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Anahid et al.

(54) SINGLE-STEP PROCESS FOR SELECTIVE HEAT TREATMENT OF METALS USING MULTIPLE HEATING SOURCES

(71) Applicant: **Raytheon Technologies Corporation**, Farmington, CT (US)

(72) Inventors: **Masoud Anahid**, Galena, OH (US); **David U. Furrer**, Marlborough, CT (US); **Matthew D. Mordasky**, Columbia, CT (US); **Anthony Patrick Ventura**, Glastonbury, CT (US)

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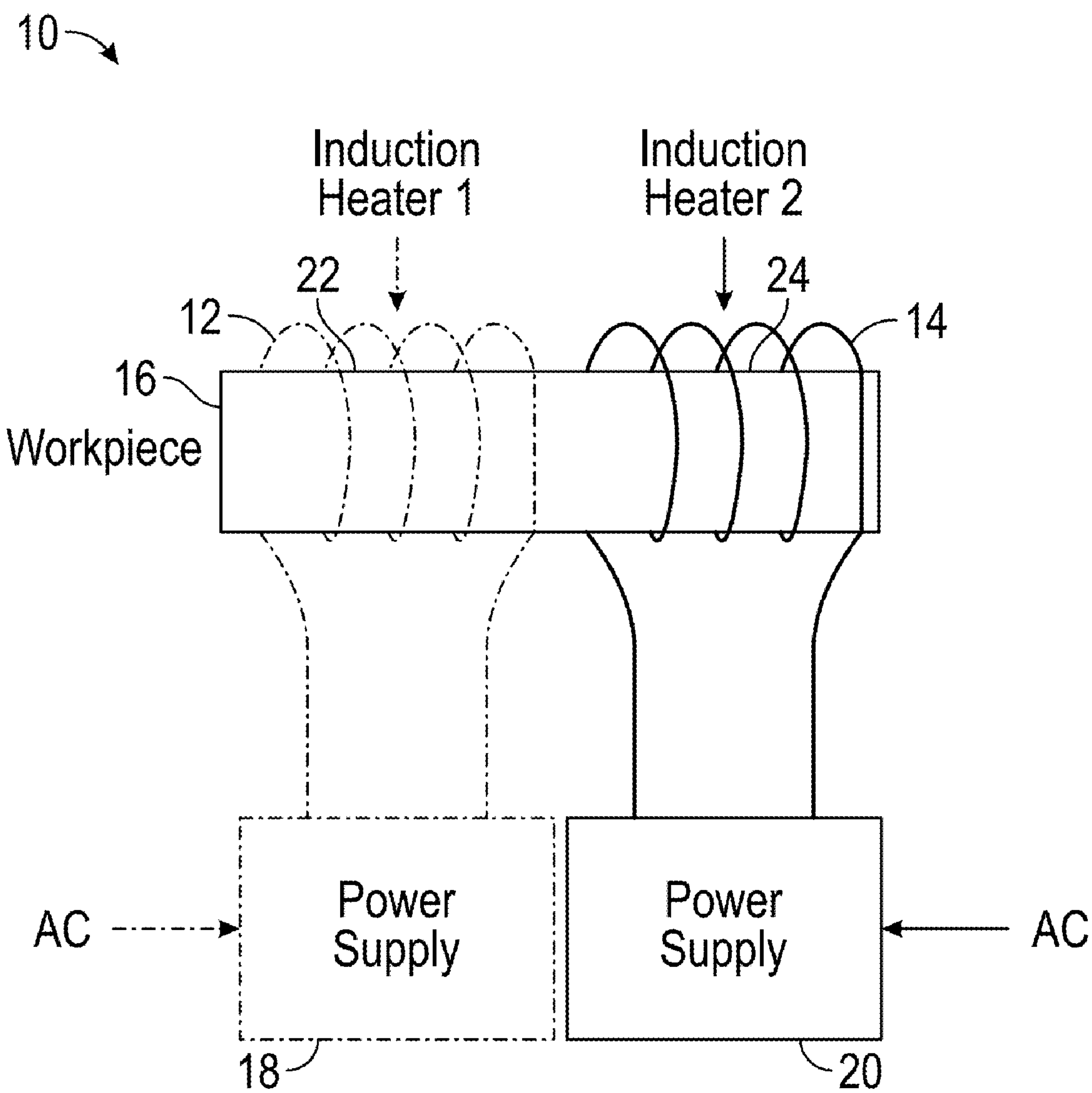
(57) **ABSTRACT**

The present disclosure provides assemblies, systems and methods for a single-step process for selective heat treatment of metals. More particularly, the present disclosure provides assemblies, systems and methods for a single-step process for selective heat treatment of metals using multiple heating sources. A hybrid modeling-test approach can be used in the design process to improve or optimize the process parameters to achieve location specific and improved/optimal microstructure and residual stress to enhance the part performance. It is also noted that performing the selective heat treatment in a single step can reduce the cycle time significantly. Moreover, large thermal gradients can be avoided in the part as different volumes of the part are heated to their desired temperature simultaneously.



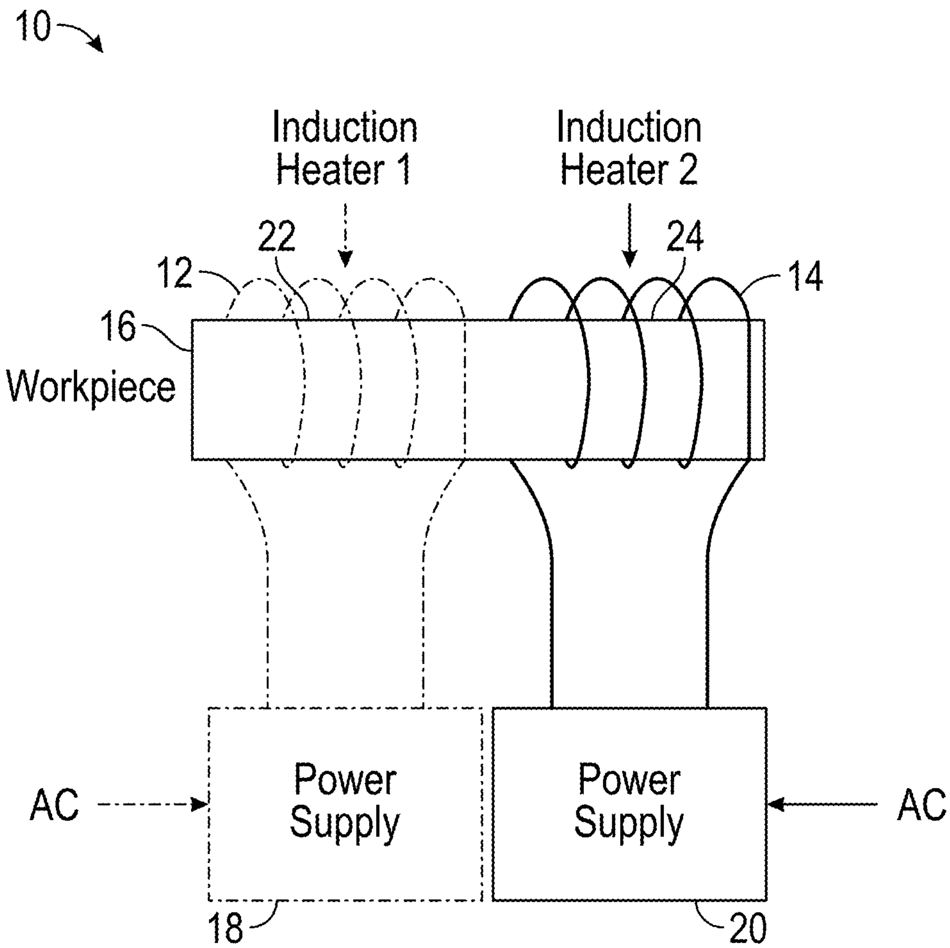

10
Induction
Heater 1
Induction
Heater 2
22
24
12
14
16
Workpiece
Power
Supply
Power
Supply
AC
AC
18
20

FIG. 1

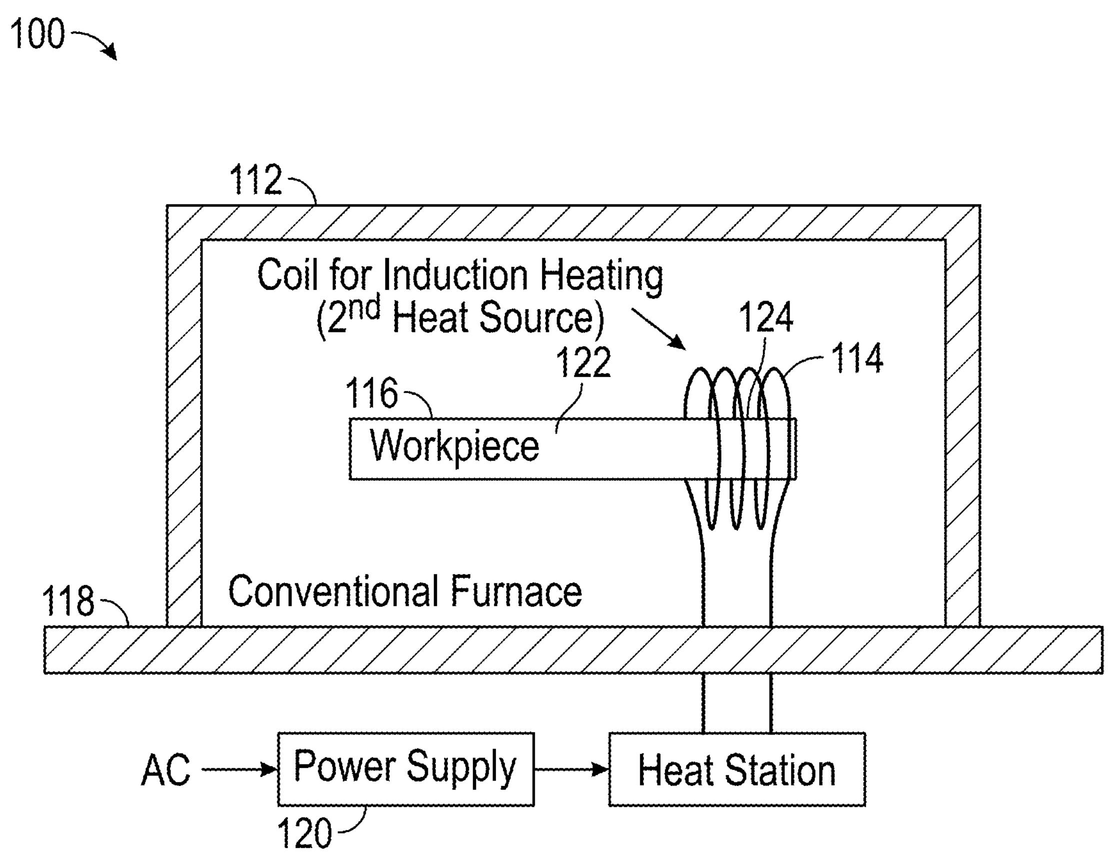

100
112
Coil for Induction Heating
(2nd Heat Source)
124
114
122
116
Workpiece
118
Conventional Furnace
AC
Power Supply
Heat Station
120

FIG. 2

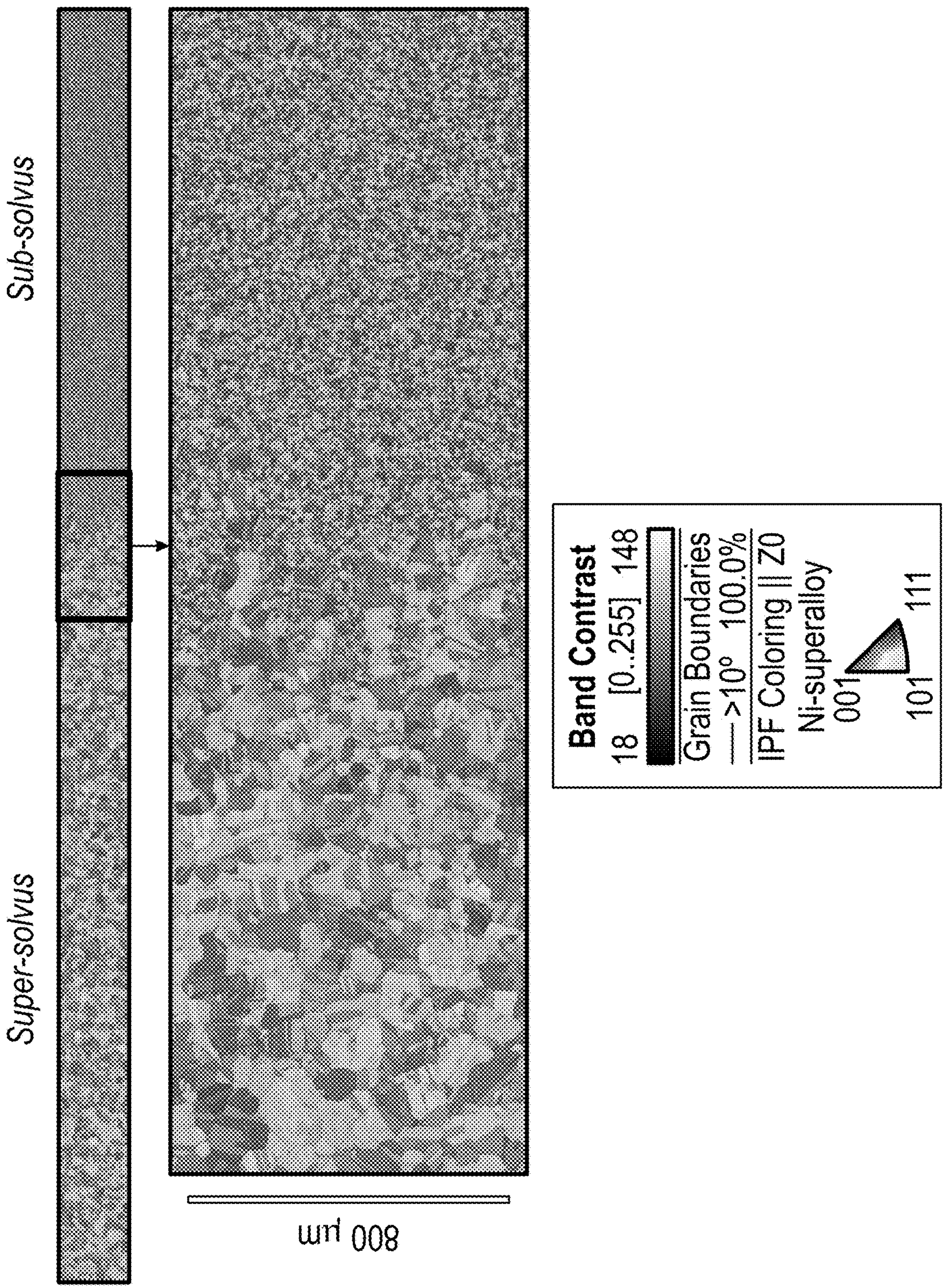

Sub-solvus
Super-solvus
800 μm
Band Contrast
18 [0..255] 148
Grain Boundaries
>10° 100.0%
IPF Coloring || Z0
Ni-superalloy
001
101
111

FIG. 3

SINGLE-STEP PROCESS FOR SELECTIVE HEAT TREATMENT OF METALS USING MULTIPLE HEATING SOURCES

TECHNICAL FIELD

[0001] The present disclosure relates to assemblies, systems and methods for a single-step process for selective heat treatment of metals and, more particularly, to assemblies, systems and methods for a single-step process for selective heat treatment of metals using multiple heating sources.

BACKGROUND

[0002] In general, there are existing dual heat treatment practices using multiple heating sources. These processes are done in multiple steps with a single heating source used in each step. These processes create a large thermal gradient as different volumes of the part are heated to their desired temperature at different steps. The cycle time is also increased as multiple steps are involved.

BRIEF DESCRIPTION

[0003] The present disclosure provides assemblies, systems and methods for a single-step process for selective heat treatment of metals. More particularly, the present disclosure provides assemblies, systems and methods for a single-step process for selective heat treatment of metals using multiple heating sources. It is noted that there is currently no conventional technology that utilizes multiple heating sources in a single step for the selective heat treatment of metals.

[0004] The present disclosure provides for a heat treatment assembly including a first heating source and a second heating source, the first heating source configured to be positioned relative to a first portion of a metal component, and the second heating source configured to be positioned relative to a second portion of the metal component, and wherein the first and second heating sources are configured and dimensioned to provide selective heat treatment to the first and second portions of the metal component in a single-step process.

[0005] In addition to one or more of the features described, or as an alternative to any of the foregoing embodiments, the first and second heating sources are independent of one another.

[0006] In addition to one or more of the features described, or as an alternative to any of the foregoing embodiments, the first heating source is in communication with a first power supply, and the second heating source is in communication with a second power supply.

[0007] In addition to one or more of the features described, or as an alternative to any of the foregoing embodiments, the first and second heating sources are configured and dimensioned to provide selective heat treatment to the first and second portions of the metal component in a single-step process to achieve location specific microstructure and mechanical properties of the first and second portions of the metal component.

[0008] In addition to one or more of the features described, or as an alternative to any of the foregoing embodiments, a hybrid modeling-test approach is utilized to achieve location specific microstructure and mechanical properties of the first and second portions of the metal component.

[0009] In addition to one or more of the features described, or as an alternative to any of the foregoing embodiments, the first heating source is configured to heat the first portion of the metal component to a first temperature in the single-step process; and wherein the second heating source is configured to heat the second portion of the metal component to a second temperature in the single-step process.

[0010] In addition to one or more of the features described, or as an alternative to any of the foregoing embodiments, the first temperature is different than the second temperature.

[0011] In addition to one or more of the features described, or as an alternative to any of the foregoing embodiments, the metal component comprises a nickel-chromium alloy, and wherein the first heating source is configured to heat the first portion of the nickel-chromium alloy to a super-solvus temperature in the single-step process; and wherein the second heating source is configured to heat the second portion of the nickel-chromium alloy to a sub-solvus temperature in the single-step process.

[0012] In addition to one or more of the features described, or as an alternative to any of the foregoing embodiments, the metal component comprises a nickel-chromium alloy, and wherein the first heating source is configured to heat the first portion of the nickel-chromium alloy to a sub-solvus temperature in the single-step process; and wherein the second heating source is configured to heat the second portion of the nickel-chromium alloy to a super-solvus temperature in the single-step process.

[0013] In addition to one or more of the features described, or as an alternative to any of the foregoing embodiments, the first and second heating sources are configured and dimensioned to provide selective heat treatment to the first and second portions of the metal component in a simultaneous single-step process.

[0014] The present disclosure provides for a method for selective heat treatment including positioning a first heating source relative to a first portion of a metal component; positioning a second heating source relative to a second portion of the metal component; and providing selective heat treatment to the first and second portions of the metal component, via the first and second heating sources, in a single-step process.

[0015] In addition to one or more of the features described, or as an alternative to any of the foregoing embodiments, the first and second heating sources are independent of one another.

[0016] In addition to one or more of the features described, or as an alternative to any of the foregoing embodiments, the first heating source is in communication with a first power supply, and the second heating source is in communication with a second power supply.

[0017] In addition to one or more of the features described, or as an alternative to any of the foregoing embodiments, wherein providing selective heat treatment to the first and second portions of the metal component, via the first and second heating sources, in the single-step process achieves location specific microstructure and mechanical properties of the first and second portions of the metal component.

[0018] In addition to one or more of the features described, or as an alternative to any of the foregoing embodiments, further comprising utilizing a hybrid modeling-test approach to achieve location specific microstructure and mechanical properties of the first and second portions of the metal component.

[0019] In addition to one or more of the features described, or as an alternative to any of the foregoing embodiments, the first heating source heats the first portion of the metal component to a first temperature in the single-step process; and wherein the second heating source heats the second portion of the metal component to a second temperature in the single-step process.

[0020] In addition to one or more of the features described, or as an alternative to any of the foregoing embodiments, the first temperature is different than the second temperature.

[0021] In addition to one or more of the features described, or as an alternative to any of the foregoing embodiments, the metal component comprises a nickel-chromium alloy, and wherein the first heating source heats the first portion of the nickel-chromium alloy to a super-solvus temperature in the single-step process; and wherein the second heating source heats the second portion of the nickel-chromium alloy to a sub-solvus temperature in the single-step process.

[0022] In addition to one or more of the features described, or as an alternative to any of the foregoing embodiments, the metal component comprises a nickel-chromium alloy, and wherein the first heating source heats the first portion of the nickel-chromium alloy to a sub-solvus temperature in the single-step process; and wherein the second heating source heats the second portion of the nickel-chromium alloy to a super-solvus temperature in the single-step process.

[0023] In addition to one or more of the features described, or as an alternative to any of the foregoing embodiments, the first and second heating sources provide selective heat treatment to the first and second portions of the metal component in a simultaneous single-step process.

[0024] The above described and other features are exemplified by the following figures and detailed description.

[0025] Any combination or permutation of embodiments is envisioned. Additional features, functions and applications of the disclosed assemblies, systems and methods of the present disclosure will be apparent from the description which follows, particularly when read in conjunction with the appended figures. All references listed in this disclosure are hereby incorporated by reference in their entireties.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] The following figures are example embodiments wherein the like elements are numbered alike.

[0027] Features and aspects of embodiments are described below with reference to the accompanying drawings, in which elements are not necessarily depicted to scale.

[0028] Example embodiments of the present disclosure are further described with reference to the appended figures. It is to be noted that the various steps, features and combinations of steps/features described below and illustrated in the figures can be arranged and organized differently to result in embodiments which are still within the scope of the present disclosure. To assist those of ordinary skill in the art in making and using the disclosed assemblies, systems and methods, reference is made to the appended figures, wherein:

[0029] FIG. **1** is a schematic of an example heat treatment assembly, according to the present disclosure;

[0030] FIG. **2** is a schematic of another example heat treatment assembly, according to the present disclosure;

[0031] FIG. **3** shows the electron backscatter diffraction (EBSD) map for a nickel-chromium alloy specimen/component heat treated using an example coil-in-furnace configuration/method.

DETAILED DESCRIPTION

[0032] The example embodiments disclosed herein are illustrative of assemblies for a single-step process for selective heat treatment of metals, and systems of the present disclosure and methods/techniques thereof. It should be understood, however, that the disclosed embodiments are merely examples of the present disclosure, which may be embodied in various forms. Therefore, details disclosed herein with reference to example assemblies for a single-step process for selective heat treatment of metals and associated processes/techniques of fabrication/assembly and use are not to be interpreted as limiting, but merely as the basis for teaching one skilled in the art how to make and use the assemblies/systems and/or alternative assemblies/systems of the present disclosure.

[0033] The present disclosure provides assemblies, systems and methods for a single-step process for selective heat treatment of metals.

[0034] More particularly, the present disclosure provides assemblies, systems and methods for a single-step process for selective heat treatment of metals using multiple heating sources.

[0035] The present disclosure provides assemblies, systems and methods for using multiple heating sources in a single step for selective heat treatment of metals in order to achieve location specific microstructure and mechanical properties. As such, the present disclosure provides an improved engineered way to manufacture multi-microstructure parts. The assemblies, systems and methods of the present disclosure are not limited to engine disks or the like, and can be utilized for any product where location specific properties are desired.

[0036] There is currently no conventional technology that utilizes multiple heating sources in a single process to produce parts with location specific properties.

[0037] With the assemblies, systems and methods of the present disclosure, there is essentially no limitation on the type of the heating source. Any combination of heating sources (e.g., furnace, induction coil, laser, and/or microwaves, etc.) can be utilized in the heat treatment techniques of the present disclosure.

[0038] It is noted that a hybrid modeling-test approach can be used in the design process to improve or optimize the process parameters to achieve location specific and improved/optimal microstructure and residual stress to enhance the part performance. It is also noted that performing the selective heat treatment in a single step can reduce the cycle time significantly. Moreover, large thermal gradients can be avoided in the part as different volumes of the part are heated to their desired temperature simultaneously.

[0039] It is noted that there have been different dual heat treatment methods to produce dual property turbine disks. For example, a thermal gradient can be created in the part by using active cooling on the bore of the disk when it is placed into a conventional furnace or within an induction coil. See, for example, U.S. Pat. Nos. 5,312,497 and 5,527,020, the entire contents of each incorporated herein by reference in their entireties.

[0040] While these approaches produce the desired dual microstructure in the disk, fine grain bore and coarse grain rim, they add to the cost and complexity of the solution heat treatment. They also can require specialized air pressure lines going into a furnace that must remain operable for process viability. Another method involves insulating volumes to manage an optimal solution temperature for each volume.

[0041] There are existing dual heat treatment practices involving multiple heating sources. However, these processes are done in multiple steps with a single heating source used in each step.

[0042] An example is a dual heat treatment process to produce dual property turbine disks. To achieve the properties in the bore, the entire part is heat treated sub-solvus first in a conventional furnace. In the second phase the rim is re-solutioned super-solvus using a local induction heating coil. The part is then aged after the dual-property heat treatment. This process does produce a fine grain structure in the bore and a coarse grain in the rim. However, the induction heating process creates a large thermal gradient from rim to the bore that produces a transition zone that is overaged/under-solutioned. This approach is experience-based and only considers the grain size in the design process. Precipitate size and residual stress are two other important characteristics which can significantly impact the part performance and are not necessarily optimized in the conventional process. The conventional method also results in increased cycle time as the heat treatment process is done in two steps. As such and as noted, there is currently no conventional technology that utilizes multiple heating sources in a single step for the selective heat treatment of metals.

[0043] The present disclosure provides for using multiple heating sources in a single process to achieve location specific microstructure and properties. This technique works by heating different volumes of the part to their respective desired temperatures simultaneously. It is noted that different combinations of heating sources can be utilized in the heat treatment assemblies/techniques of the present disclosure.

[0044] FIG. **1** is a schematic of an example heat treatment assembly **10**, according to the present disclosure. In example embodiments, heat treatment assembly **10** includes a first heating source **12** and a second heating source **14**. In general and as discussed further below, the first and second heating sources **12**, **14** are configured and dimensioned to provide selective heat treatment to a metal component **16** in a single-step process.

[0045] As shown in FIG. **1**, example first heating source **12** can take the form of an induction heater (e.g., induction coil), and the second heating source **14** can take the form of an induction heater (e.g., induction coil), although the present disclosure is not limited thereto. Rather, it is noted that heating sources **12**, **14** can take a variety of forms (e.g., different combinations of various heating sources **12**, **14** can be utilized in the heat treatment assemblies **10** and/or methods/techniques of the present disclosure).

[0046] Example first heating source **12** can be in communication with a first power supply **18** (e.g., AC power supply), and second heating source **14** can be in communication with a second power supply **20** (e.g., AC power supply). In example embodiments, the first and second heating sources **12**, **14** are independent of one another.

[0047] As shown in FIG. **1**, example first heating source **12** can be positioned relative to a first portion/volume **22** of the metal component **16**, and the example second heating source **14** can be positioned relative to a second portion/volume **24** of the metal component **16**. It is noted that other heating sources **12**, **14** (e.g., lasers, microwaves, etc.) can be utilized depending on the application.

[0048] As such, the first and second heating sources **12**, **14** of heat treatment assembly **10** can be utilized in a single-step process to provide selective heat treatment to metal component **16** (e.g., to achieve location specific microstructure and mechanical properties of metal component **16**). This technique via heat treatment assembly **10** can operate by heating the different volumes **22**, **24** of the component/part **16** to their respective (different, or similar) desired temperatures simultaneously (and in a single-step process). It is noted that a hybrid modeling-test approach can be used in the design process of assembly **10** to optimize the heating and cooling processes to achieve location specific and optimal microstructure and residual stress of metal component **16**.

[0049] As such, FIG. **1** demonstrates a schematic of an example heat treatment assembly **10** with two independent induction heaters **12**, **14**. With respect to example heat treatment assembly **10**, it is noted that process parameters and/or coil geometry and location for each induction heater **12**, **14** can be utilized/optimized independently to achieve the required dual temperature in the portions **22**, **24** of the component/part **16**.

[0050] FIG. **2** is a schematic of another example heat treatment assembly **100**, according to the present disclosure. In example embodiments, heat treatment assembly **100** includes a first heating source **112** and a second heating source **114**. In general and as discussed further below, the first and second heating sources **112**, **114** are configured and dimensioned to provide selective heat treatment to a metal component **116** in a single-step process.

[0051] As shown in FIG. **2**, example first heating source **112** can take the form of a furnace, and the second heating source **114** can take the form of an induction heater (e.g., induction coil), although the present disclosure is not limited thereto. Rather, it is noted that heating sources **112**, **114** can take a variety of forms.

[0052] Example first heating source **112** can be in communication with a first power supply **118**, and second heating source **114** can be in communication with a second power supply **120** (e.g., AC power supply). In example embodiments, the first and second heating sources **112**, **114** are independent of one another.

[0053] As shown in FIG. **2**, the metal component **116** can be positioned within the first heating source **112** to heat the entire first portion/volume **122** of the metal component **116** (e.g., all of component **116**), and the example second heating source **114** can be positioned relative to a second portion/volume **124** of the metal component **116**. As such, example heat treatment assembly **100** provides a coil-in-furnace configuration, where a furnace **112** is utilized as a main heat source and an induction coil **114** can be used as a secondary heating source to heat a local region **124** in the component/part **116** above that of the remaining region/portion **122** of the component/part **116** not heated by coil **114**. It is noted that other heating sources **112**, **114** (e.g., lasers, microwaves, etc.) can be utilized depending on the application.

[0054] As such, the first and second heating sources **112**, **114** of heat treatment assembly **100** can be utilized in a single-step process to provide selective heat treatment to metal component **116** (e.g., to achieve location specific microstructure and mechanical properties of metal component **116**). This technique via heat treatment assembly **100** can operate by heating the different volumes **122**, **124** of the component/part **116** to their respective (different, or similar) desired temperatures simultaneously (and in a single-step process). It is noted that a hybrid modeling-test approach can be used in the design process of assembly **100** to optimize the heating and cooling processes to achieve location specific and optimal microstructure and residual stress of metal component **116**.

[0055] As such, FIG. **2** demonstrates a schematic of an example heat treatment assembly **100** with two independent heaters **112**, **114**. With respect to example heat treatment assembly **100**, it is noted that process parameters and/or coil geometry and location for induction heater **114** can be utilized/optimized independently to achieve the required dual temperature in the portions **122**, **124** of the component/part **116**.

[0056] The assemblies, systems and methods of the present disclosure can provide improved quality components/parts **16**, **116** by enhancing the microstructure in the transition zone by eliminating the large thermal gradient that occurs using existing conventional dual heat treatment techniques in multiple steps.

[0057] FIG. **3** shows the electron backscatter diffraction (EBSD) map for a nickel-chromium alloy specimen/component **116** heat treated using the coil-in-furnace configuration/method as discussed relative to assembly **100** of FIG. **2**. In this experiment, the first and second portions **122**, **124** of the component/specimen **116** were heat treated sub-solvus (first portion **122**) and super-solvus (second portion **124**) simultaneously via assembly **100**.

[0058] There are many benefits of the assemblies, systems and methods of the present disclosure, including, without limitation: providing for improved quality parts by enhancing the microstructure in the transition zone by eliminating the large thermal gradient which occurs using existing dual heat treat techniques; provides for significant reduction in cycle time as the selective heat treatment is performed in a single process; can be integrated with modeling to provide an engineered design system to optimize and/or improve the process based on requirements of microstructure (e.g., grain size, precipitation size) and residual stress.

[0059] While particular embodiments have been described, alternatives, modifications, variations, improvements, and substantial equivalents that are or may be presently unforeseen may arise to applicants or others skilled in the art. Accordingly, the appended claims as filed and as they may be amended are intended to embrace all such alternatives, modifications variations, improvements, and substantial equivalents.

[0060] The ranges disclosed herein are inclusive of the endpoints, and the endpoints are independently combinable with each other (e.g., ranges of "up to 25 wt. %, or, more specifically, 5 wt. % to 20 wt. %", is inclusive of the endpoints and all intermediate values of the ranges of "5 wt. % to 25 wt. %," etc.). "Combinations" is inclusive of blends, mixtures, alloys, reaction products, and the like. The terms "first," "second," and the like, do not denote any order, quantity, or importance, but rather are used to distinguish one element from another. The terms "a" and "an" and "the" do not denote a limitation of quantity and are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. "Or" means "and/or" unless clearly stated otherwise. Reference throughout the specification to "some embodiments", "an embodiment", and so forth, means that a particular element described in connection with the embodiment is included in at least one embodiment described herein, and may or may not be present in other embodiments. In addition, it is to be understood that the described elements may be combined in any suitable manner in the various embodiments. A "combination thereof" is open and includes any combination comprising at least one of the listed components or properties optionally together with a like or equivalent component or property not listed.

[0061] Unless defined otherwise, technical and scientific terms used herein have the same meaning as is commonly understood by one of skill in the art to which this application belongs. All cited patents, patent applications, and other references are incorporated herein by reference in their entirety. However, if a term in the present application contradicts or conflicts with a term in the incorporated reference, the term from the present application takes precedence over the conflicting term from the incorporated reference.

[0062] Although the systems and methods of the present disclosure have been described with reference to example embodiments thereof, the present disclosure is not limited to such example embodiments and/or implementations. Rather, the systems and methods of the present disclosure are susceptible to many implementations and applications, as will be readily apparent to persons skilled in the art from the disclosure hereof. The present disclosure expressly encompasses such modifications, enhancements and/or variations of the disclosed embodiments. Since many changes could be made in the above construction and many widely different embodiments of this disclosure could be made without departing from the scope thereof, it is intended that all matter contained in the drawings and specification shall be interpreted as illustrative and not in a limiting sense. Additional modifications, changes, and substitutions are intended in the foregoing disclosure. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the disclosure.

What is claimed is:

1. A heat treatment assembly comprising:

a first heating source and a second heating source, the first heating source configured to be positioned relative to a first portion of a metal component, and the second heating source configured to be positioned relative to a second portion of the metal component; and

wherein the first and second heating sources are configured and dimensioned to provide selective heat treatment to the first and second portions of the metal component in a single-step process.

2. The heat treatment assembly of claim **1**, wherein the first and second heating sources are independent of one another.

3. The heat treatment assembly of claim **1**, wherein the first heating source is in communication with a first power supply, and the second heating source is in communication with a second power supply.

4. The heat treatment assembly of claim **1**, wherein the first and second heating sources are configured and dimensioned to provide selective heat treatment to the first and second portions of the metal component in a single-step process to achieve location specific microstructure and mechanical properties of the first and second portions of the metal component.

5. The heat treatment assembly of claim **4**, wherein a hybrid modeling-test approach is utilized to achieve location specific microstructure and mechanical properties of the first and second portions of the metal component.

6. The heat treatment assembly of claim **1**, wherein the first heating source is configured to heat the first portion of the metal component to a first temperature in the single-step process; and

wherein the second heating source is configured to heat the second portion of the metal component to a second temperature in the single-step process.

7. The heat treatment assembly of claim **6**, wherein the first temperature is different than the second temperature.

8. The heat treatment assembly of claim **1**, wherein the metal component comprises a nickel-chromium alloy, and wherein the first heating source is configured to heat the first portion of the nickel-chromium alloy to a super-solvus temperature in the single-step process; and

wherein the second heating source is configured to heat the second portion of the nickel-chromium alloy to a sub-solvus temperature in the single-step process.

9. The heat treatment assembly of claim **1**, wherein the metal component comprises a nickel-chromium alloy, and wherein the first heating source is configured to heat the first portion of the nickel-chromium alloy to a sub-solvus temperature in the single-step process; and

wherein the second heating source is configured to heat the second portion of the nickel-chromium alloy to a super-solvus temperature in the single-step process.

10. The heat treatment assembly of claim **1**, wherein the first and second heating sources are configured and dimensioned to provide selective heat treatment to the first and second portions of the metal component in a simultaneous single-step process.

11. A method for selective heat treatment comprising:

positioning a first heating source relative to a first portion of a metal component;

positioning a second heating source relative to a second portion of the metal component; and

providing selective heat treatment to the first and second portions of the metal component, via the first and second heating sources, in a single-step process.

12. The method of claim **11**, wherein the first and second heating sources are independent of one another.

13. The method of claim **11**, wherein the first heating source is in communication with a first power supply, and the second heating source is in communication with a second power supply.

14. The method of claim **11**, wherein providing selective heat treatment to the first and second portions of the metal component, via the first and second heating sources, in the single-step process achieves location specific microstructure and mechanical properties of the first and second portions of the metal component.

15. The method of claim **14** further comprising utilizing a hybrid modeling-test approach to achieve location specific microstructure and mechanical properties of the first and second portions of the metal component.

16. The method of claim **11**, wherein the first heating source heats the first portion of the metal component to a first temperature in the single-step process; and

wherein the second heating source heats the second portion of the metal component to a second temperature in the single-step process.

17. The method of claim **16**, wherein the first temperature is different than the second temperature.

18. The method of claim **11**, wherein the metal component comprises a nickel-chromium alloy, and wherein the first heating source heats the first portion of the nickel-chromium alloy to a super-solvus temperature in the single-step process; and

wherein the second heating source heats the second portion of the nickel-chromium alloy to a sub-solvus temperature in the single-step process.

19. The method of claim **11**, wherein the metal component comprises a nickel-chromium alloy, and wherein the first heating source heats the first portion of the nickel-chromium alloy to a sub-solvus temperature in the single-step process; and

wherein the second heating source heats the second portion of the nickel-chromium alloy to a super-solvus temperature in the single-step process.

20. The method of claim **11**, wherein the first and second heating sources provide selective heat treatment to the first and second portions of the metal component in a simultaneous single-step process.

* * * * *