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(54) METHOD FOR LOCALIZED ELECTRODEPOSITION ON A SURFACE OF A COMPONENT

(57) A method including applying a mask to at least a portion of a surface of a component less a defect surface, removing at least one metal oxide from the defect surface, electrodepositing metallic powder particles including a superalloy material on the defect surface by immersing the defect surface in an electrolyte bath having metal ions and the metallic powder particles including the superalloy material, agitating the electrolyte bath, and applying a current, removing the mask, and heat treating at least a portion of the component including the defect surface.

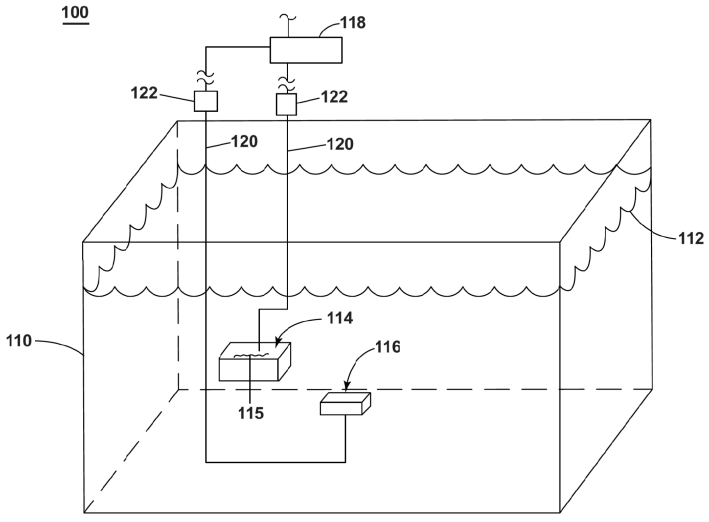


FIG. 1

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Description

PRIORITY INFORMATION

[0001] The present application claims priority to Indian Patent Application Number 202511037668 filed on April 18, 2025.

TECHNICAL FIELD

[0002] The present subject matter relates generally to an electrodeposition method and system for performing electrodeposition, and more specifically to electrodeposition repair of superalloy components.

BACKGROUND

[0003] An electrodeposition process can create, generate, or otherwise form a metallic layer of a desired component. In one example, a mold or base for the desired component can be submerged in an electrolytic liquid and electrically charged. The electric charge of the mold can attract an oppositely charged electrodepositing material through the electrolytic solution. The electrical attraction of the electrodepositing material to the mold ultimately deposits the electrodepositing material onto exposed surfaces of the mold, creating an external metallic layer.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] A full and enabling disclosure of the present disclosure, 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

FIG. 1 is a schematic perspective view of an exemplary electro-etching system.
FIG. 2 is a schematic view of another exemplary electro-etching system.
FIG. 3 is a schematic perspective view of an exemplary electrodeposition system.
FIG. 4 is a flowchart diagram illustrating an exemplary method of localized repair of a defect in a component.
FIGS. 5A, 5B, 5C, 5D, 5E, and 5F show schematic illustrations of a component during the exemplary method of localized repair as in FIG. 4.

DETAILED DESCRIPTION

[0005] Electro-etching, also known as electrochemical etching or electrolytic etching, is a process used to selectively remove material from a surface. In a typical electro-etching process, a metal component acting as an anode is submerged in an electrolyte solution and externally connected to a cathode and a direct electric current is applied between the electrodes. The electric current dissolves an oxide material from the metal component.

[0006] Electrodeposition is an additive manufacturing process where metal parts are formed through electrolytic reduction of metal ions on the surface of cathode. In a typical electrodeposition process, a cathode and an anode are immersed in an electrolyte solution. A metal layer forming a thickness builds upon the cathode surface over time as current is passed between the electrodes. Non-limiting examples of electrodeposition can include electroforming and electroplating, or a combination thereof.

[0007] As used herein, "non-sacrificial anode" will refer to an inert or insoluble anode that does not dissolve in electrolytic fluid when supplied with current from a power source, while "sacrificial anode" will refer to an active or soluble anode that can dissolve in electrolytic fluid when supplied with current from a power source. Non-limiting examples of non-sacrificial anode materials can include titanium, gold, silver, platinum, and rhodium. Non-limiting examples of sacrificial anode materials can include nickel, cobalt, copper, iron, tungsten, zinc, and lead. It will be understood that various alloys of the metals listed above may be utilized as sacrificial or non-sacrificial anodes.

[0008] The word "exemplary" is used herein to mean "serving as an example, instance, or illustration." Any implementation described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other implementations. Additionally, unless specifically identified otherwise, all embodiments described herein should be considered exemplary.

[0009] As used herein, the terms "first", "second", "third", and "fourth" may be used interchangeably to distinguish one component from another and are not intended to signify location or importance of the individual components.

[0010] All directional references (e.g., radial, axial, proximal, distal, upper, lower, upward, downward, left, right, lateral, front, back, top, bottom, above, below, vertical, horizontal, clockwise, counterclockwise, upstream, downstream, aft, etc.) are only used for identification purposes to aid the reader’s understanding of the present disclosure, and do not create limitations, particularly as to the position, orientation, or use of the disclosure. Connection references (e.g., attached, coupled, connected, and joined) are to be construed broadly and can include intermediate members between a collection of elements and relative movement between elements unless otherwise indicated. As such, connection references do not necessarily infer that two elements are directly connected and in fixed relation to one another.

[0011] The singular forms "a", "an", and "the" include plural references unless the context clearly dictates otherwise. Furthermore, as used herein, the term "set" or a "set" of elements can be any number of elements,

including only one.

[0012] 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" and "generally" 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. 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 1, 2, 4, 5, 10, 15, or 20 percent margin in either individual values, range(s) of values and/or endpoints defining range(s) of values. 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.

[0013] Reference will now be made in detail to present embodiments of the disclosure, 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 disclosure. The exemplary drawings are for purposes of illustration only and the dimensions, positions, order, and relative sizes reflected in the drawings attached hereto can vary.

[0014] Aspects of the present disclosure are directed to a system and method for electrodeposition repair of a superalloy component. Superalloy components are commonly used in aircraft applications where mechanical strength, heat resistance, and corrosion resistance are of high importance with regard to safety and aircraft operability. Such components used in an aircraft must be free of surface defects like cracks and crevices to ensure airworthiness of the aircraft. When such a component develops surface defects, replacement of the component is necessary, thereby increasing down-time and costs. Accordingly, there is a need for methods of repairing superalloy components with surface defects.

[0015] A method of repairing a defect on a superalloy component is disclosed herein including the steps of removing metal oxides from at least a portion including a defect on a surface of a component by electro-etching, plating nickel or cobalt on the defect while incorporating metallic powder particles that include a superalloy material by electrodeposition, and heat treating at least the portion including the defect. It has been found that the disclosed method allows for thin layers of superalloy material to gradually, evenly build up on a defect having irregular or jagged geometry such as a crack without causing undesired porosity (e.g. a greater than negligible or zero porosity) in the electroformed layers.

[0016] FIG. 1 is a schematic illustration of an electro-etching system 100. A tank 110 can carry an electrolytic solution 112. In a non-limiting example, the electrolytic solution 112 can be an acid solution such as a solution of sulfuric acid, nitric acid, hydrochloric acid, or a combination thereof in distilled water. A concentration of acid the electrolytic solution 112 can be in a range from greater than 2%. It should be understood that the electrolytic solution 112 having a concentration in the aforementioned range is conductive. In a non-limiting example, a concentration of the electrolytic solution 112 can be in a range from 60% to 80%. It has been found that by utilizing a concentration of the electrolytic solution 112 in the aforementioned range, rapid but controlled etching of desired compositions such as metal oxides can be achieved without etching an underlying substrate material.

[0017] Two electrodes can each be at least partially provided in the tank 110. The electrodes can include a component 114 functioning as an anode (e.g. a working electrode) and a cathode 116. The component 114 includes a defect 115. Although an entirety of the component 114 is illustrated as being submerged in the electrolytic solution 112, it is contemplated that only a portion of the component 114, particularly a portion of the component 114 including the defect 115, can be submerged in the electrolytic solution 112. In a non-limiting example, the cathode 116 can include a metal material such as nickel, platinum, or stainless steel. Additionally or alternatively, the cathode 116 can be in the form of a plate or a wire.

[0018] A power source 118, which can include a controller or controller module, can electrically couple to the component 114 and the cathode 116 by electrical conduits 120 to form a circuit via the electrolytic solution 112. Optionally, a switch 122 or sub-controller can be included along the electrical conduits 120 between the power source 118, the component 114, and the cathode 116.

[0019] During operation of the electro-etching system 100, a current is flows from the component 114 to the cathode 116 to remove at least one metal oxide, preferably all metal oxides, located on a surface of the component 114. The electro-etching system 100 can be operated at room temperature, up to a temperature of 70 °C. By operating the electro-etching system at room temperature, no additional eternal heating is required. By heating the electro-etching system 100, a speed of the electro-etching can be increased. The length of time in which the component 114 and the cathode 116 are supplied with current in the electrolytic solution 112

can determine how much material is etched from the component 114. With an increasing length of time in which the component 114 and the cathode 116 are supplied with current in the electrolytic solution 112, more material is etched from the component 114. In a non-limiting example, electro-etching can be carried out for a range of time from one minute to 2 minutes. Electro-etching can also be considered electropolishing. The purpose of the electro-etching or electropolishing is to remove one or more metal oxides or other materials that would prevent adherence of particles on a defect surface included on the component, such as coatings.

[0020] FIG. 2 is a schematic illustration of another exemplary electro-polishing or electro-etching system 200. The electro-etching system 200 is similar to the electro-etching system 100; therefore, like parts will be identified with like numerals increased to the 200 series with it being understood that the description of the electro-etching system 100 applies to the electro-etching system 200 unless noted otherwise.

[0021] The electro-etching system 200 is similar to the electro-etching system 100 in that a current is supplied from a power source 218 to a component 214 functioning as an anode, the component 214 including a defect 215, and to a cathode 216 by electrical conduits 220 optionally including switches 222. The electro-etching system 200, however, utilizes a fiber brush or sponge material 224 that is soaked in electrolytic solution (e.g. the electrolytic solution 112 of FIG. 1) and coupled to the cathode 216 instead of the tank 110 of FIG. 1.

[0022] During operation of the electro-etching system 200, the component 214 is placed on a workbench or other surface (not shown), and the fiber brush or sponge material 224 coupled with the cathode 216 is brushed over at least a portion of a surface of the component 214. By way of non-limiting example, the fiber brush or sponge material 224 coupled with the cathode 216 is brushed over the defect 215 to remove at least one metal oxide from the surface of the component 214.

[0023] FIG. 3 is a schematic illustration of an electrodeposition system 300. The electrodeposition system 300 includes a tank 326, an anode 328, a component 330 functioning as a cathode (e.g. the component 114 of FIG. 1 or the component 214 of FIG. 2 following electro-etching), a power source 332, electrical conduits 334, and a switch 336. It will be understood that the component 330 can be taken immediately from the electro-etching system and immersed into the tank 326. Additionally or alternatively, the component 330 can have any excess electrolytic solution from electro-etching removed before being placed in the tank 326.

[0024] An electrolytic solution 338 can be provided in the tank 326. By way of non-limiting example, the electrolytic solution 338 can contain metal ions 340. By way of further, non-limiting examples, the electrolytic solution 338 can be nickel sulfamate based. Metallic powder particles 342 that include a superalloy material can be suspended in the electrolytic solution 338.

[0025] The metallic powder particles 342 include a superalloy material. The super alloy material can be at least one prealloyed superalloy that can include high strength alloys, such as, but not limited to, a nickel-cobalt-phosphorus alloy, a nickel-molybdenum alloy, nickel aluminide, Inconel alloys such as IN718, Ni_3Al, Ni_3Ta, Ni_3Ti, Ni_3Nb, Ni_3Mo, NiAl, or Rene' 108, in some non-limiting examples. As used herein, a "prealloyed" material, e.g. a prealloyed powder material, can refer to the particles of that material having the same alloy composition as the overall material as is known in the art. Other powder metallurgy alloying methods known in the art includes, but are not limited to, admixing, diffusion alloying, and hybrid alloying. In addition, as used herein, a "high strength alloy" can refer to an alloy having a material property above a predetermined threshold including, but not limited to, an ultimate tensile strength (UTS) greater than 60 ksi (690 MPa) at 1200 °F (650 °C), or a ductility greater than 3% at 1200 °F (650 °C). By selecting an alloy having a UTS or ductility within the aforementioned ranges, the metallic powder particles 342 have a composition that corresponds with the component 330. A particle size of the metallic powder particles 342 can be in a range from 50 nanometers (nm) to 50 micrometers (μm). In a non-limiting example, the particle size of the metallic powder particles 342 can be in a range from 1 μm to 25 μm. It has been found that metallic powder particles 342 having a particle size within the aforementioned ranges can build up in thin layers to fill a crack, crevice or other defect in a component without undesirable porosity that can be caused by larger metallic powder particles 342 or agglomerations of the metallic powder particles 342.

[0026] The anode 328 and the component 330 can be located within the tank 326 and submerged in a bath of the electrolytic solution 338. In a non-limiting example, the anode 328 can be a sacrificial including at least nickel and the component 330 can be a superalloy component having the same composition as the metallic powder particles 342. In a non-limiting example, the component 330 includes a nickel-cobalt-phosphorus alloy, a nickel-molybdenum alloy, nickel aluminide, Inconel alloys such as IN718, Ni_3Al, Ni_3Ta, Ni_3Ti, Ni_3Nb, Ni_3Mo, NiAl, or Rene' 108, in some non-limiting examples. The component 330 includes a defect 358 such as a crack, crevice, and/or porosity.

[0027] For localized electrodeposition, at least a portion of the component 330 is masked. Masking can include applying at least one of a tape or an epoxy to an entirety of a surface of the component 330 portion less a surface of the defect 358.

[0028] The anode 328 can be spaced from the component 330 within the bath of the electrolytic solution 338. The anode 328 and the component 330 can also

be electrically coupled to the power source 332 by way of electrical conduits 334 as shown. A switch 336 can be provided between the anode 328 and the power source 332. The power source 332 can include a controller module to control the flow of current through the electrical conduits 334. Additionally or alternatively, a separate controller can be provided and electrically coupled to the power source 332.

[0029] At least one of a stirring rod 346 coupled to a motor 348 and an air pump 350 can be provided in or on the tank 326 to agitate the electrolytic solution 338 and suspend the metallic powder particles 342 within the electrolytic solution 338. The stirring rod 346 can include blades or fins submerged within the electrolytic solution 338. The stirring rod 346 is configured to rotate by the motor 348. The air pump 350 can include an air intake port 352 located within the tank 326 and fluidly coupled through a wall of the tank 326 to a source of air (not shown). The air pump 350 is configured to flow an air jet 354 through the electrolytic solution 338 adjacent to the defect 358. In some examples, the motor 348 and the air pump 350 are each electrically coupled to the power source 332. Additionally or alternatively, one or both of the motor 348 and the air pump 350 can be operably controlled by a separate controller. Further still, it is contemplated that the air pump can be located outside of the tank 326 while a nozzle fluidly coupled thereto can be located within the tank 326.

[0030] A heat source 356 can be thermally coupled with the tank 326. The heat source is configured to increase a temperature of the electrolytic solution 338 by at least one of conduction, convection, or radiation. The heat source 356 can be electrically coupled to the power source 332. Additionally or alternatively, the heat source 356 can be operably controlled by a separate controller.

[0031] During operation, the bath of electrolytic solution 338 is heated by the heat source 356. A temperature of the bath of electrolytic solution 338 during electrodeposition is in a range from ambient temperature (25 °C) to 80 °C dependent on properties of the component 330 and metallic powder particles 342. For example, if a temperature of the bath of electrolytic solution 338 is outside of the aforementioned range, particles to be electrodeposited may not adhere as desired and/or the component 330 could be damaged. In a non-limiting example, the temperature of the bath of electrolytic solution 338 during electrodeposition can be in a range from 25 °C to 45 °C, which allows for less process complication as little to no additional heating of the bath of electrolytic solution 338 is required. In another non-limiting example, the temperature of the bath of electrolytic solution 338 during electrodeposition can be in a range from 45 °C to 60 °C, which allows for a balance between additional heat added and increased productivity and current density of the bath of electrolytic solution 338. In yet another non-limiting example, the temperature of the bath of electrolytic solution 338 can be in a range from 60 °C to 80 °C, which can improve productivity and current density of the bath of electrolytic solution 338.

[0032] A current flows from the anode 328 to the component 330 to electroform a composite metal layer 360 at a surface of the defect 358. Supply of the current in the electrolytic solution 338 can cause metal ions 340 as well as the metallic powder particles 342 to accumulate onto or within the defect 358. A range of current density applied can be from 5 amperes per square foot (amp/sft) to 300 amp/sft. In a non-limiting example, the current density applied can be in a range from 25 amp/sft to 200 amp/sft. In another non-limiting example, the current density applied can be in a range from 25 amp/sft to 100 amp/sft. The current density applied affects a rate of the electrodeposition process. Generally, higher current density applied leads to faster electrodeposition but can produce undesirable porosity or cracks. By setting the current density in the aforementioned ranges, thin layers of metallic powder particles 342 can form on the defect 358 without introducing undesirable porosity or cracks. The current density applied can also be increased incrementally. That is, the power source 332 or a separate controller can be set to apply a first current density for an increment of time, then apply a second current density different from the first current density for a subsequent increment of time. The number of increments is not limited, but can include, for example, 2 or more increments. By applying the current density in multiple increments of time, a uniform and non-porous deposit is ensured during the electrodeposition.

[0033] In addition, the bath of electrolytic solution 338 is intermittently agitated by at least one of the stirring rod 346 or the air pump 350 to suspend the metallic powder particles 342 within the electrolytic solution 338 and/or direct the metallic powder particles 342 to the defect 358. Intermittent as used herein refers to occurring in intervals, such as an interval where the electrolytic solution 338 is agitated at a first speed or intensity and a subsequent interval where the electrolytic solution 338 is not agitated at all or is agitated at a second speed or intensity that is less than the first speed or intensity. In a non-limiting example, the electrolytic solution 338 is agitated, then agitation is paused for a range of time from 5 seconds to 30 seconds, then agitation is restarted. It is appreciated that relatively larger particle sizes of the metallic powder particles 342 settle more quickly than relatively smaller metallic powder particles 342, thereby requiring shorter pauses in agitation.

[0034] It is appreciated that by agitating the bath of electrolytic solution 338, the metallic powder particles 342 are mixed and dispersed within the electrolytic solution 338. The stirring rod 346, the air pump 350, or a combination thereof can be configured or arranged to sweep any of the metallic powder particles 342 that may aggregate near the bottom or in corners of the

tank 326 in an upward direction and toward the component 330. In some examples, the stirring rod 346, the air pump 350, or a combination thereof can produce turbulent flows, circulating currents, or other flow features within the electrolytic solution 338. Agitating the bath of electrolytic solution 338 ensures the presence of a thin layer of metallic powder particles 342 on the surface of the defect 358 at all times during the electrodeposition while not allowing the metallic powder particle layer including the superalloy material to become too thick thereby leading to porosity in the final deposit.

[0035] It is also appreciated that by intermittently agitating the bath of electrolytic solution 338, the stirring rod 346, the air pump 350, or a combination thereof can direct the metallic powder particles 342 onto the defect 358, and the metallic powder particles 342 can accumulate on a surface of the component 330 having any direction or surface orientation forming the composite metal layer 360. Particularly, by reducing or stopping agitation in intervals, only thin layers of metallic powder particles 342 can accumulate on the defect 358, thereby ensuring that as the composite metal layer 360 builds on the defect 358, clusters of particles or particle agglomerates do not impede infiltration of the electrolytic solution 338 into the composite metal layer 360 causing undesired porosity. It is appreciated that intermittent agitation in particular allows for sufficient residence time of the metallic powder particles 342 in a location of the defect 358. The use of intermittently activated air jets adjacent to the defective portion is also intended to achieve the same effect.

[0036] A rate of electrodeposition, referring to a rate at which the metallic powder particles 342 including the superalloy material deposit onto the defect 358, can be calculated based upon the current supplied. A profilometer can be used to determine a depth of the defect 358. In a non-limiting example, a volume of the defect can be calculated. Accordingly, from the depth of the defect 358 and the rate of electrodeposition, a minimum amount of time required to complete the electrodeposition such that the defect 358 is effectively filled and the component 330 is whole can be calculated. In a non-limiting example where the electrodeposition is run for longer than the minimum amount of time required to effectively fill the defect 358, an excess of metallic powder particles 342 that are not flush with a remainder of the component 330 surrounding the defect 358, not smooth, or a combination thereof can be smoothed by grinding and/or polishing. In some embodiments, a controller of the electro-etching system 200 operates the switches switch 336 according to the deposition time determined based on the rate of electrodeposition and the measured depth of the defect 358. In some embodiments, the electro-etching system 200 includes a sensor for monitoring the thickness of the deposit at the location of the defect 358, and the electrodeposition is stopped when the measured thickness of the deposition reaches the approximate depth of the defect 358.

[0037] FIG. 4 is a flowchart diagram illustrating a method 400 of localized repair of a defect in a component such as the component 114 (FIG. 1), 214 (FIG. 2), 330 (FIG. 3) having corresponding defect 115 (FIG. 1), 215 (FIG. 2), 358 (FIG. 3). It is contemplated that this can include a superalloy component. It is contemplated that the component can include a surface portion and a defect surface different from the surface portion.

[0038] At 402, a mask is applied to at least a portion of the component. By way of non-limiting example, this can include applying a mask to at least a portion of the surface portion. By way of still further example, this can include applying a mask to an entirety of the component less the surface defining the defect surface. In this manner, the only portion free of masking may be the defect surface (e.g. a portion of the surface portion is masked) and the defect surface is surrounded by the mask. By way of non-limiting examples, this can be accomplished by applying at least one of a tape, an epoxy, or a resin such as those found in nail polish to an entirety of the surface portion less the defect surface. The masking may occur before any other portion of the method.

[0039] At 404, at least one metal oxide is removed from the defect surface of the component. Removing the at least one metal oxide can include electro-etching with an acid solution. In a non-limiting example, electro-etching can be done by applying an acidic solution (e.g. the electrolytic solution 112 of FIG. 1) over the defect surface utilizing a bath (e.g. the tank 110 of FIG. 1). Additionally or alternatively, electro-etching can be done by applying an acidic solution applied over the defect surface utilizing a cleaning element. In a non-limiting example, the cleaning element can be a fiber brush or sponge (e.g. the fiber brush or sponge material 224 of FIG. 2) soaked in an electrolytic solution. Additionally or alternatively, the at least one metal oxide can be removed mechanically by dry polishing or grinding the defect surface with an abrasive paper or cloth.

[0040] At 406, the reformation of metal oxides on the defect surface can optionally be prevented by removing excess acid solution if any remains on the component from the removal of at least one metal oxide, at 404. In a non-limiting example, the component can optionally be rinsed after removing the at least one metal oxide, at 404, and prior to electrodeposition, at 408.

[0041] At 408, the defect surface is filled by electrodeposition. In this manner, the defect surface can be repaired. For example, if the defect surface is a crack or crevice, a portion of a volume of the crack or crevice can be filled with metallic powder particles that include a superalloy material (e.g. the metallic powder particles 342 of FIG. 3). The component can be moved directly to an electrodeposition electrolyte bath (e.g. the tank 326 including the electrolytic solution 338 of FIG. 3) after removing the at least one metal oxide at 404 so that no additional metal oxides may form on the component prior to electrodeposition.

[0042] Electrodeposition can be completed by immersing the component in an electrolyte bath having the metallic powder particles that include a superalloy material, agitating the electrolyte bath (e.g. by the stirring rod 346 or the air pump 350 of FIG. 3), and applying a current (e.g. by the power source 332 of FIG. 3). A minimum length of time which the current is applied can be determined based upon a depth of the defect surface and a value of the current applied. The bath can include a nickel sulfamate based electrolytic solution. In addition to the metallic powder particles that include a superalloy material, an anode comprising at least nickel can be further included in the electrolyte bath. It should be understood that the bath can include a non-nickel based electrolytic solution and the anode can comprise a non-nickel based metal. The metallic powder particles that include a superalloy material can be at least intermittently suspended in the electrolyte bath by at least one of rotating a stirring rod and supplying an air jet to the electrolyte bath for agitation periods and pause periods, a length of the pause periods being 5 seconds to 30 seconds. The air jet can be located adjacent to the defect surface. The stirring rod can be rotated during agitation periods at a speed from 250 rpm to 750 rpm, which results in consistent, uniform layers of metallic powder particles (e.g. the metallic powder particles 342 of FIG. 3) depositing on the defect surface. In a non-limiting example, the stirring rod can be rotated at a speed of 250 rpm to 350 rpm, which enhances adherence of the metallic powder particles to the defect surface. Suspension of metallic powder particles that include a superalloy material within the electrolytic solution can provide for deposition of a composite material onto the component, preserving the needed superalloy material within the composite material without the need of providing the various alloying elements dissolved within the electrodeposition bath. In this manner, direct incorporation of the superalloy material, e.g. highly prealloyed powders or ex-situ created precipitates, is enabled in the composite electroformed layer. The use of the stirring rod, the air pump, or a combination thereof in particular can provide for a more uniform incorporation of the metallic powder particles that include a superalloy material at sufficient concentrations to fill the defect and can ensure an abundance of unagglomerated particles at the defect. Smoothing of the filled defect surface can be achieved by grinding or polishing following the application of the current such that the filled defect surface is smooth and flush with the surface surrounding the defect.

[0043] In a non-limiting example, the electrodeposition can include electrodepositing a composite layer of nickel and a superalloy material on the defect surface.

[0044] At 410, following electrodeposition the mask applied at 402 can be removed. Non-limiting examples of removing the mask applied at 402 can include manually peeling or scraping the mask off, dissolving the mask in acetone or other similar solvent, or heating at a temperature in a range from 200 °C to 300 °C causing the mask material to melt off without damaging the component.

[0045] At 412, heat treatment can occur. The heat treatment can include a single heat treatment by applying heat at a consistent temperature. Alternatively, the heat treatment can include a first heat treatment by applying heat at a first temperature then a second heat treatment by applying heat at a second temperature less than the first temperature. It is contemplated that in a non-limiting example, smoothing of the filled defect surface by grinding or polishing can be performed before or after the heat treatment at 412.

[0046] FIG. 5A is a schematic representation of a component 500 immediately following completion of the masking at 402 (FIG. 4). More specifically, a mask 502 as indicated by the diagonal lines has been applied to the surface portion of component 500. The component 500 includes a defect 504 different from a remaining surface portion of the component 500. In the non-limiting illustrated example, the mask 502 is applied to all surface portions of the component 500 except a defect surface 506. In other words, only the defect surface 506 of the component 500 is exposed and all other surface portions of the component 500 that are different from the defect surface 506 are masked and not exposed. The mask 502 can include a suitable tape or epoxy coating. It will be understood that less or no portions of the component 500 may be masked. At least one metal oxide 508 can be present on the defect surface 506. While multiple metal oxide types can be present on the defect surface 506 only a single metal oxide type is schematically shown for ease of illustration.

[0047] FIG. 5B is a schematic representation of the component 500 immediately following completion of 404 (FIG. 4). At 404 (FIG. 4), the at least one metal oxide 508 is removed from the defect surface 506 (e.g. a surface of the defect 115 of FIG. 1 or of the defect 215 of FIG. 2) of the component 500 (e.g. the component 114 of FIG. 1 or the component 214 of FIG. 2). Preferably at 404 (FIG. 4), all of the at least one metal oxides 508 are removed from the defect surface 506. Thus, immediately following 404 (FIG. 4), the defect surface 506 is free of all of the at least one metal oxide 508. Removing the at least one metal oxide 508 from the defect surface 506 can be achieved by electro-etching. Electro-etching includes applying an acidic solution 510, such as electrolytic solution 112 (FIG. 1) to the defect surface 506. The acidic solution can be applied to the defect surface 506 via submersion of the defect surface 506 in a bath (e.g. by at least partially submerging the component 500 in a tank such as the tank 110 of FIG. 1) or via brushing with a cleaning element (e.g. by brushing the component 500 with a fiber brush or sponge material such as the fiber brush or sponge material 224 soaked in electrolytic solution of FIG. 2). By removing metal oxides from the defect surface 506, a good metallurgical bond can be achieved (e.g. at 408 of

FIG. 4) between a composite metal layer (e.g. the composite metal layer 360 of FIG. 3) and the component 500.

[0048] FIG. 5C is a schematic representation of the component 500 immediately following completion of 406 (FIG. 4). At 406, any excess of the acidic solution 510 remaining on the component 500 following the removal of the at least one metal oxide is removed from the component 500. Removing excess of the acidic solution 510 from the component 500 can include at least one of rinsing the component 500 with distilled water or vigorously shaking the component 500.

[0049] FIG. 5D is a schematic representation of the component 500 immediately following completion of 408 (FIG. 4). Immediately following completion of 406 (FIG. 4), the component 500 is moved directly to an electrodeposition system (e.g. the electrodeposition system 300 of FIG. 3), particularly to a tank (e.g. electrodeposition tank 326 of FIG. 3) containing an electrolytic solution (e.g. the electrolytic solution 338 of FIG. 3). At 408 (FIG. 4), the defect 504 (e.g. the defect 358 of FIG. 3) of the component 500 (e.g. the component 330 of FIG. 3) is filled with a composite metal layer 512 (e.g. the composite metal layer 360 of FIG. 3) by electrodepositing a composite layer of a superalloy material and nickel on the defect surface 506 as described with respect to FIG. 3.

[0050] FIG. 5E is a schematic representation of the component 500 immediately following completion of 410 (FIG. 4). At 410, the mask 502 is removed leaving the composite metal later 512.

[0051] FIG. 5F is a schematic representation of the component 500 immediately following completion of 412 (FIG. 4). At 412, at least one heat treatment is performed on at least a portion of the component 500. The heat treatment of the component 500 can provide for dissolving and reprecipitation of the superalloy material of the composite metal layer 512. For example, the at least one portion of the component 500 can be a portion of the component 500 including the defect. It is contemplated that the at least one heat treatment can include a first heat treatment performed in a first temperature range, a second, hot isostatic pressing (HIP) treatment performed in a second, HIP temperature range, and a third aging heat treatment performed in a third, aging temperature range.

[0052] The first heat treatment can dissolve the metallic powder particles (e.g. the metallic powder particles 342 of FIG. 3) of the composite metal layer 512 into a metal matrix to form a single-phase, homogeneous, solid-solutioned matrix. The first heat treatment can strengthen a metallurgical bond between the metallic powder particles of the composite metal layer 512 and the component 500. In a non-limiting example, the first heat treatment can be performed for a time period in a range from 12 hours to 36 hours at a steady first temperature range, the first temperature range being in a range from 1000 °C to 1250 °C. By performing the first heat treatment for a time period within the aforementioned range of length of time and at a temperature within the aforementioned range of temperature, metallic powder particles effectively homogenize within a matrix of the composite metal layer 512 by dissolving any gamma prime phases. Time and temperature are correlated. For example, at a lower temperature, a longer heat treatment is necessary and conversely, at a higher temperature, a shorter heat treatment length is necessary to homogenize the composite metal layer 512. The component 500 is subsequently cooled to room temperature gradually. It is understood that, in some examples, particles of the composite metal layer 512 can have a uniform or non-uniform size, shape, arrangement, distribution, or the like after performing the first heat treatment on the component 500.

[0053] The HIP treatment can close internal voids and microporosity in the composite metal layer 512. In a non-limiting example, the HIP treatment can be performed for a time period in a range from 2 hours to 4 hours at a temperature from 1100 °C and 1300 °C and at a pressure from 12 kilopounds per square inch (ksi) to 20 ksi. By performing a HIP treatment within the aforementioned ranges of time, pressure, and temperature, a microstructure of the composite metal layer 512 can have improved strength, durability and resistance to wear resulting from a lack of internal voids or microporosity.

[0054] The aging heat treatment can optionally be performed subsequently to at least one of the first heat treatment or the HIP treatment. The aging heat treatment can form precipitates in the metallic powder particles. Optionally, the aging heat treatment can form precipitates in the metal matrix of the composite metal layer 512. The aging heat treatment includes two phases with each phase being performed at a different temperature. In a non-limiting example, a first phase of the aging heat treatment can be performed at a first temperature in a range from 700 °C to 900 °C for a time period ranging in length from 4 hours to 12 hours. The component 500 is then cooled gradually to a second temperature in a range from 55 °C to 700 °C. As a second phase of the aging heat treatment, the component is held at the second temperature for a time period ranging in length from 4 hours to 12 hours. The component 500 is then again cooled to room temperature gradually. By performing the aging heat treatment in two phases as described above, strengthening phases of the composite metal layer 512 can be precipitated. It is contemplated that the second phase of the aging heat treatment can be omitted if, for example, aging can occur during service of the component 500.

[0055] Aspects of the present disclosure provide for a variety of benefits. Suspension of metallic powdered or particulate particles including a superalloy material within an electrolyte by intermittent agitation can provide for deposition of a composite material including the superalloy material onto a superalloy component in

order to repair an irregularly shaped defect in the superalloy component.

[0056] To the extent not already described, the different features and structures of the various embodiments can be used in combination with each other as desired. That one feature cannot be illustrated in all of the embodiments is not meant to be construed that it cannot be, but is done for brevity of description. Thus, the various features of the different embodiments can be mixed and matched as desired to form new embodiments, whether or not the new embodiments are expressly described. All combinations or permutations of features described herein are covered by this disclosure.

[0057] This written description uses examples to disclose the disclosure, including the best mode, and also to enable any person skilled in the art to practice the disclosure, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the disclosure 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 have 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 languages of the claims.

[0058] Further aspects of the disclosure are defined by the following clauses:

A method comprising applying a mask to at least a portion of a surface of a component less a defect surface; removing at least one metal oxide from the defect; electrodepositing metallic powder particles including a superalloy material on the defect surface by immersing the defect surface in an electrolyte bath having metal ions and the metallic powder particles including the superalloy material, agitating the electrolyte bath, and applying a current; removing the mask; and heat treating at least the defect surface.

[0059] The method of any preceding clause, wherein the defect surface is at least one of a crack, a crevice, or porosity.

[0060] The method of any preceding clause, wherein applying the mask comprises applying at least one of a tape, an epoxy, or a resin to an area of the surface of the component surrounding the defect surface.

[0061] The method of any preceding clause, wherein removing the mask includes at least one of peeling or scraping the mask off of the component, dissolving the mask with a solvent, or melting the mask by applying heat.

[0062] The method of any preceding clause wherein the solvent is acetone.

[0063] The method of any preceding clause wherein applying heat comprises applying heat at a temperature in a range from 200 °C to 300 °C.

[0064] The method of any preceding clause, wherein the component is a superalloy component.

[0065] The method of any preceding clause, wherein the superalloy component comprises at least one of a nickel-cobalt-phosphorus alloy, a nickel-molybdenum alloy, nickel aluminide, or an Inconel alloy.

[0066] The method of any preceding clause, wherein electrodepositing the metallic powder particles including the superalloy material on the defect surface includes electrodepositing a composite layer of nickel and superalloy.

[0067] The method of any preceding clause, wherein removing the at least one metal oxide comprises dry polishing or grinding.

[0068] The method of any preceding clause, wherein removing the at least one metal oxide comprises electro-etching.

[0069] The method of any preceding clause, wherein the component is rinsed after removing the at least one metal oxide and prior to the electrodepositing.

[0070] The method of any preceding clause, wherein rinsing of the component prevents reformation of the at least one metal oxide.

[0071] The method of any preceding clause, wherein the electro-etching comprises applying an acidic solution over the defect surface utilizing a bath.

[0072] The method of any preceding clause, wherein the bath comprises an electro-etching electrolytic solution.

[0073] The method of any preceding clause, wherein the electro-etching comprises an anode and a cathode, the anode being the component and the cathode being a metal material comprising at least one of nickel, platinum, or stainless steel.

[0074] The method of any preceding clause, wherein the electro-etching comprises applying an acidic solution over the defect surface utilizing a cleaning element.

[0075] The method of any preceding clause, wherein the cleaning element is at least one of a fiber brush or a sponge material soaked in an electro-etching electrolytic solution.

[0076] The method of any preceding clause, wherein the electro-etching electrolytic solution comprises at least one of sulfuric acid, nitric acid, hydrochloric acid, or a combination thereof.

[0077] The method of any preceding clause, wherein the electro-etching is carried out for a range of time from one minute to two minutes.

[0078] The method of any preceding clause, wherein the component is moved directly to the electrolyte bath after removing the at least one metal oxide.

[0079] The method of any preceding clause, wherein an anode comprising at least nickel is further included in the electrolyte bath.

[0080] The method of any preceding clause, wherein the electrolyte bath comprises a nickel sulfamate electrolyte having the metallic powder particles including the superalloy material.

[0081] The method of any preceding clause, wherein the metallic powder particles including the superalloy

material comprise at least one of a nickel-cobalt-phosphorus alloy, a nickel-molybdenum alloy, nickel aluminide, and Inconel alloy.

[0082] The method of any preceding clause, wherein a particle size of the metallic powder particles including the superalloy material is in a range from 50 nanometers to 50 micrometers.

[0083] The method of any preceding clause, wherein the metallic powder particles including the superalloy material are at least intermittently suspended in the electrolyte bath.

[0084] The method of any preceding clause, wherein agitating the electrolyte bath comprises intermittently agitating the electrolyte bath by at least one of rotating a stirring rod and supplying an air jet to the electrolyte bath.

[0085] The method of any preceding clause, wherein the air jet is located adjacent to the defect surface.

[0086] The method of any preceding clause, wherein the air jet is provided by an air pump from an air intake port through the electrolytic solution.

[0087] The method of any preceding clause, wherein intermittently stirring the electrolyte bath with the stirring rod comprises rotating the stirring rod at a speed greater than or equal to 250 rpm and less than or equal to 750 rpm.

[0088] The method of any preceding clause, wherein intermittently stirring the electrolyte bath with the stirring rod comprises rotating the stirring rod at a speed greater than or equal to 250 rpm and less than or equal to 350 rpm.

[0089] The method of any preceding clause, wherein intermittently agitating the electrolyte bath includes agitation periods and pause periods, a length of the pause periods being greater than or equal to 5 seconds and less than or equal to 30 seconds.

[0090] The method of any preceding clause, wherein a temperature of the electrolyte bath is increased by a heat source during the electroforming.

[0091] The method of any preceding clause, wherein the temperature of the electrolyte bath is in a range from ambient temperature to 80 °C.

[0092] The method of any preceding clause, wherein the current applied has a current density that increases incrementally during the electrodepositing.

[0093] The method of any preceding clause, wherein the electrodepositing is run for at least a minimum amount of time determined by a value of the current applied and a depth of the defect surface.

[0094] The method of any preceding clause, wherein the electrodepositing is run for longer than the minimum amount time and excess metallic powder particles are removed by grinding or polishing such that the defect surface is flush with the surface of the component surrounding the defect surface.

[0095] The method of any preceding clause, wherein the depth of the defect surface is measured by a profilometer.

[0096] The method of any preceding clause, wherein heat treating comprises applying heat at a first temperature then applying heat at a second temperature less than the first temperature.

[0097] The method of any preceding clause, wherein the first temperature is in a range from 1000 °C to 1250 °C.

[0098] The method of any preceding clause, wherein the first temperature is applied for a time period ranging in length from 12 hours to 36 hours.

[0099] The method of any preceding clause, wherein the applying heat at a first temperature forms a single-phase homogeneous, solid-solutioned matrix.

[0100] The method of any preceding clause, wherein the second temperature is in a range from 700 °C to 900 °C.

[0101] The method of any preceding clause, wherein the second temperature is applied for a time period ranging in length from 2 hours to 12 hours.

[0102] The method of any preceding clause, wherein heat treating further comprises applying heat at a third temperature less than the second temperature.

[0103] The method of any preceding clause, wherein the third temperature is in a range from 55 °C to 700 °C.

[0104] The method of any preceding clause, wherein the third temperature is applied for a time period ranging in length from 4 hours to 12 hours.

[0105] The method of any preceding clause, wherein applying heat at the second temperature, the third temperature, or a combination thereof forms precipitates in the metallic powder particles including the superalloy material.

[0106] The method of any preceding clause, wherein heat treating comprises a hot isostatic pressure treatment at a temperature in a range from 1100 °C to 1300 °C and a pressure in a range from 12 kilopounds per square inch to 20 kilopounds per square inch.

[0107] The method of any preceding clause, wherein the electrodepositing is run for at least a minimum amount of time determined by a value of the current applied and a depth of the defect surface.

[0108] The method of any preceding clause, wherein electrodepositing the metallic powder particles including the superalloy material on the defect surface includes electrodepositing a composite layer of nickel and a superalloy material.

Claims

1. A method comprising:

applying a mask to at least a portion of a surface of a component less a defect surface;

removing at least one metal oxide from the defect surface;

electrodepositing metallic powder particles in-

cluding a superalloy material on the defect surface by immersing the defect surface in an electrolyte bath having metal ions and the metallic powder particles including the superalloy material, agitating the electrolyte bath, and applying a current;
removing the mask; and
heat treating at least the defect surface.

2. The method of claim 1, wherein applying the mask comprises applying at least one of a tape, an epoxy, or a resin to an area of the surface of the component surrounding the defect surface.

3. The method of any preceding claim, wherein removing the mask includes at least one of peeling or scraping the mask off of the component, dissolving the mask with a solvent, or melting the mask by applying heat.

4. The method of any preceding claim, wherein the electrodepositing is run for at least a minimum amount of time determined by a value of the current applied and a depth of the defect surface.

5. The method of any preceding claim, wherein the component is a superalloy component.

6. The method of claim 2, wherein electrodepositing the metallic powder particles including the superalloy material on the defect surface includes electrodepositing a composite layer of nickel and a superalloy material.

7. The method of any preceding claim, wherein removing the at least one metal oxide comprises electro-etching.

8. The method of claim 7, wherein the component is rinsed after removing the at least one metal oxide and prior to the electrodepositing; and/or

wherein the electro-etching comprises applying an acidic solution over the defect surface utilizing a bath; or
wherein the electro-etching comprises applying an acidic solution over the defect surface utilizing a cleaning element.

9. The method of any preceding claim, wherein the component is moved directly to the electrolyte bath after removing the at least one metal oxide.

10. The method of any preceding claim, wherein an anode comprising at least nickel is further included in the electrolyte bath; optionally
wherein the electrolyte bath comprises a nickel sulfamate electrolyte having the metallic powder particles including the superalloy material.

11. The method of any preceding claim, wherein the metallic powder particles including the superalloy material are at least intermittently suspended in the electrolyte bath.

12. The method of claim 11, wherein agitating the electrolyte bath comprises intermittently agitating the electrolyte bath by at least one of rotating a stirring rod and supplying an air jet to the electrolyte bath.

13. The method of claim 12, wherein the air jet is located adjacent to the defect surface; and/or.

wherein intermittently stirring the electrolyte bath with the stirring rod comprises rotating the stirring rod at a speed greater than or equal to 250 rpm and less than or equal to 750 rpm; optionally
wherein intermittently stirring the electrolyte bath with the stirring rod comprises rotating the stirring rod at a speed greater than or equal to 250 rpm and less than or equal to 350 rpm.

14. The method of claim 11, wherein intermittently agitating the electrolyte bath includes agitation periods and pause periods, a length of the pause periods being greater than or equal to 5 seconds and less than or equal to 30 seconds.

15. The method of any preceding claim, wherein heat treating comprises applying heat at a first temperature then applying heat at a second temperature less than the first temperature.

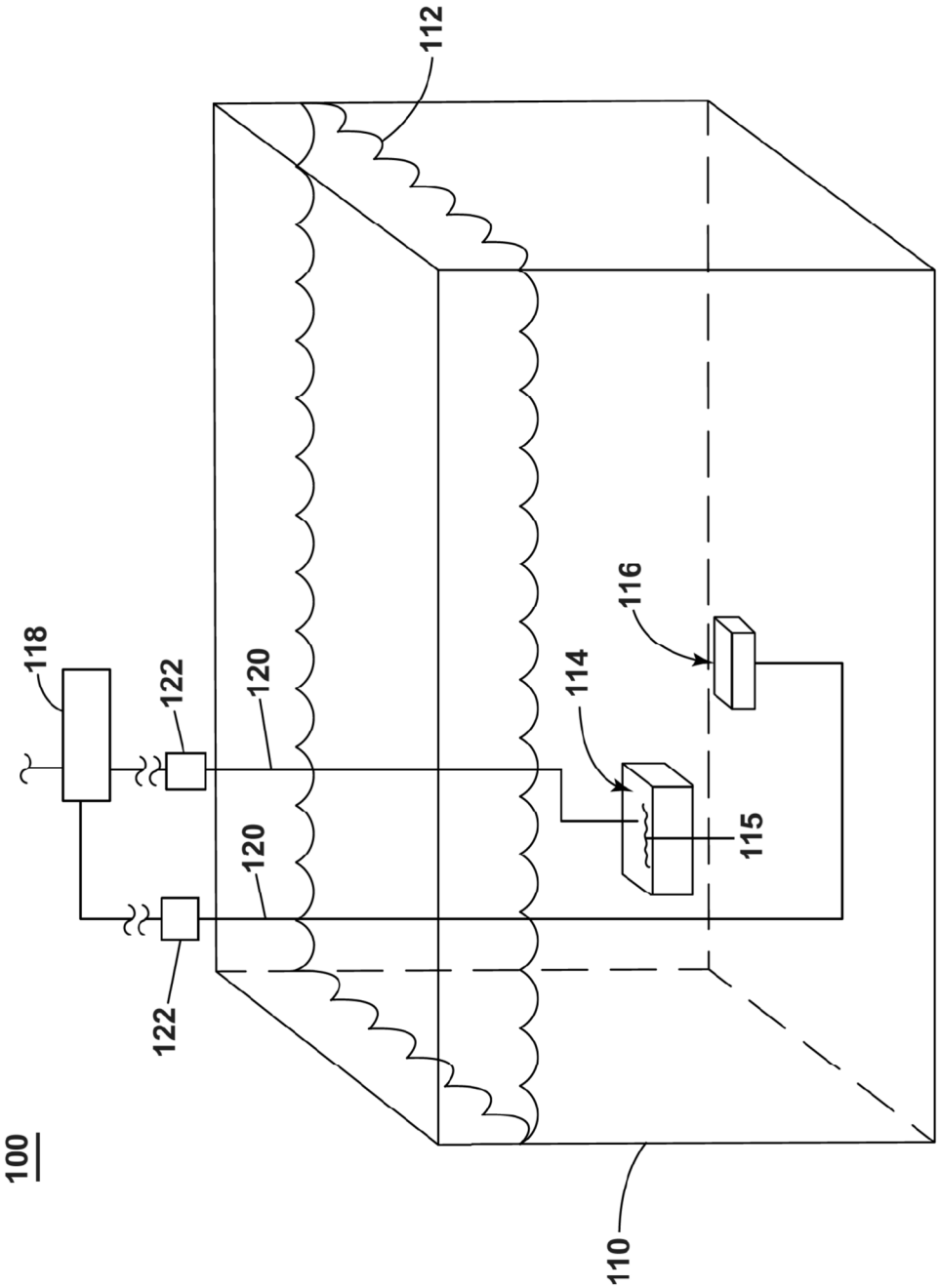


FIG. 1

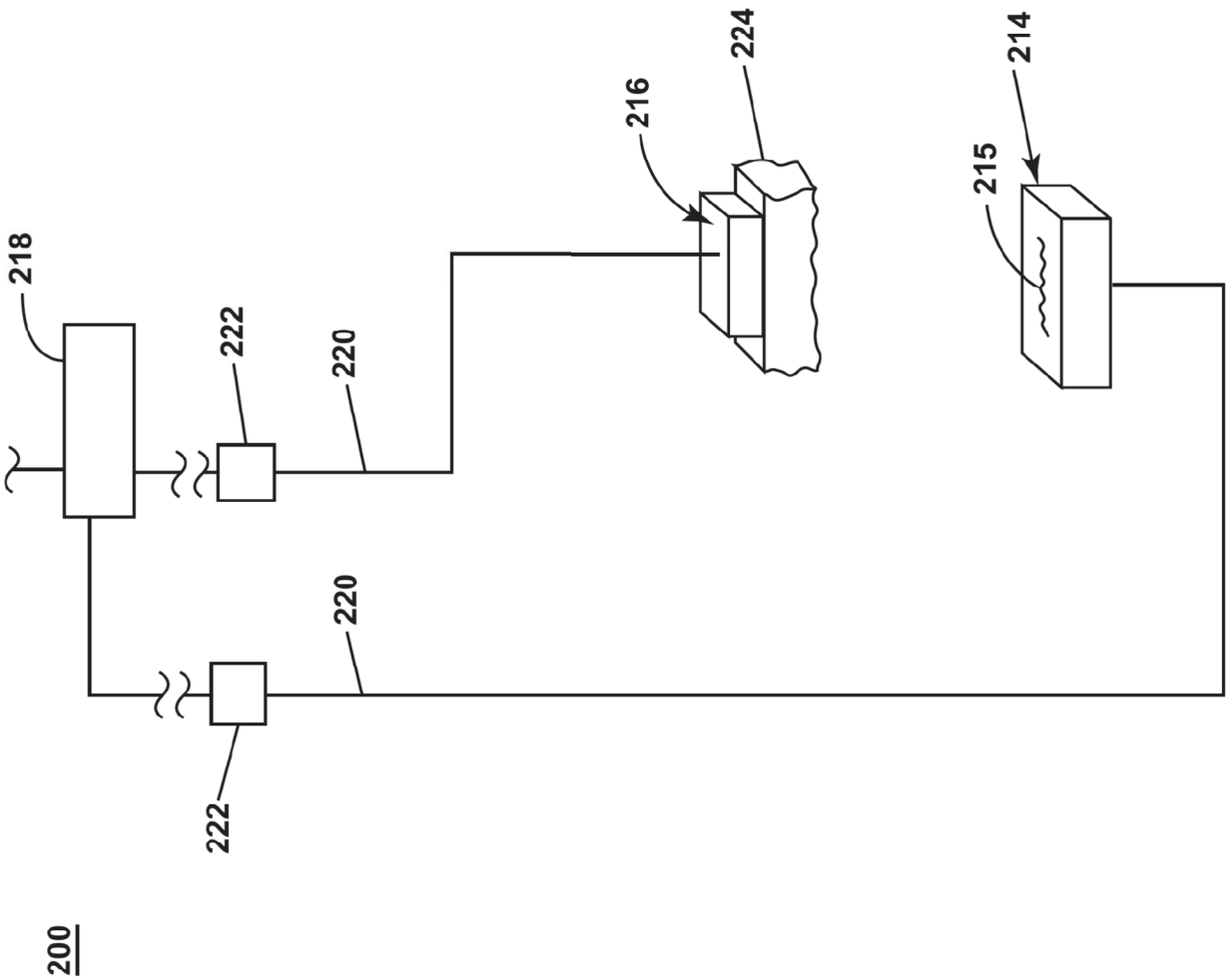


FIG. 2

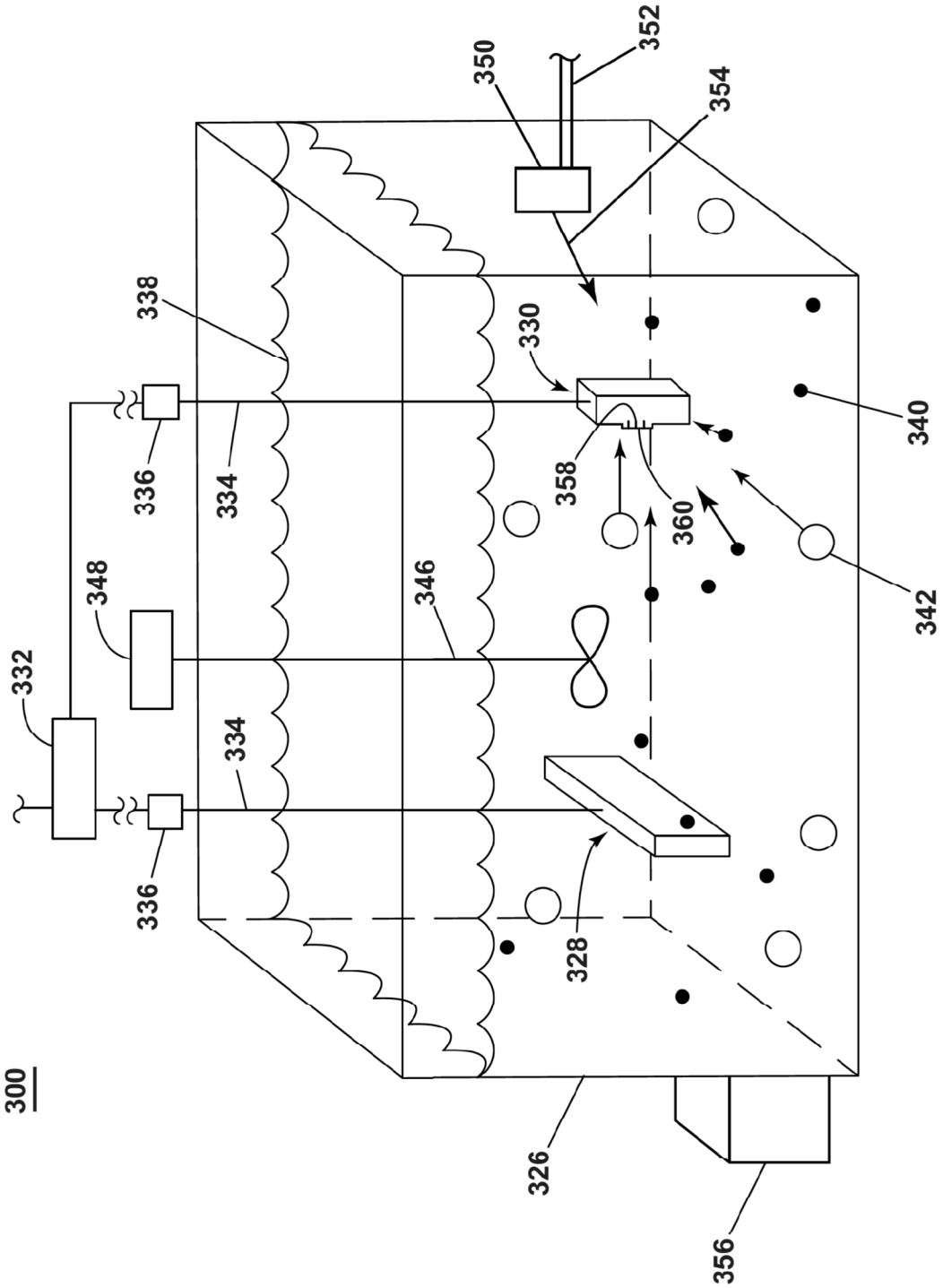

300
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328
330
332
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334
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FIG. 3

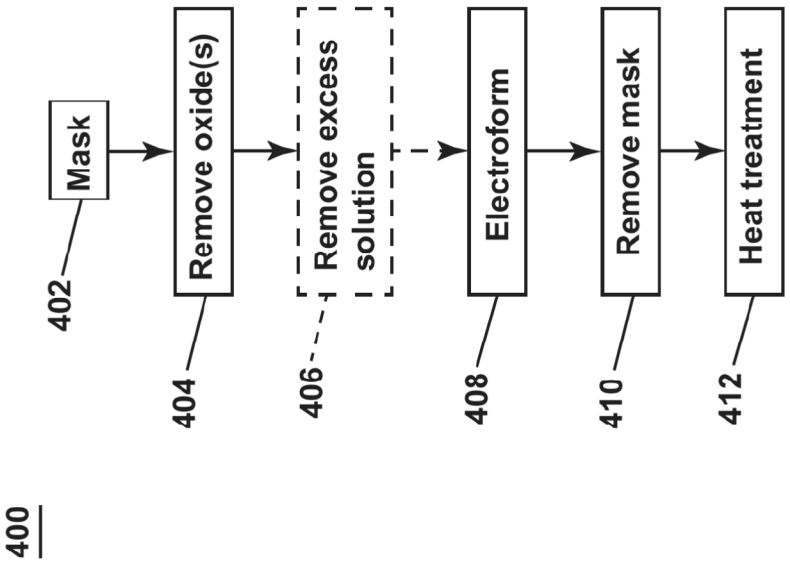

400
Mask
402
Remove oxide(s)
404
Remove excess solution
406
Electroform
408
Remove mask
410
Heat treatment
412

FIG. 4

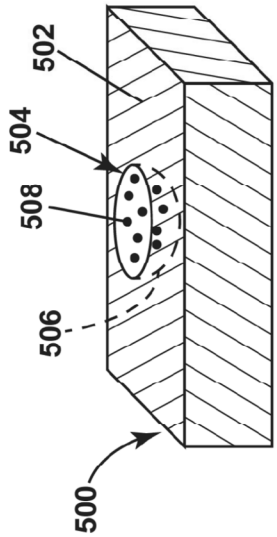


FIG. 5A

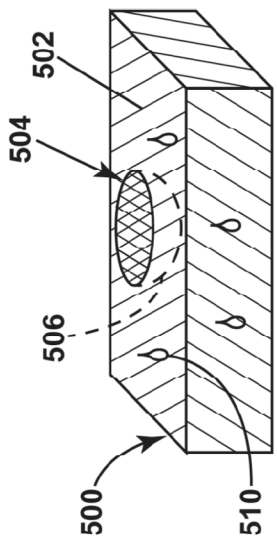


FIG. 5B

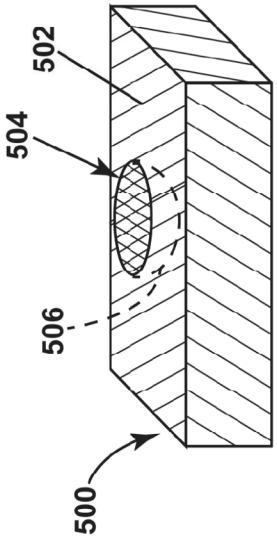


FIG. 5C

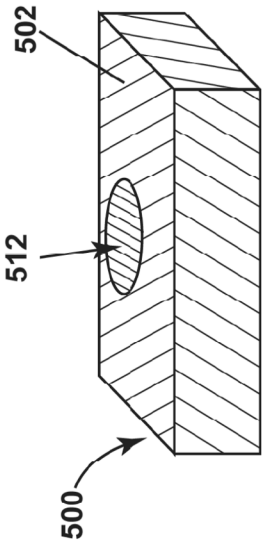


FIG. 5D

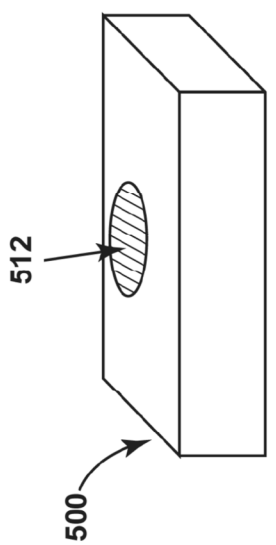


FIG. 5E

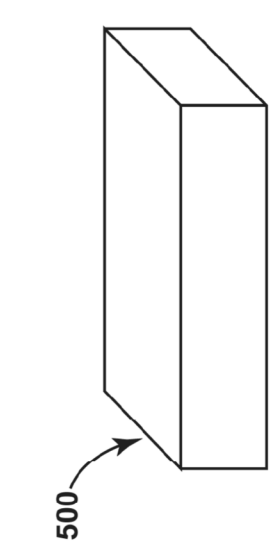


FIG. 5F

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EUROPEAN SEARCH REPORT

Application Number
EP 26 16 9048

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
Y	WO 2024/259076 A2 (RTX CORP [US]) 19 December 2024 (2024-12-19) * paragraphs [0085], [0095] - [0107] *	1-15	INV. C25D15/00 C25D3/12 C25D5/40 C25D5/50 C25F1/04 C25F3/02 C25F3/14
Y	US 2024/0279833A1 (NASSERRAFI RAHBAR [US] ET AL) 22 August 2024 (2024-08-22) * paragraphs [0020] - [0067] * * figure 1 *	1-15	
A	US 2018/195192 A1 (MARTEL NATHAN T [US] ET AL) 12 July 2018 (2018-07-12) * paragraph [0061] * * figure 8 *	12,13	

TECHNICAL FIELDS SEARCHED (IPC)

C25D
C25F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	16 September 2026	Le Hervet, Morgan

CATEGORY OF CITED DOCUMENTS

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16-09-2026

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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US 20240279833 A1	22-08-2024	EP 4428271 A2	11-09-2024
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		US 2018195192 A1	12-07-2018

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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Patent documents cited in the description

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