110 and the braze precursor material 108 are disposed on the braze region 104. At 202a an exothermic reaction is initiated in the braze precursor material 108 and the heat source material 110, such that an exothermic reaction of the braze precursor material 108 takes place, forming molten braze material. The molten braze material can infiltrate the braze region 104 and thus repair substrate 106. The heat source material 110 can provide additional heat for the exothermic reaction of the braze precursor material 108. The heat source material 110 is capable of exothermically reacting to facilitate brazing. In some embodiments, the heat source material 110 does not alter the braze composition. In other embodiments, depending on the desired properties for the solidified braze material 109, the heat source material 110 may alloy with the molten braze material to participate in metallurgical bonding of the molten braze material to the substrate 106. Once cooled, the heat source material 110 forms a solidified heat source material 111. Furthermore, once cooled, the molten braze material solidifies, creating a solidified braze material 109 in braze region 104 of the substrate 106.

[0038] As shown in FIG. 4, it may be necessary to join two metallic components. Accordingly, a first component 120 and a second component 130 can be brought together such that a joint gap 140 is formed between the first and second components. At 200b the braze precursor material 108 is disposed on, in, or around the joint gap 140. At 202b an exothermic reaction is initiated in the braze precursor material 108, forming a molten braze material from the braze precursor material 108 that fills joint gap 140. The molten braze material can re-solidify, resulting in solidified braze

material 109 in the joint gap 140 between the first component 120 and the second component 130, thus effectively joining the two components.

[0039] Similar to example embodiments as shown in FIG. 3, in FIG. 5, a heat source material 110 can be disposed on or around the braze precursor material 108 to facilitate brazing. For example, at 200c the braze precursor material 108 can be disposed on the joint gap 140 and the heat source material 110 can be disposed on or around the braze precursor material 108. At 202c an exothermic reaction is initiated in the braze precursor material 108 and the heat source material 110, forming molten braze material. The molten braze material can infiltrate the joint gap 140. Once cooled, the molten braze material solidifies, creating a solidified braze material 109 in the joint gap 140, thus joining the two components together. The heat source material 110 can provide additional heat to the braze material formed from the exothermic reaction of the braze precursor material 108. The heat source material 110 can be capable of exothermically reacting to facilitate brazing of the molten braze material and/or improving the quality of the braze. In some embodiments, the heat source material 110 does not participate in the braze. For example, the heat source material 110, does not alloy with the molten braze material to participate in bonding of the molten braze material to component 120 and component 130. However, in other embodiments, depending on the desired properties for the solidified braze material 109, the heat source material 110 may mix with the molten braze material to participate in metallurgical bonding of the molten braze material to component 120 and component 130. Once cooled, the heat source material 110 forms a solidified heat source material 111.

[0040] A method 300 as shown in FIG. 6 may be used for brazing components. At 302 the method includes providing a substrate having a braze region thereon. The braze region can include a repair region such as a pit, a partial crack, a through-thickness crack, or combinations thereof. In embodiments, the braze region includes a joint gap between one or more components to be joined together. The substrate can be a metallic substrate such as a nickel-based alloy, including nickel-based superalloys, an iron-based alloy, including iron-based superalloys, a cobalt-based alloy, including cobalt-based superalloys, a titanium-based alloy, or combinations thereof. Illustrative nickel-base alloys include superalloys including at least about 40 wt % Ni, and at least one component from the group consisting of cobalt, chromium, aluminum, tungsten,

molybdenum, titanium, and iron. Examples of nickel-base superalloys are designated by the trade names Inconel®, Nimonic®, Rene® and Udimet®, and include directionally solidified and single crystal superalloys. Illustrative cobalt-base alloys include superalloys including at least about 30 wt % Co, and at least one component from the group consisting of nickel, chromium, aluminum, tungsten, molybdenum, titanium, and iron. Examples of cobalt-base superalloys are designated by the trade names Haynes®, Nozzaloy®, Stellite® and Ultimet®. In the case of turbine components, the substrate may be in the form of a turbine nozzle, shroud, shroud hanger, pressure balance seal, blade, case or combustor component.

[0041] At 304, the method includes optionally pretreating the substrate. For example, the substrate can be pretreated to remove contaminants, such as oxide layers, dust, or corrosion products, so as to facilitate wetting of the brazing material to the substrate 106. For example, the repair region may be chemically cleaned, detergent washed, or mechanically ground, sanded, grit blasted or drilled to prepare the surface for brazing.

[0042] At 306 the method includes disposing a braze precursor material on the braze region of the substrate. The composition of the braze precursor material will be explained in more detail hereinbelow.

[0043] At 308, the method includes optionally disposing a heat source material on or around the brazing material on the braze region. The heat source material can be an exothermic heat source material capable of providing heat upon reaction so as to raise the temperature of the braze precursor material and/or molten braze material, so as to achieve a desired braze temperature resulting in metallurgical bonding between the braze material and the substrate. The heat source material can be formulated depending on the composition of the braze precursor material and the underlying substrate. For example, in embodiments the heat source material can include one or more metal powders, such as at least two metal powders. For example, the heat source material can include a mixture of aluminum powder and nickel powder. In some embodiments, the heat source material does not participate in the braze. For instance, elements or components of the heat source material do not substantially mix or alloy with the elements of the braze material along braze regions on the substrate. Thus, the heat source material facilitates brazing but does not substantially alter the composition

of the braze. In other embodiments, it may be desirable for certain components of the heat source material to participate in the braze. In such embodiments, the heat source material can melt and alloy with the molten braze material and elements of the molten heat source material can participate in metallurgical bonding with the molten braze material along braze regions on the substrate.

[0044] In addition to providing a source of auxiliary heat for the braze reaction, the heat source material can help improve the quality of the resulting braze. For instance, addition of the heat source material can result in a denser solidified braze material and may facilitate wetting of the braze material to the substrate.

[0045] At 310 the method includes initiating an exothermic reaction of the braze precursor material for brazing the braze region of the substrate. The braze precursor material can be ignited with an external heat source, such as a combustion torch, a laser, or an electric heater. For example, in certain embodiments, a hydrogen-oxygen torch can be used to ignite the braze precursor material. Accordingly, in certain embodiments the braze precursor material can be heated directly to initiate the exothermic reaction. In other embodiments, the braze precursor material may be indirectly heated to initiate the exothermic reaction, such as by heating the underlying substrate.

[0046] Once initiated, the exothermic reaction of the braze precursor material is capable of rapidly propagating through the volume of the reacting material and the heat can raise the temperature sufficiently so as to melt the braze precursor material and provide a metallurgical bond to the substrate. Accordingly, the exothermic reaction of the braze precursor material produces a molten braze material. In embodiments where the repair region constitutes a pit or a crack, the molten braze material flows into and fills the pit or crack. In other embodiments, where the braze is used to join components, the molten braze material flows into and fills the joint gap between the components. For example, the molten braze material can reach a braze temperature that can partially melt adjacent surfaces of the substrate such that the molten substrate material intermixes with the molten braze material, thus bonding the molten braze material with the substrate.

[0047] Upon completion of the exothermic reaction at 310, the molten braze material cools, thus re-solidifying to form a brazed substrate. The solidified braze material has suitable ductility and strength, such that the repaired substrate or joined

components can be used in their respective applications. For example, the solidified braze material can comprise a nickel-based alloy having at least 5 vol.% gamma (FCC) phase. The braze material thus provided has sufficient ductility and thermochemical compatibility with metal substrates as compared to other known exothermic materials. At 312, optional surface treatment of the brazed substrate can be performed. For instance, additional machining, polishing, or other surface modification of the substrate can be performed so as to restore the desired geometry, surface finish, and/or surface chemistry to the brazed substrate.

[0048] The braze material described herein includes one or more metal powders. For example, the braze material can include nickel powder, aluminum powder, platinum-group metal powder, or combinations thereof. For example, “platinum-group metal powder” as used herein refers to metal powders including one or more of the platinum-group metals including platinum, palladium, rhodium, ruthenium, osmium, and iridium. In some embodiments, the powder included in the braze precursor material may be made of any materials, such as, nickel, chromium, iron, niobium, tantalum, molybdenum, titanium, aluminum, palladium, titanium, cobalt, carbon, manganese, silicon, boron, copper, or any combination thereof. In some embodiments, the powders included in the braze precursor material may be partially pre-alloyed. As used herein “metal powder” is not limited to only elemental metal powders. For example, a powder containing pre-alloyed nickel-palladium powder would be considered both a nickel powder and a palladium powder, given that both metal elements are present in the powder. Similarly, powder mixtures containing multiple metal elements can be used as suitable powders according to example embodiments provided herein. For example, the braze precursor material can include a pre-alloyed nickel-palladium powder, a pre-alloyed nickel-cobalt powder, a pre-alloyed nickel-chromium powder, and any combination thereof. Furthermore, the powders utilized can be pretreated according to suitable processes prior to being introduced into the braze precursor material. For example, the powders can be partially or fully oxidized prior to their incorporation into the braze precursor material.

[0049] As shown in FIG. 7, in one embodiment, the braze precursor material can include a ternary alloy composition containing certain atomic percentages of nickel, aluminum, and palladium as indicated by area 250. In embodiments, the braze precursor

material can include an atomic ratio of palladium to nickel of from about 0.43 to 2.33, such as 0.54 to 1.67. In other embodiments, the braze precursor material can include an atomic ratio of aluminum to a sum of palladium and nickel of from about 0.15 to 0.67, such as from about 0.16 to 0.47. In some embodiments, the atomic ratio of aluminum to a sum of palladium and nickel is from about 0.12 to about 0.4. In some embodiments, the braze precursor material comprises less than or equal to 50 atomic % nickel. In embodiments, the braze precursor material is nickel-based, wherein nickel is the single greatest element of the braze material by atomic weight.

[0050] Indeed, the specific amounts of metal powders used in the braze precursor material can be tailored depending on the material of the underlying substrate but also on the desired braze temperature, ductility, and/or strength of the braze material. The braze precursor material provided is capable, upon ignition, of propagating and sustaining an exothermic reaction producing a braze temperature above the solidus temperature of the braze material. For instance, once ignited, metal powders in the braze precursor material begin to melt, forming a molten braze material including elements of the metal powders in the braze precursor material.

[0051] Advantageously, since the braze precursor material provided herein is capable of exothermically generating a braze temperature above the solidus temperature for the resulting braze material, no furnace is required for repair. Furthermore, because the brazing process occurs very rapidly, and often in about 10 to about 100 seconds, brazing can be accomplished without the use of vacuum or reducing atmosphere, such as in ambient atmosphere.

[0052] Optionally, the braze material can include one or more elements for lowering the melting temperature of the braze material so as to ensure that the braze precursor material melts fully during the brazing process. Melting point suppressants for brazes of interest can include silicon, boron, palladium, titanium, phosphorus, or combinations thereof.

[0053] The braze precursor material can also include one or more flux materials for promoting de-oxidation and subsequent wetting of the substrate.

[0054] The braze precursor material may contain a variety of further alloying additions, such as for enhancing strength, ductility, and oxidation resistance of the braze. The cost of braze constituents, as well as material availability and compatibility

to the substrate, are also considerations. Additionally, the braze precursor material may include one or more metal oxides so as to increase the adiabatic reaction temperature, delay the initiation temperature of the reaction, and/or modify the final braze composition. For example, the braze precursor material can include up to about 15 atomic % of nickel oxide and/or cobalt oxide.

[0055] As noted, the braze precursor material includes one or more metal powders, for example, nickel powder, cobalt powder, aluminum powder, palladium powder, platinum powder, or combinations thereof. In such embodiments, the particle size and packing density of the powders selected can be critical for propagating and sustaining the exothermic reaction such that the desired braze temperature can be reached and maintained for a desired period of time. For example, including metal powders having median particle sizes that are too low or too high can result in a braze material that does not reach the desired braze temperature or can reach braze temperature too quickly and cool before the brazing process is completed. Indeed, if the exothermic reaction cannot produce enough heat for a sufficient period of time to fully melt the braze precursor material, achieving a good metallurgical repair is impossible. Accordingly, in embodiments, the nickel powder in the braze precursor material has a median particle size of from about 50 μm to about 90 μm , and the aluminum powder has a median particle size of from about 3 μm and less than 75 μm , such as about 5 μm to about 35 μm , such as from about 10 μm to about 30 μm . The desired ratio of the median particle size of the nickel powder to the median particle size of the aluminum powder is from about 7:1 to about 2:1.

[0056] The braze precursor material can be disposed in any suitable form, including a preform pellet. For example, in embodiments, the braze precursor material includes one or more metal powders compacted into a preform pellet having density in the range 40-85% of theoretical. The theoretical density can be calculated according to any suitable method. For instance, the theoretical density of a cylindrical pellet can be calculated by measuring the bulk pellet volume, V_B :

$$V_B = h * \pi r^2$$

where h is the pellet height and r is the pellet radius. The theoretical pellet volume, V_T , can be obtained by summing the mass of each powder constituent, m_i , divided by the powder's corresponding elemental density, ρ_i :

$$V_T = \sum_i \frac{m_i}{\rho_i}$$

Once the theoretical pellet volume is obtained, theoretical density, ρ_T , can be calculated as follows:

$$\rho_T[\%] = V_T/V_B * 100$$

[0057] In other embodiments, the metal particles forming the braze precursor material can be formulated in a suitable binder/solvent matrix to make a paste, slurry, or putty that can be easily applied to repair regions of the substrate. The solvents can be either aqueous or organic. The binders are often water-based materials such as polyethylene oxide and various acrylics; or solvent-based materials. The slurry can contain a variety of other conventional additives, such as dispersants, wetting agents, deflocculants, stabilizers, anti-settling agents, thickening agents, plasticizers, emollients, lubricants, surfactants, anti-foam agents, and curing modifiers. The slurry can be deposited on the substrate (or between two substrates being joined) by any convenient technique, in one or more layers, such as by extrusion from a syringe. Prior to being heated to a brazing temperature, the slurry can be heat-treated by any suitable means, so as to remove some or all of its volatile components.

[0058] Optionally, the braze precursor material can be disposed in the form of a tape preform. For example, the slurry described above can be tape-cast to produce a free-standing sheet or tape. Tape-casting methods are known in the art. Usually, the slurry is tape-cast onto a removable support sheet, e.g., a plastic sheet formed of a material such as Mylar®. Substantially all of the volatile material in the slurry is then allowed to evaporate. The removable support sheet is then detached from the green braze precursor tape. The resulting tape usually has a thickness in the range of about 100 microns to about 2000 microns. The free-standing, green braze precursor tape can then be cut to a size appropriate for the particular brazing technique and applied to the location where brazing will take place. Various techniques can be used to temporarily hold the tape in place, prior to the actual brazing step, including adhesives and tack-welds.

[0059] The use of the braze material in the form of a metal sheet or “foil” is also known in the art. As one example, the braze precursor material, in the form of a powder, can first be combined with a binder and/or with additional metal powder which is

similar in composition to the substrate. The combined material is then deposited onto a support sheet, e.g., by a cold spray technique. The support sheet is then removed, leaving the desired metal foil. Foils of this type can also be prepared by other methods as well, e.g., an amorphous metal ribbon technique. A “pre-forming” technique could also be used, wherein the previously-described green tape can be treated to remove any binder, to form a metallic sheet. Prior to the actual brazing step, the foil can be temporarily held in place on the substrate, as described above.

[0060] The braze precursor material can be disposed on the substrate via cold spray, where particles are accelerated using a supersonic carrier gas at a sufficiently low temperature to prevent melting or interdiffusion of the particles, resulting in a dense deposit on the substrate surface.

[0061] Methods for in-situ repair of a gas turbine engine component are also provided. The method includes providing a substrate having a repair region thereon; disposing a braze precursor material comprising a nickel powder, an aluminum powder, and a platinum group metal powder on the braze region; and initiating an exothermic reaction of the braze precursor material to affect braze repair of the substrate.

[0062] Accordingly, the present subject matter is directed to a method of furnace-less brazing, such as repair of a substrate or joining of components. More particularly, the present subject matter provides a braze precursor material capable of sustaining an exothermic reaction such that the heat from the exothermic reaction facilitates brazing of a substrate. Advantageously, the methods provided herein allow for the local, ambient-atmosphere repair of metal components, including components in the hot gas path of a gas turbine engine. The methods also allow for in-module, in-case, and on-wing repairs, as well as repairs on large structures, without the need for disassembly and controlled-atmosphere furnace brazing. The methods reduce cycle time, cost, and labor of repairs.

[0063] The following examples are presented in order to provide a more complete understanding of the repair method. The specific techniques, conditions, materials and reported data set forth as illustrations are exemplary and should not be construed as limiting the scope of the inventive subject matter.

[0064] In an example, a substrate of Nimonic®-263 nickel-based superalloy was provided. The braze precursor material comprised a 10mm diameter cold-pressed

pellet containing an elemental powder mixture of 50 atomic % aluminum and 50 atomic% nickel. The density of the pellet of braze precursor material was about 75%. The nickel particles have a D50 of 70 μm and the aluminum particles have a D50 of 20 μm . The braze precursor material was placed on the Nimonic®-263 substrate. The braze precursor material was heated with a torch to initiate an exothermic reaction. As shown in FIG. 8, the elemental powder constituents of the braze precursor material alloyed with the substrate surface, resulting in a thin reaction zone between the substrate and the braze.

[0065] In yet another example, a substrate of GTD-222 nickel-based superalloy was provided. The braze precursor material comprised a cold-pressed pellet approximately 12.5 mm in diameter and containing an elemental powder mixture of 37.5 atomic% palladium, 37.5 atomic % aluminum, balance nickel. The density of the pellet of braze precursor material was about 78%. The nickel particles have a D50 of 70 μm and the aluminum particles have a D50 of 20 μm . The braze precursor material was placed over a cavity in the GTD-222 substrate and heated with a torch to initiate an exothermic reaction. As shown in FIG. 9, the elemental powders making up the braze precursor material fully reacted and partially melted the substrate surface, resulting in a thin reaction zone between the substrate and the braze.

[0066] In yet another example, a substrate of Nimonic®-263 was provided. The braze precursor material comprised a cold-pressed pellet approximately 12.5 mm in diameter and containing an elemental powder mixture of 40 atomic% palladium, 12 atomic % aluminum, balance nickel. The density of the pellet of braze precursor material was about 68%. The nickel particles have a D50 of 70 μm and the aluminum particles have a D50 of 20 μm . The braze precursor material was placed over a cavity in the Nimonic®-263 substrate and heated with a torch to initiate an exothermic reaction. The elemental powders making up the braze precursor material fully reacted and partially melted the substrate surface. As shown in FIG. 10, the resultant braze contains greater than 5 volume % of gamma-FCC phase. Specifically, gamma phase (FCC-(Ni,Pd)) appears dark in the microphotograph whereas Pd_2Al with some gamma phase (FCC-(Ni,Pd)) appears brighter in the microphotograph.

[0067] While exemplary aspects provided herein are directed to gas turbine engines, the disclosure is not so limited. For example, it is conceivable that the braze

material described herein can be used to repair any metallic or ceramic component, especially where the use of a braze furnace is not practical.

[0068] Further aspects of the invention are provided by the subject matter of the following clauses:

[0069] 1. A method of furnace-less brazing of a substrate, comprising: providing a substrate having a braze region thereon; disposing braze precursor material containing a nickel powder, an aluminum powder, and a platinum group metal powder on the braze region; and initiating an exothermic reaction of the braze precursor material such that the exothermic reaction produces a braze material that reaches a temperature above the solidus temperature for the braze material.

[0070] 2. The method of any preceding clause wherein the braze material cools to form a solidified braze material comprising a nickel alloy having at least 5 vol.% gamma face-centered-cubic (FCC) phase.

[0071] 3. The method of any preceding clause wherein the braze precursor material comprises an atomic ratio of palladium to nickel of from about 0.43 to 2.33, wherein the braze precursor material comprises an atomic ratio of aluminum to a sum of palladium and nickel of from about 0.15 to 0.67, further wherein the braze precursor material comprises less than or equal to 50 atomic% of nickel.

[0072] 4. The method of any preceding clause wherein the braze precursor material comprises an atomic ratio of palladium to nickel of from about 0.54 to 1.67, wherein the braze precursor material comprises an atomic ratio of aluminum to the sum of palladium and nickel of from about 0.16 to 0.47, further wherein the braze precursor material comprises less than or equal to 50 atomic% nickel.

[0073] 5. The method of any preceding clause wherein the braze precursor material further comprises boron, cobalt, titanium, platinum, one or more metal oxides, or combinations thereof.

[0074] 6. The method of any preceding clause wherein a ratio of a median particle size of the nickel powder to a median particle size of the aluminum powder is from about 7:1 to about 2:1.

[0075] 7. The method of any preceding clause wherein a ratio of a median particle size of the platinum-group metal powder to a median size of the aluminum powder is from about 7:1 to about 2:1.

- [0076] 8. The method of any preceding clause wherein a median particle size of the aluminum powder is between about 8 μm to about 50 μm , such as from about 10 μm to about 30 μm .
- [0077] 9. The method of any preceding clause wherein a median particle size of the nickel powder is from about 50 μm to about 90 μm .
- [0078] 10. The method of any preceding clause wherein the braze temperature is above a liquidus temperature of the braze material.
- [0079] 11. The method of any preceding clause wherein the braze temperature is capable of partially melting an adjacent surface of the metal substrate to enhance bonding between the braze material and the substrate.
- [0080] 12. The method of any preceding clause wherein the braze region comprises a repair region comprising a pit, partial crack, or through-thickness crack in the substrate.
- [0081] 13. The method of any preceding clause wherein the braze region comprises a joint gap between two metallic substrates to be joined.
- [0082] 14. The method of any preceding clause wherein the substrate is part of a component for a gas turbine engine.
- [0083] 15. The method of any preceding clause comprising prior to initiating an exothermic reaction of the braze precursor material, disposing a heat source material on the braze precursor material on the braze region.
- [0084] 16. A braze precursor material, comprising: a nickel powder, an aluminum powder, and a platinum-group metal powder, the braze precursor material capable of producing a braze material via an exothermic reaction, wherein after the exothermic reaction a solidified braze material is formed, the solidified braze material comprising a nickel alloy having at least 5 vol.% gamma (FCC) phase.
- [0085] 17. The braze precursor material of any preceding clause wherein the braze precursor material comprises an atomic ratio of palladium to nickel of from about 0.43 to 2.33, wherein the braze precursor material comprise an atomic ratio of aluminum to the sum of palladium and nickel of from about 0.15 to 0.67, further wherein the braze precursor material comprises less than or equal to 50 atomic% nickel.
- [0086] 18. The braze precursor material of any preceding clause wherein the braze precursor material comprises an atomic ratio of palladium to nickel of from

about 0.54 to 1.67, wherein the braze precursor material comprises an atomic ratio of aluminum to the sum of palladium and nickel of from about 0.16 to 0.47.

[0087] 19. The braze precursor material of any preceding clause wherein the braze precursor material has a density of from about 40% to about 85% theoretical.

[0088] 20. The braze precursor material of any preceding clause wherein a median particle size of the aluminum powder is between about 8 μm to about 50 μm , such as from about 10 μm to about 30 μm , and wherein a median particle size of the nickel powder is from about 50 μm to about 90 μm .

[0089] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they include structural elements that do not differ from the literal language of the claims or if they include equivalent structural elements with insubstantial differences from the literal language of the claims.

WHAT IS CLAIMED IS:

1. A method of furnace-less brazing of a substrate, comprising:
providing a substrate having a braze region thereon;
disposing braze precursor material containing a nickel powder, an aluminum powder, and a platinum group metal powder on the braze region; and
initiating an exothermic reaction of the braze precursor material such that the exothermic reaction produces a braze material that reaches a temperature above the solidus temperature for the braze material.
2. The method of claim 1, wherein the braze material cools to form a solidified braze material comprising a nickel alloy having at least 5 vol.% gamma face-centered-cubic (FCC) phase.
3. The method of claim 1, wherein the braze precursor material comprises an atomic ratio of palladium to nickel of from about 0.43 to 2.33, wherein the braze precursor material comprises an atomic ratio of aluminum to a sum of palladium and nickel of from about 0.15 to 0.67, further wherein the braze precursor material comprises less than or equal to 50 atomic% of nickel.
4. The method of claim 1, wherein the braze precursor material comprises an atomic ratio of palladium to nickel of from about 0.54 to 1.67, wherein the braze precursor material comprises an atomic ratio of aluminum to the sum of palladium and nickel of from about 0.16 to 0.47, further wherein the braze precursor material comprises less than or equal to 50 atomic% nickel.
5. The method of claim 1, wherein the braze precursor material further comprises at least one of boron, cobalt, titanium, platinum, or one or more metal oxides.
6. The method of claim 1, wherein a ratio of a median particle size of the nickel powder to a median particle size of the aluminum powder is from about 7:1 to about 2:1.
7. The method of claim 1, wherein a ratio of a median particle size of the platinum-group metal powder to a median size of the aluminum powder is from about 7:1 to about 2:1.

8. The method of claim 1, wherein a median particle size of the aluminum powder is between about 8 μm to about 50 μm , such as from about 10 μm to about 30 μm .

9. The method of claim 1, wherein a median particle size of the nickel powder is from about 50 μm to about 90 μm .

10. The method of claim 1, wherein the braze temperature is above a liquidus temperature of the braze material.

11. The method of claim 1, wherein the braze temperature is capable of partially melting an adjacent surface of the metal substrate to enhance bonding between the braze material and the substrate.

12. The method of claim 1, wherein the braze region comprises a repair region comprising a pit, partial crack, or through-thickness crack in the substrate.

13. The method of claim 1, wherein the braze region comprises a joint gap between two metallic substrates to be joined.

14. The method of claim 1, wherein the substrate is part of a component for a gas turbine engine.

15. The method of claim 1, comprising disposing a heat source material on the braze precursor material on the braze region.

16. A braze precursor material, comprising:
a nickel powder, an aluminum powder, and a platinum-group metal powder,
the braze precursor material capable of producing a braze material by an exothermic reaction,

wherein after the exothermic reaction a solidified braze material is formed, the solidified braze material comprising a nickel alloy having at least 5 vol.% gamma (FCC) phase.

17. The braze precursor material of claim 16, wherein the braze precursor material comprises an atomic ratio of palladium to nickel of from about 0.43 to 2.33, wherein the braze precursor material comprise an atomic ratio of aluminum to the sum of palladium and nickel of from about 0.15 to 0.67, further wherein the braze precursor material comprises less than or equal to 50 atomic% nickel.

18. The braze precursor material of claim 16, wherein the braze precursor material comprises an atomic ratio of palladium to nickel of from about 0.54 to 1.67,

wherein the braze precursor material comprises an atomic ratio of aluminum to the sum of palladium and nickel of from about 0.16 to 0.47, further wherein the braze precursor material comprises less than or equal to 50 atomic% nickel.

19. The braze precursor material of claim 16, wherein the braze precursor material has a density of from about 40% to about 85% theoretical.

20. The braze precursor material of claim 16, wherein a median particle size of the aluminum powder is between about 8 μm to about 50 μm , such as from about 10 μm to about 30 μm , and wherein a median particle size of the nickel powder is from about 50 μm to about 90 μm .