

APPARATUS AND METHOD FOR PERFORMING WELDING AT ELEVATED TEMPERATURE

ABSTRACT

A welding apparatus (50) includes a workpiece housing (52) having a window (70) therethrough and having a welding access therethrough for a welder (63) to an interior (54) of the workpiece housing (52). The workpiece housing (52) is metallic with a heat insulation (64) on an internal surface (66) thereof. A lamp heat source (72) is directed through the window (70) and at the workpiece (20) in the interior (54) of the workpiece housing (52). A gas source (86) delivers a controllable flow of a shielding gas to the interior (54) of the workpiece housing (52). A temperature sensor (100) senses a temperature of the workpiece (20) within the interior (54) of the workpiece housing (52). A feedback controller (104) controls the power to the lamp heat source (72) responsive to the temperature of the workpiece (20). To perform welding, the workpiece (20) is placed into the interior (54) of the workpiece housing (52) so as to have its temperature sensed by the temperature sensor (100), and the gas source (86) is operated to envelope the workpiece (20) in the shielding gas. The workpiece (20) is heated by powering the lamp heat source (72) responsive to a setpoint input (106) and to the temperature of the workpiece (20). The workpiece (20) is welded using a welder (63) operating through the welding access.

Fig. 2



US005897801A

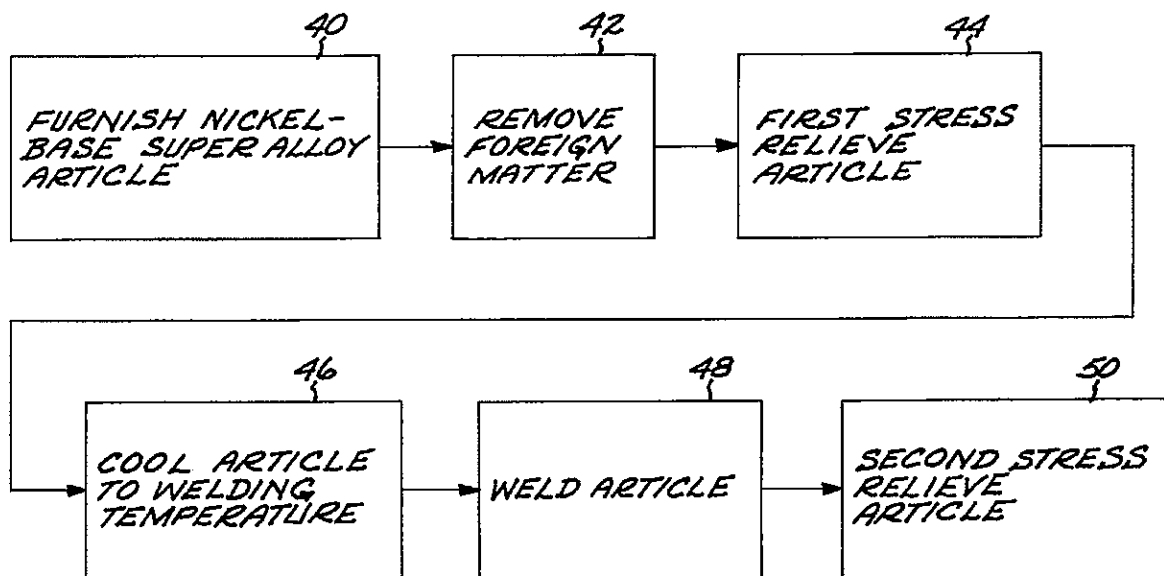
United States Patent [19][11] **Patent Number:** **5,897,801****Smashey et al.**[45] **Date of Patent:** **Apr. 27, 1999**[54] **WELDING OF NICKEL-BASE
SUPERALLOYS HAVING A NIL-DUCTILITY
RANGE**[75] **Inventors:** Russell W. Smashey, Loveland;
Thomas J. Kelly, Cincinnati; John H.
Snyder, Fairfield; Ronald L.
Sheranko, Cincinnati, all of Ohio[73] **Assignee:** General Electric Company, Cincinnati,
Ohio[21] **Appl. No.:** 08/787,356[22] **Filed:** Jan. 22, 1997[51] **Int. Cl.⁶** B23K 9/04[52] **U.S. Cl.** 219/137 WM; 148/524;
219/76.15; 228/119[58] **Field of Search** 219/121.14, 121.13,
219/121.38, 121.46, 121.64, 129, 137 WM,
76.15, 76.14; 148/524, 525, 527; 228/119[56] **References Cited****U.S. PATENT DOCUMENTS**

2,184,534	12/1939	Smith et al.	219/10
3,997,374	12/1976	Dill et al.	
4,176,433	12/1979	Lee et al.	148/527
4,285,459	8/1981	Baladjanian et al.	228/119
4,611,744	9/1986	Fraser et al.	228/119
4,655,383	4/1987	Fournes et al.	228/119
4,737,200	4/1988	Herchenroeder et al.	148/410
4,903,888	2/1990	Clark et al.	228/119

4,981,644	1/1991	Chang	420/442
5,060,842	10/1991	Qureshi et al.	228/119
5,071,054	12/1991	Dzogan et al.	228/119
5,083,002	1/1992	Hoback et al.	219/74
5,106,010	4/1992	Stueber et al.	228/232
5,170,027	12/1992	Brodersen	219/72
5,319,179	6/1994	Joecks et al.	219/137
5,374,319	12/1994	Stueber et al.	148/404
5,509,980	4/1996	Lim	148/525
5,554,837	9/1996	Goldwater et al.	219/121.64

Primary Examiner—Clifford C. Shaw**Attorney, Agent, or Firm**—Andrew C. Hess; David L.
Narciso[57] **ABSTRACT**

An article made of a nickel-base superalloy having a nil-ductility range from the solidus temperature of the alloy to about 600° F. below the solidus temperature is welded, as for example in the weld repair of surface cracks, by removing foreign matter from the area to be welded, first stress relieving the article, adjusting the temperature of the article to a welding temperature of from about 1800° F. to about 2100° F., welding a preselected area in an inert atmosphere at the welding temperature, and second stress relieving the article. Welding is preferably accomplished by striking an arc in the preselected area so as to locally melt the alloy in the preselected area, providing a filler metal having the same composition as the nickel-based superalloy of the article, and feeding the filler metal into the arc so that the filler metal is melted and fused with the article to form a weldment upon solidification.

17 Claims, 3 Drawing Sheets

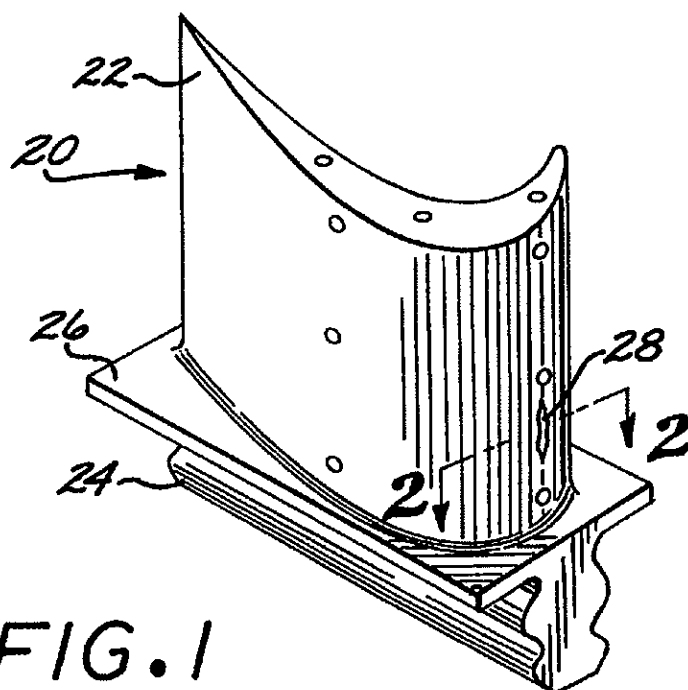


FIG. 1

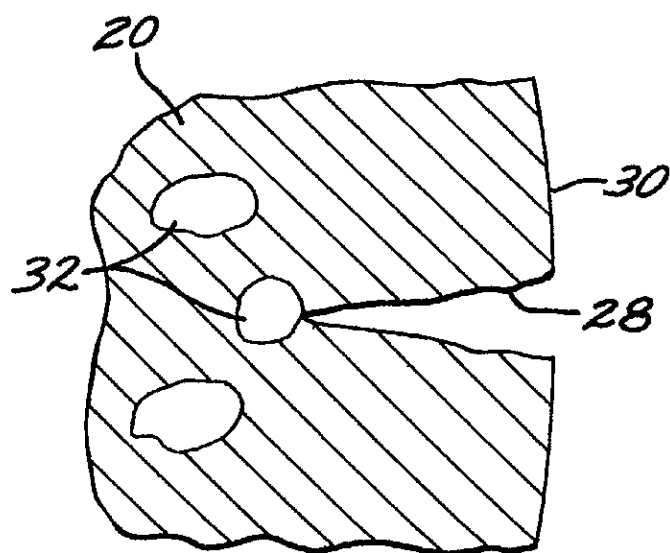


FIG. 2

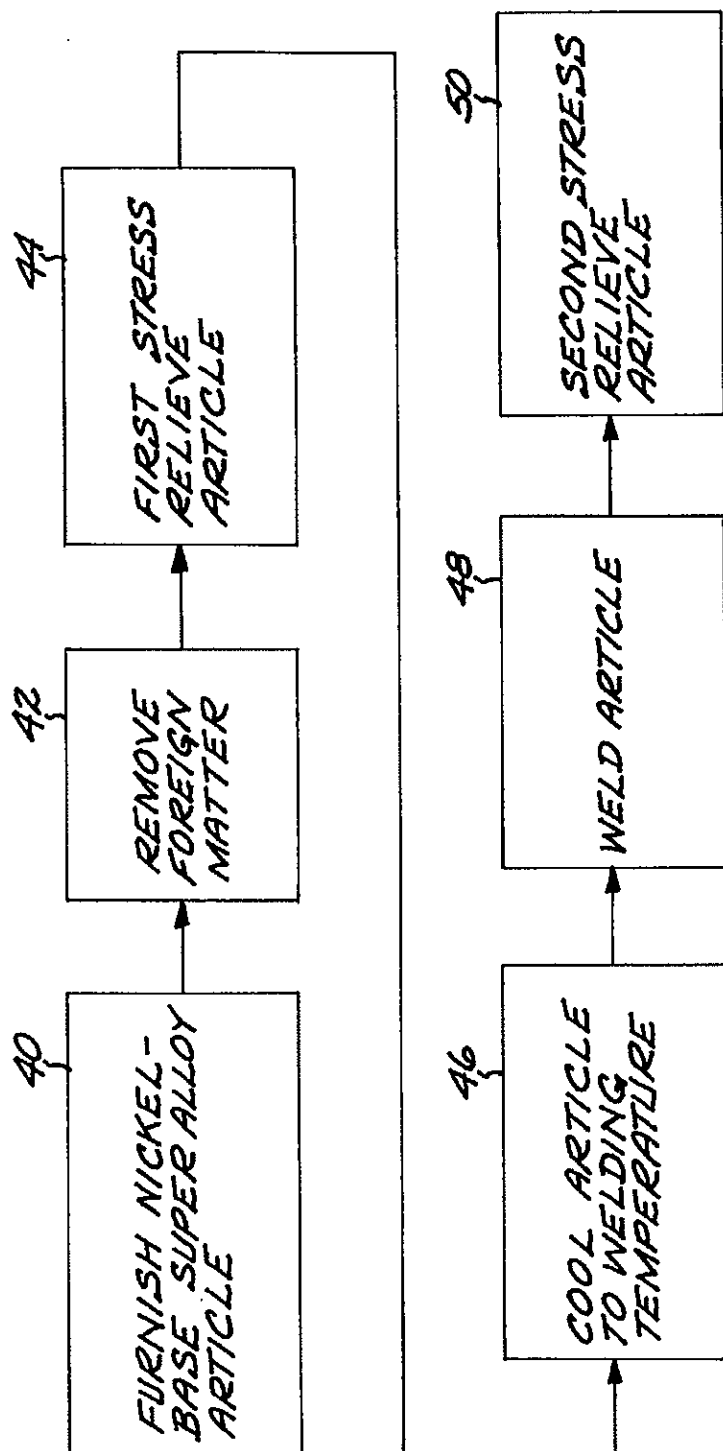


FIG. 3

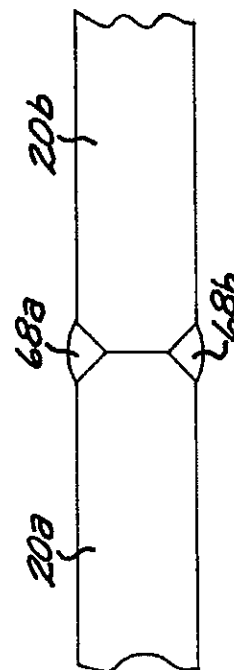
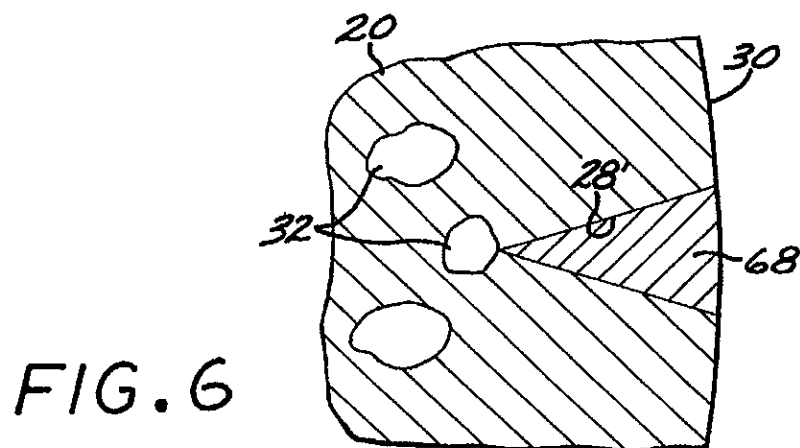
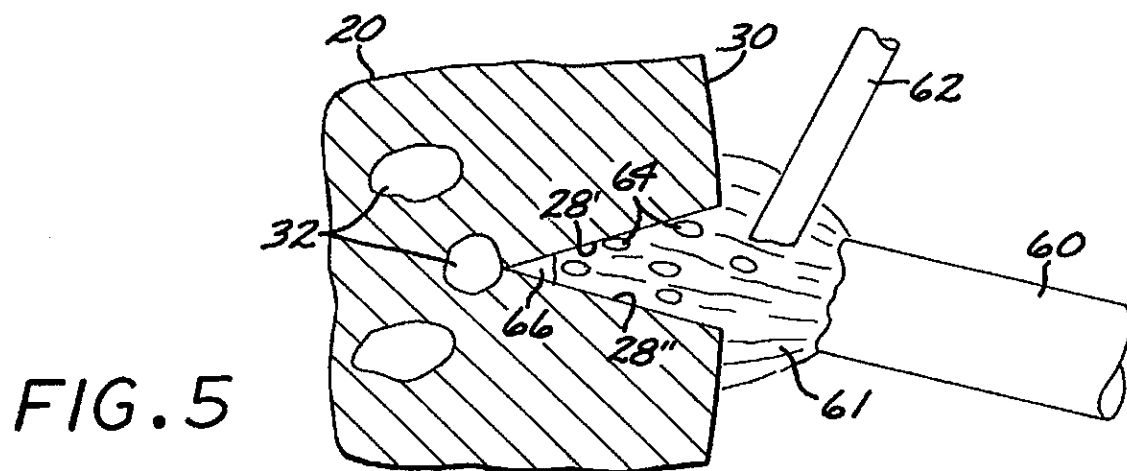
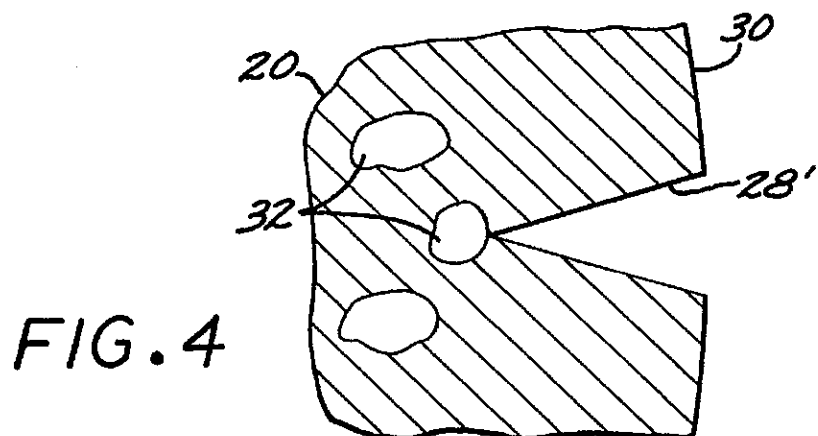


FIG. 7



WELDING OF NICKEL-BASE SUPERALLOYS HAVING A NIL-DUCTILITY RANGE

The invention herein described was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 USC 2457).

BACKGROUND OF THE INVENTION

This invention relates to welding, and, more particularly, to the welding of nickel-base superalloys having limited ductility at elevated temperature.

Nickel-base superalloys are alloys containing about 50 percent or more by weight of nickel, plus alloying elements that are added to improve the mechanical and physical properties of the alloy. These materials are used in aircraft gas turbine components and other applications which require good strength, creep resistance, fracture toughness, and other mechanical properties at elevated temperatures such as 1500° F. and higher for extended periods of time. For example, high-pressure turbine blades and vanes in aircraft gas turbine engines, as well as structural elements exposed to high temperatures for prolonged periods during service, are commonly made of nickel-base superalloys.

The selection of the types and amounts of alloying elements present in the alloy, in combination with the thermal processing, determines to a large degree the properties of the alloy. In some cases, the nickel-base superalloy is moderately strong and moderately ductile, even at high temperatures. In other cases, the combination of alloying elements causes the material to be very strong but of limited ductility even at temperatures approaching the melting point, a temperature at which many alloys become highly ductile.

In one class of nickel-base superalloy of interest here, the alloy has very small, substantially no (nil), ductility in the temperature range between the solidus (freezing) temperature of the alloy and a temperature about 600° F. below the solidus temperature. This behavior plays a significant role in the properties of the alloy, because as the alloy is cooled through this range, or is processed or operated while in this range, the material is highly susceptible to the formation of cracks and other defects which remain in the structure upon cooling to room temperature and during service. Such cracks can also form later in the processing, as for example during welding and post-weld heat treatments. Examples of such nickel-base superalloys having a "nil-ductility range" are Rene 108 and Mar-M247.

Articles made of nickel-base superalloys are usually cast from the melt into a mold, with investment casting being the most popular approach, and then further processed. The as-cast articles sometimes have surface crack defects such as hot tears and surface-connected porosity due to shrinkage defects, which problems are acute for the alloys having a nil-ductility range. These surface defects are deleterious to the properties of the article, either directly or by preventing the closure of interior porosity and shrinkage cavities during subsequent processing.

If the surface defects are not too severe, as is often the case, they may be repaired. However, existing repair techniques involving welding procedures are not fully successful in removing the surface defects, particularly for the nickel-base superalloys with a nil-ductility range. It is often the case that the repair procedure itself leads to even further

defects, which in turn must be repaired. The procedures are accordingly very labor intensive, time consuming, and expensive. They also result in products which may have reduced properties at the location of the repair.

There is accordingly a need for an improved technique for repairing surface defects in articles made of nickel-base superalloys having a nil-ductility range at elevated temperature. The present invention fulfills this need, and further provides related advantages.

SUMMARY OF THE INVENTION

The present invention provides a welding technique for nickel-base superalloy articles of limited ductility near the solidus temperature. The approach may be used for weld repair of defects such as surface cracks on a single such article, or for joining of two such articles together. Care is taken in the welding procedure to avoid a material state where the existing defects propagate further into the structure and so that new defects are not formed. Strain-age cracking is thereby avoided or minimized.

In accordance with the invention, a method of welding a nickel-base superalloy having a nil-ductility range from the solidus temperature of the alloy to about 600° F. below the solidus temperature comprises the steps of furnishing an article made of a nickel-base superalloy having a nil-ductility range from the solidus temperature of the alloy to about 600° F. below the solidus temperature, and removing any foreign matter present in a preselected area of the article to be welded. Foreign matter is preferably removed by a combination of grinding away material around the preselected area and chemically cleaning the preselected area. The method further includes first heating the article at a first stress-relieving temperature in the nil-ductility range, adjusting the temperature of the article to a bulk-material welding temperature within the nil-ductility range, but less than the first-stress-relieving temperature, welding the preselected area of the article, in an inert atmosphere, at the welding temperature, and second heating the article from the welding temperature to a second stress relieving temperature in the nil-ductility range, but above the welding temperature. The steps of first heating, adjusting, welding, and second heating are accomplished without reducing the temperature of the preselected area to substantially less than the bulk temperature of the article. No hot isostatic pressing is required in this processing.

The nickel-base superalloy is one having a nil-ductility range, such as R108 or Mar-M247. For such alloys, the preferred first heating temperature is from about 2000° F. to about 2200° F., a temperature which stress relieves the alloy. The bulk-material welding temperature is preferably from about 1750° F. to about 2100° F. Welding is preferably performed by striking an arc in the preselected area so as to locally melt the alloy in the preselected area, providing a filler metal, and feeding the filler metal into the arc so that the filler metal is melted and fused with the article. Upon cooling, the filler metal forms a weldment. The second heating temperature is from about 2000° F. to about 2200° F. The steps of first heating, adjusting, welding, and second heating are preferably accomplished in a high-purity inert gas atmosphere to prevent reaction of the atmosphere with the alloying elements in the superalloy.

The present approach thus provides an approach for welding difficult to-weld nickel-based superalloys that have a nil-ductility range just below their solidus temperature. Other features and advantages of the present invention will be apparent from the following more detailed description of

the preferred embodiment, taken in conjunction with the accompanying drawings, which illustrate, by way of example, the principles of the invention. The scope of the invention is not, however, limited to this preferred embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a gas turbine blade article;

FIG. 2 is an enlarged sectional view through the article of FIG. 1, taken generally along line 2—2;

FIG. 3 is a block diagram of a process for repairing the article of FIG. 1, according to the invention;

FIG. 4 is an enlarged sectional view like that of FIG. 2, after removing foreign matter;

FIG. 5 is an enlarged sectional view like that of FIGS. 2 and 4, during welding;

FIG. 6 is an enlarged sectional view like that of FIGS. 2, 4, and 5, after welding is complete; and

FIG. 7 is an elevational view of two articles welded together by the approach of the invention.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 depicts an article that is a component of a gas turbine engine such as a turbine blade or turbine vane, and in this case a high-pressure turbine blade article 20, made of a nickel-base superalloy having a nil-ductility range from the solidus temperature of the alloy to about 600° F. below the solidus temperature. Other gas turbine components can benefit from the welding approach of the invention, such as, for example, structural castings. The turbine blade 20 includes an airfoil 22 against which the flow of hot exhaust gas is directed. The turbine blade 20 is mounted to a turbine disk (not shown) by a dovetail 24 which extends downwardly from the airfoil 22 and engages a slot on the turbine disk. A platform 26 extends longitudinally outwardly from the area where the airfoil 22 is joined to the dovetail 24.

The present invention applies to nickel-base superalloy having a nil-ductility range from the solidus temperature of the alloy to about 600° F. below the solidus temperature. Such alloys are at least about 50 percent by weight nickel with a high alloying content that results in the low ductility near the solidus temperature. The "nil-ductility" range means that the alloy has a low ductility in tensile testing in this temperature range, on the order of 1 percent or less. Examples of operable nickel-base superalloys within this definition include the following alloys, whose nominal compositions are stated in weight percent: R108, having a nominal composition of 0.07–0.10 percent carbon, 8.0–8.7 percent chromium, 9.0–10.0 percent cobalt, 0.4–0.6 percent molybdenum, 9.3–9.7 percent tungsten, 2.5–3.3 percent tantalum, 0.6–0.9 percent titanium, 5.25–5.75 percent aluminum, 0.01–0.02 percent boron, 1.3–1.7 percent hafnium, 0.1 percent maximum manganese, 0.06 percent maximum silicon, 0.01 percent maximum phosphorus, 0.004 percent maximum sulfur, 0.005–0.02 percent zirconium, 0.1 percent maximum niobium, 0.1 percent maximum vanadium, 0.1 percent maximum copper, 0.2 percent maximum iron, 0.003 percent maximum magnesium, 0.002 percent maximum oxygen, 0.002 percent maximum nitrogen, balance nickel and incidental impurities; Mar M-246, having a nominal composition of 8.25 percent copper, 10.0 percent cobalt, 0.7 percent molybdenum, 10.0 percent tungsten, 1.0 percent titanium, 5.5 percent aluminum, 0.5 percent maximum iron, 0.15

percent carbon, 0.015 percent boron, 0.05 percent zirconium, 1.5 percent hafnium, 3.0 percent tantalum, balance nickel and incidental impurities; Mar M-200, having a nominal composition of 0.15 percent carbon, 9 percent chromium, 10 percent cobalt, 1 percent iron, 5 percent aluminum, 0.015 percent boron, 2 percent titanium, 12.5 percent tungsten, 0.05 percent zirconium, 1 percent niobium, balance nickel and incidental impurities; AF2-1DA, having a nominal composition of 0.35 percent carbon, 12 percent chromium, 10 percent cobalt, 3 percent molybdenum, 0.5 percent maximum iron, 4.6 percent aluminum, 0.015 percent boron, 3 percent titanium, 6 percent tungsten, 0.1 percent zirconium, 1.5 percent tantalum, balance nickel and incidental impurities; Udimet 500, having a nominal composition of 0.1 percent carbon, 18 percent chromium, 17 percent cobalt, 4 percent molybdenum, 2 percent iron, 3 percent aluminum, 3 percent titanium, balance nickel and incidental impurities; B1900, having a nominal composition of 0.1 percent carbon, 8 percent chromium, 10 percent cobalt, 6 percent molybdenum, 6 percent aluminum, 0.015 percent boron, 1 percent titanium, 0.1 percent zirconium, 4 percent tantalum, balance nickel and incidental impurities; Inconel 100, having a nominal composition of 0.18 percent carbon, 9.5 percent chromium, 15 percent cobalt, 3 percent molybdenum, 5.5 percent aluminum, 0.015 percent boron, 4.2 percent titanium, 0.06 percent zirconium, 1 percent vanadium, balance nickel and incidental impurities; Udimet 700, having a nominal composition of 0.1 percent carbon, 15 percent chromium, 18.5 percent cobalt, 5.25 percent molybdenum, 4.25 percent aluminum, 0.03 percent boron, 3.5 percent titanium, balance nickel and incidental impurities; and Rene 80, having a nominal composition of 0.17 percent carbon, 14 percent chromium, 9.5 percent cobalt, 4 percent molybdenum, 3 percent aluminum, 0.015 percent boron, 5 percent titanium, 4 percent tungsten, 0.03 percent zirconium, balance nickel and incidental impurities.

According to conventional processing, the article such as the turbine blade 20 is cast from molten metal in a mold, typically an investment casting mold. The cast article is cooled to ambient temperature. As a result of the casting operation, an undesirable casting defect 28 is present at a surface 30 of the blade 20. (The present approach is applicable to other types of defects as well.)

FIG. 2 illustrates the casting defect 28 in greater detail. In this case, the defect 28 is a large crack or opening extending inwardly toward the interior of the blade 20. Such an article also typically has interior porosity 32 resulting from the facts that the outer portion of the article solidifies first against the mold wall, and that the center portions of the article thereafter experience externally constrained shrinkage upon solidification that results in cavities and porosity. The interior porosity, or shrinkage cavity, may be entirely interior to the article or may be connected to the surface through the defect 28.

FIG. 3 illustrates the approach of the invention, as applied to such an article. The article 20, made of the nickel-base superalloy, and with the defect 28 and the interior porosity 32 is provided, numeral 40. Any foreign matter is removed, numeral 42, from a preselected area of the article to be welded, in this case the region of the defect 28. The foreign matter is typically of three types. The foreign matter may be pieces of material of another composition, such as ceramic particles from the investment casting mold that have adhered to the inside surfaces of the defect 28. The foreign matter may also be a chemical contaminant or an oxide film. To remove the pieces of material of another composition, some of the material found at the surface of the area to be welded

is removed, preferably by grinding as with a rotary grinder. In the case of the weld repair of the defect shown in FIG. 2, material inside the defect 28 is removed by grinding or other technique, enlarging the width of the defect as shown at groove 28' in FIG. 4. The groove 28' is preferably at least two times, or even three times, the width of the original defect 28, ensuring that particles of foreign matter are removed. To remove the chemical contaminants, the surfaces of the defect 28 (if no grinding is performed) or the groove 28' (if grinding is performed) are cleaned in a suitable cleaning agent. Preferably, for the nickel-base superalloy the cleaning is performed by ultrasonic cleaning in acetone for about 5 to 30 minutes, followed by air drying.

After the foreign matter is removed, the article is first stress relieved by heating to a suitable stress relieving temperature, numeral 44. The stress relieving temperature is preferably from about 2000° F. to about 2200° F. for 1 to 4 hours. The stress relieving is performed in the weld chamber in a high-purity atmosphere whose nature will be discussed subsequently.

After stress relieving, the article is cooled from the stress-relieving temperature to a bulk-material welding temperature, numeral 46. The bulk-material welding temperature is preferably from about 1750° F. to about 2100° F. For the most preferred Rene 108 alloy, the preferred bulk-metal welding temperature is about 1900° F. The term "bulk-metal welding temperature" refers to the fact that the entire article is heated to that temperature, and the local region being welded is heated even further. The welding is performed in the welding apparatus under an inert gas such as argon.

In the latter preferred case of welding under a high-purity inert argon gas, care is taken to maintain the oxygen content of the inert gas at less than about 1 part per million (ppm), because residual oxygen strongly oxidizes alloying elements in the nickel-base superalloy, to reduce the weld quality. For the same reason, the moisture content of the inert gas is maintained very low, with a dew point of the inert gas of less than about -80° F. The oxygen and moisture contents may be maintained at these low levels by passing the inert gas through a nickel-train gas purifier operated at 1600° F. before it enters the welding chamber, and continuously monitoring the oxygen content of the inert gas.

The welding chamber is preferably a glove box operating at one atmosphere of the inert gas processed as just described to achieve high purity. The interior of the glove box is preheated prior to the start of welding to outgas oxygen, moisture, and other residual gases.

The welding process is performed, numeral 48. FIG. 5 illustrates a preferred approach. A tungsten electrode 60 is positioned adjacent to the region to be welded, here the groove 28'. An electrical current is passed between the electrode 60 and the article 20 to form an arc 61, with the highest current density passing through the area of the groove 28'. The current is adjusted so that the sides of the groove 28' become molten, as indicated at numeral 28". The objective is to locally melt the nickel-base superalloy of the article 20, just in the area to be welded, here the groove 28' earlier ground into the region of the defect 28. This objective is readily accomplished by skilled welders or by automated welding equipment.

At the same time, a filler metal is provided. Preferably, a weld rod 62 of filler metal is provided, having been previously cleaned by the chemical cleaning same procedure described in relation to step 42. The weld rod 62 is slowly fed and introduced into the arc 61, as shown in FIG. 5, so

that droplets 64 of the filler metal are melted off the end of the rod 62 to form a filler pool 66 in the interior of the groove 28'. The filler metal 66 and the molten nickel-base superalloy 28" mix together. The electrode 60 and rod 62 are moved longitudinally along the length of the groove 28' (i.e., movement out of the plane of the drawing in FIG. 5), with the rate of movement selected so that a sufficient amount of filler metal is melted into the groove 28' to fill it. As the electrode 60 and rod 62 move, the melted material behind this welding material source cools and solidifies, leaving a weldment 68 filling what was previously the groove 28', as shown in FIG. 6. The weldment 68 is strongly bonded to the groove region 28' of the article 20, because of the care taken to remove foreign matter, the care taken to maintain a high-purity welding atmosphere, and the intermixing and fusion of the filler metal and the base material of the article 20.

The filler metal of the weld rod 62 may be any suitable material. However, it is preferred that the filler metal be of the same composition as the nickel-base superalloy making up the article 20, so that there is a match of chemical and physical properties in the repaired region.

After the welding 48 is complete, the article 20, with the weldment 68 in place, is second stress relieved, numeral 50, by heating from the welding temperature to a second stress relieving temperature. The second stress relieving temperature is preferably from about 2000° F. to about 2200° F., for a time of about 1 hour. For the most preferred Rene 108 nickel-base superalloy, the second stress relieving temperature is about 2100° F. The stress relieving is performed in the same inert atmosphere as the welding. After stress relieving for an operable period of time, about 1 hour, the article is cooled from the stress-relieving temperature at a relatively slow rate of less than about 100° F. per hour to a temperature of less than about 1600° F., in order to minimize the re-introduction of internal residual stresses in the article. These numerical values are typical, inasmuch as the required cooling rate may be slower for large articles.

It is preferred that the steps 44, 46, 48, and 50 be conducted in a single apparatus, the welding apparatus, which has an oven with the capability to heat and cool as indicated. Performing these steps in a single apparatus avoids oxidation and possible contamination that could occur in moving the article from one apparatus to another. It is also preferred that these steps 44, 46, 48, and 50 be accomplished without reducing the temperature of the pre-selected area to substantially less than the bulk temperature of the article, to avoid the introduction of overly large strains and cracking prior to completion of the welding operation.

An advantage of the present approach is that no hot isostatic pressing is required to accomplish the welding.

Welding according to the present approach has been described in terms of weld repair of articles 20 with defects therein. However, as illustrated in FIG. 7, it may also be used to weld together two different articles 20a and 20b. The same steps as described previously are preferably used, resulting in weldments 68a and 68b.

Optionally, the article may be hot isostatically pressed to remove porosity either before or after the welding operation.

This invention has been described in connection with specific embodiments and examples. However, those skilled in the art will recognize various modifications and variations of which the present invention is capable without departing from its scope as represented by the appended claims.

What is claimed is:

1. A method of welding a nickel-base superalloy having a malleability range from the solidus temperature of the alloy to about 600° F. below the solidus temperature, comprising the steps of

furnishing an article made of a nickel-base superalloy having a nil-ductility range from the solidus temperature of the alloy to about 600° F. below the solidus temperature;

removing any foreign matter present in a welding area of the article to be welded;

first heating the article at a first stress-relieving temperature in the nil-ductility range;

adjusting the temperature of the article to a bulk-material welding temperature within the nil-ductility range, but less than the first-stress-relieving temperature;

welding the welding area of the article, in an inert atmosphere, at the welding temperature; and

second heating the article from the welding temperature to a second stress relieving temperature in the nil-ductility range, but above the welding temperature,

the steps of first heating, adjusting, welding, and second heating being accomplished without reducing the temperature of the welding area to substantially less than the bulk temperature of the article.

2. The method of claim 1, wherein the step of furnishing includes the step of

furnishing a nickel base superalloy having a composition, in weight percent, selected from the group consisting of R108, having a nominal composition of 0.07–0.10 percent carbon, 8.0–8.7 percent chromium, 9.0–10.0 percent cobalt, 0.4–0.6 percent molybdenum, 9.3–9.7 percent tungsten, 2.5–3.3 percent tantalum, 0.6–0.9 percent titanium, 5.25–5.75 percent aluminum, 0.01–0.02 percent boron, 1.3–1.7 percent hafnium, 0.1 percent maximum manganese, 0.06 percent maximum silicon, 0.01 percent maximum phosphorus, 0.004 percent maximum sulfur, 0.005–0.02 percent zirconium, 0.1 percent maximum niobium, 0.1 percent maximum vanadium, 0.1 percent maximum copper, 0.2 percent maximum iron, 0.003 percent maximum magnesium, 0.002 percent maximum oxygen, 0.002 percent maximum nitrogen, balance nickel and incidental impurities; Mar M-246, having a nominal composition of 8.25 percent copper, 10.0 percent cobalt, 0.7 percent molybdenum, 10.0 percent tungsten, 1.0 percent titanium, 5.5 percent aluminum, 0.5 percent maximum iron, 0.15 percent carbon, 0.015 percent boron, 0.05 percent zirconium, 1.5 percent hafnium, 3.0 percent tantalum, balance nickel and incidental impurities; Mar M-200, having a nominal composition of 0.15 percent carbon, 9 percent chromium, 10 percent cobalt, 1 percent iron, 5 percent aluminum, 0.015 percent boron, 2 percent titanium, 12.5 percent tungsten, 0.05 percent zirconium, 1 percent niobium, balance nickel and incidental impurities; AF2-1DA, having a nominal composition of 0.35 percent carbon, 12 percent chromium, 10 percent cobalt, 3 percent molybdenum, 0.5 percent maximum iron, 4.6 percent aluminum, 0.015 percent boron, 3 percent titanium, 6 percent tungsten, 0.1 percent zirconium, 1.5 percent tantalum, balance nickel and incidental impurities; Udimet 500, having a nominal composition of 0.1 percent carbon, 18 percent chromium, 17 percent cobalt, 4 percent molybdenum, 2 percent iron, 3 percent aluminum, 3 percent titanium, balance nickel and incidental impurities; B1900, having a nominal composition of 0.1 percent carbon, 8 percent chromium, 10 percent cobalt, 6 percent molybdenum, 6 percent aluminum, 0.015 percent boron, 1 percent titanium, 0.1 percent zirconium, 4 percent tantalum, balance nickel and incidental impu-

rities; Inconel 100, having a nominal composition of 0.18 percent carbon, 9.5 percent chromium, 15 percent cobalt, 3 percent molybdenum, 5.5 percent aluminum, 0.015 percent boron, 4.2 percent titanium, 0.06 percent zirconium, 1 percent vanadium, balance nickel and incidental impurities; Udimet 700, having a nominal composition of 0.1 percent carbon, 15 percent chromium, 18.5 percent cobalt, 5.25 percent molybdenum, 4.25 percent aluminum, 0.03 percent boron, 3.5 percent titanium, balance nickel and incidental impurities; and Rene 80, having a nominal composition of 0.17 percent carbon, 14 percent chromium, 9.5 percent cobalt, 4 percent molybdenum, 3 percent aluminum, 0.015 percent boron, 5 percent titanium, 4 percent tungsten, 0.03 percent zirconium, balance nickel and incidental impurities.

3. The method of claim 1, wherein the step of removing includes the step of

removing foreign matter from the region of a crack in the article by grinding away material around the crack.

4. The method of claim 1, wherein the step of removing includes the step of

removing foreign matter from the region of a crack in the article by grinding away material around the crack to a width of at least about 2 times the width of the crack.

5. The method of claim 1, wherein the step of removing includes the step of

chemically cleaning the welding area.

6. The method of claim 1, wherein the step of first heating includes the step of

heating the article to a temperature of from about 2000° F. to about 2200° F.

7. The method of claim 1, wherein the step of adjusting the temperature includes the step of

adjusting the temperature to a welding temperature of from about 1800° F. to about 2100° F.

8. The method of claim 1, wherein the step of welding includes the step of

striking an arc in the welding area so as to locally melt the alloy in the welding area.

9. The method of claim 1, wherein the step of welding includes the step of

providing a filler metal having the same composition as the nickel-based superalloy of the article.

10. The method of claim 1, wherein the step of second heating includes the step of

heating the article to a temperature of from about 2000° F. to about 2200° F.

11. The method of claim 1, wherein there is no step of hot isostatic pressing at any time in the processing.

12. A method of welding a nickel-base superalloy having a nil-ductility range from the solidus temperature of the alloy to about 600° F. below the solidus temperature, comprising the steps of

furnishing an article made of a nickel-base superalloy having a nil-ductility range from the solidus temperature of the alloy to about 600° F. below the solidus temperature;

removing any foreign matter present in a welding area of the article to be welded;

first heating the article to a temperature of from about 2000° F. to about 2200° F.;

adjusting the temperature of the article to a bulk-material welding temperature of from about 1800° F. to about 2100° F.; and

welding the welding area of the article, in an inert atmosphere, at the bulk-material welding temperature, the step of welding including the steps of striking an arc in the welding area so as to locally melt the alloy in the welding area, providing a filler metal, and feeding the filler metal into the arc so that the filler metal is melted and fused with the article; and second heating the article from the bulk-material welding temperature to a temperature of from about 2000° F. to about 2200° F., the steps of first heating, adjusting, welding, and second heating being accomplished without reducing the temperature of the welding area to substantially less than the bulk temperature of the article.

13. The method of claim 12, wherein the step of furnishing includes the step of

furnishing a nickel base superalloy having a composition, in weight percent, selected from the group consisting of R108, having a nominal composition of 0.07–0.10 percent carbon, 8.0–8.7 percent chromium, 9.0–10.0 percent cobalt, 0.4–0.6 percent molybdenum, 9.3–9.7 percent tungsten, 2.5–3.3 percent tantalum, 0.6–0.9 percent titanium, 5.25–5.75 percent aluminum, 0.010.02 percent boron, 1.3–1.7 percent hafnium, 0.1 percent maximum manganese, 0.06 percent maximum silicon, 0.01 percent maximum phosphorus, 0.004 percent maximum sulfur, 0.005–0.02 percent zirconium, 0.1 percent maximum niobium, 0.1 percent maximum vanadium, 0.1 percent maximum copper, 0.2 percent maximum iron, 0.003 percent maximum magnesium, 0.002 percent maximum oxygen, 0.002 percent maximum nitrogen, balance nickel and incidental impurities; Mar M-246, having a nominal composition of 8.25 percent copper, 10.0 percent cobalt, 0.7 percent molybdenum, 10.0 percent tungsten, 1.0 percent titanium, 5.5 percent aluminum, 0.5 percent maximum iron, 0.15 percent carbon, 0.015 percent boron, 0.05 percent zirconium, 1.5 percent hafnium, 3.0 percent tantalum, balance nickel and incidental impurities; Mar M200, having a nominal composition of 0.15 percent carbon, 9 percent chromium, 10 percent cobalt, 1 percent iron, 5 percent aluminum, 0.015 percent boron, 2 percent titanium, 12.5 percent tungsten, 0.05 percent zirconium, 1 percent niobium, balance nickel and incidental impurities; AF2-1DA, having a nominal composition of 0.35 percent carbon, 12 percent chromium, 10 percent cobalt, 3 percent molybdenum, 0.5 percent

maximum iron, 4.6 percent aluminum, 0.015 percent boron, 3 percent titanium, 6 percent tungsten, 0.1 percent zirconium, 1.5 percent tantalum, balance nickel and incidental impurities; Udimet 500, having a nominal composition of 0.1 percent carbon, 18 percent chromium, 17 percent cobalt, 4 percent molybdenum, 2 percent iron, 3 percent aluminum, 3 percent titanium, balance nickel and incidental impurities; B1900, having a nominal composition of 0.1 percent carbon, 8 percent chromium, 10 percent cobalt, 6 percent molybdenum, 6 percent aluminum, 0.015 percent boron, 1 percent titanium, 0.1 percent zirconium, 4 percent tantalum, balance nickel and incidental impurities; Inconel 100, having a nominal composition of 0.18 percent carbon, 9.5 percent chromium, 15 percent cobalt, 3 percent molybdenum, 5.5 percent aluminum, 0.015 percent boron, 4.2 percent titanium, 0.06 percent zirconium, 1 percent vanadium, balance nickel and incidental impurities; Udimet 700, having a nominal composition of 0.1 percent carbon, 15 percent chromium, 18.5 percent cobalt, 5.25 percent molybdenum, 4.25 percent aluminum, 0.03 percent boron, 3.5 percent titanium, balance nickel and incidental impurities; and Rene 80, having a nominal composition of 0.17 percent carbon, 14 percent chromium, 9.5 percent cobalt, 4 percent molybdenum, 3 percent aluminum, 0.015 percent boron, 5 percent titanium, 4 percent tungsten, 0.03 percent zirconium, balance nickel and incidental impurities.

14. The method of claim 12, wherein the step of providing includes the step of

providing a filler metal having the same composition as the nickel-based superalloy of the article.

15. The method of claim 12, wherein the step of removing includes the step of

removing foreign matter from the region of a crack in the article by grinding away material around the crack.

16. The method of claim 12, wherein the step of removing includes the step of

removing foreign matter from the region of a crack in the article by grinding away material around the crack to a width of at least about 2 times the width of the crack.

17. The method of claim 12, wherein the step of removing includes the step of

chemically cleaning the welding area.

* * * * *



US006124568A

United States Patent [19]

Broderick et al.

[11] **Patent Number:** **6,124,568**[45] **Date of Patent:** **Sep. 26, 2000**[54] **HEATING APPARATUS FOR A WELDING OPERATION AND METHOD THEREFOR**

[75] Inventors: **Thomas F. Broderick**, Springboro;
Richard R. Worthing, Jr., Cincinnati;
Lawrence J. Roedl, West Chester, all
of Ohio; **John M. Powers**,
Independence, Ky.; **Warren D.**
Grossklaus, Jr., West Chester, Ohio

[73] Assignee: **General Electric Company**, Cincinnati,
Ohio

[21] Appl. No.: **09/223,793**

[22] Filed: **Dec. 31, 1998**

[51] Int. Cl.⁷ **B23K 9/23**

[52] U.S. Cl. **219/137 WM; 219/72;**
228/232

[58] Field of Search **219/137 R, 137 WM,**
219/72; 228/232

[56] **References Cited****U.S. PATENT DOCUMENTS**

5,106,010 4/1992 Stueber et al. 228/232
5,319,179 6/1994 Joecks et al. 219/137 R
5,897,801 4/1999 Smashey et al. 219/137 WM

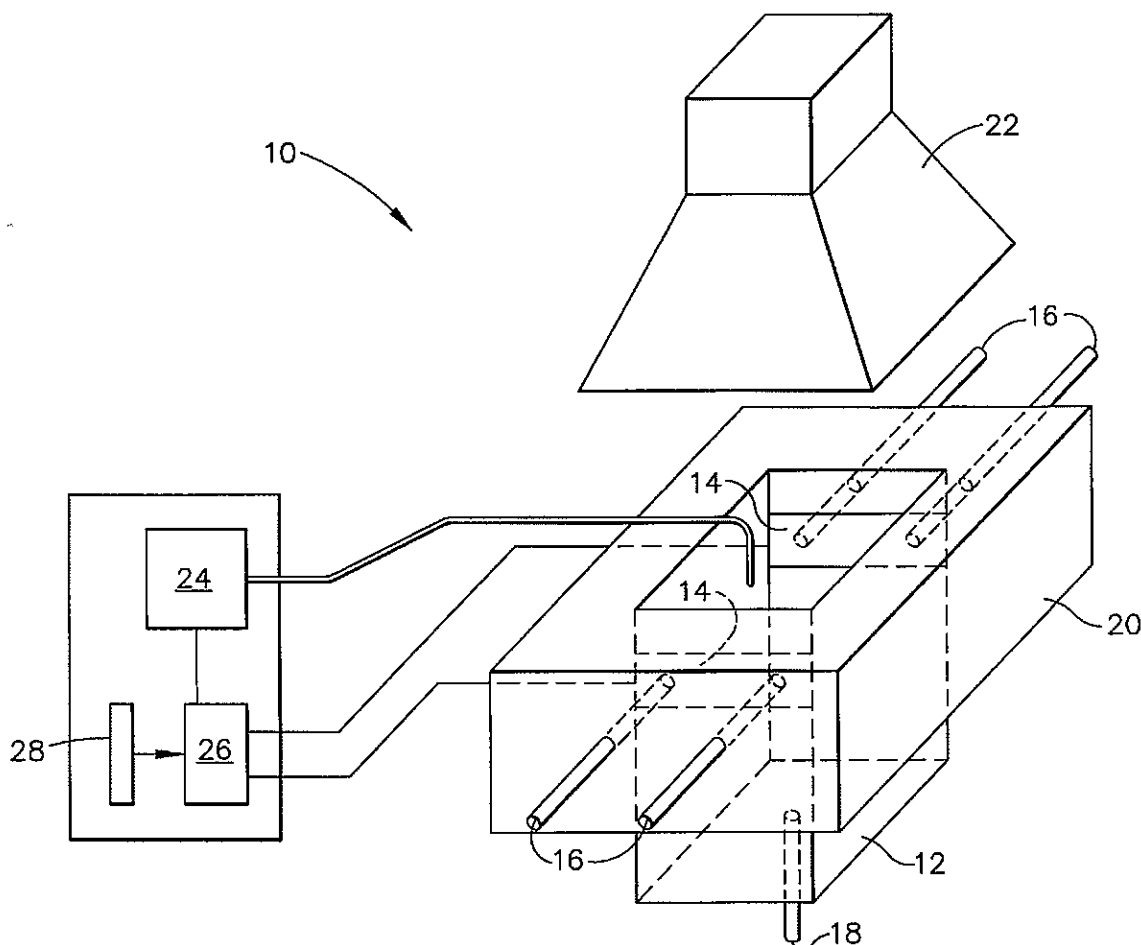
Primary Examiner—Clifford C. Shaw

Attorney, Agent, or Firm—Andrew C. Hess; Gerry S.
Gressel

[57] **ABSTRACT**

A heating apparatus and method for welding a superalloy article. The apparatus and method of this invention provide for pre-weld and post-weld heat treatments to be performed on an article within the same enclosure in which the welding operation is performed. The apparatus accurately controls the temperature of the component to be welded throughout the temperature treatment profiles with the use of means for welding the article, means for heating the article, and means for sensing the article temperature. The apparatus also works in conjunction with a memory storage device that stores appropriate pre-weld and post-weld heat treatment temperature profiles and a welding temperature profile for the article.

5 Claims, 2 Drawing Sheets



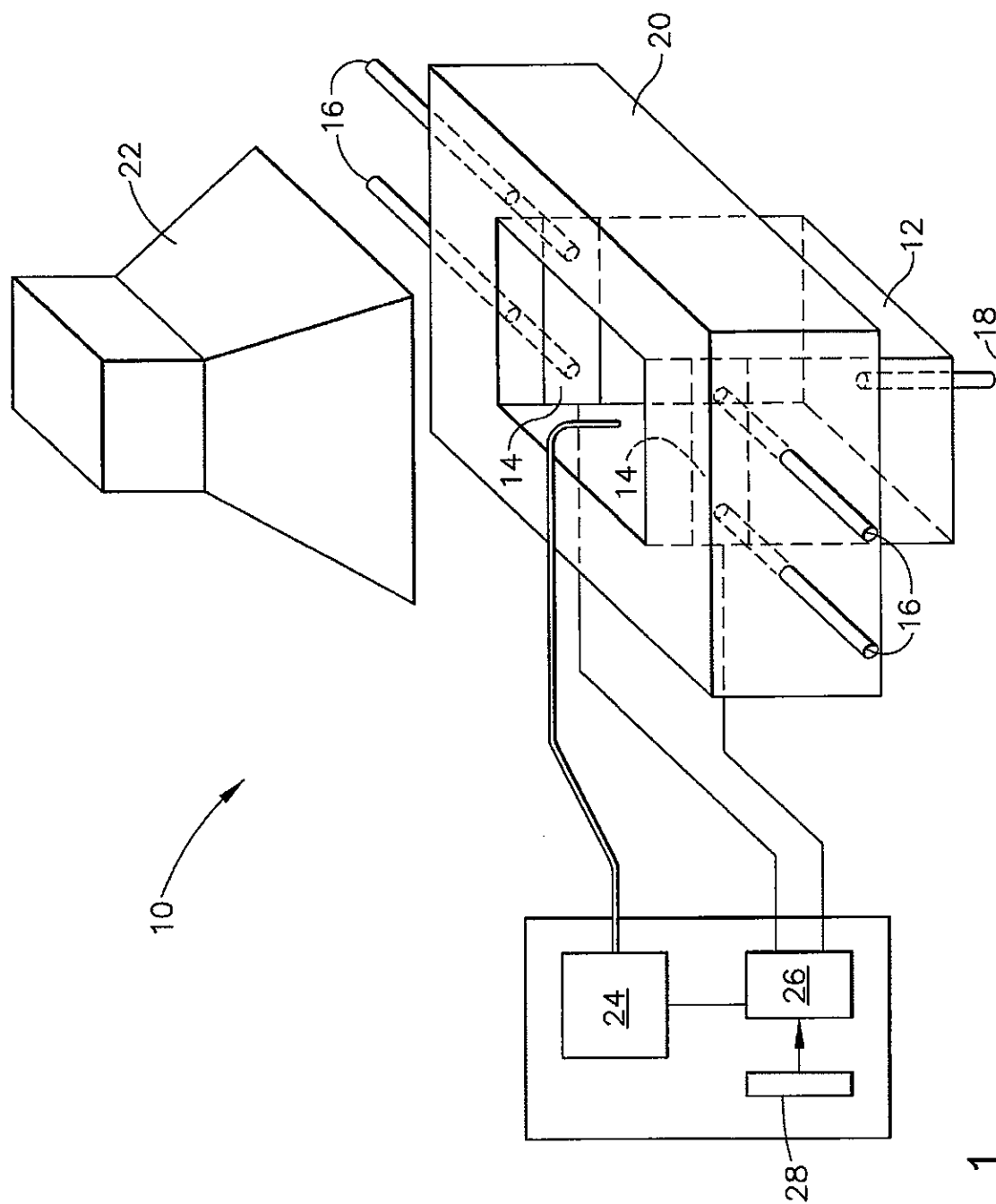


FIG. 1

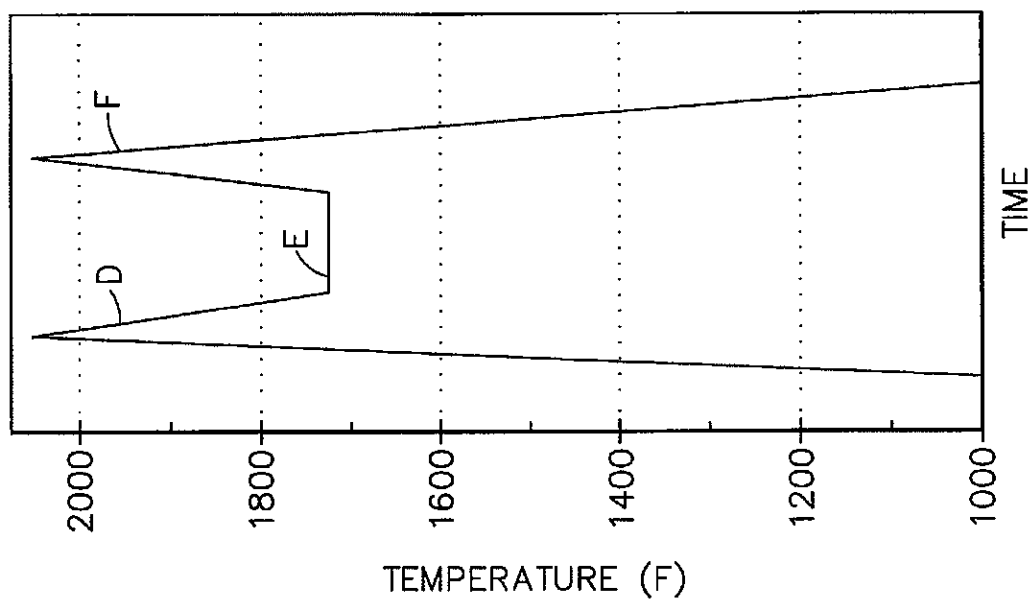


FIG. 3

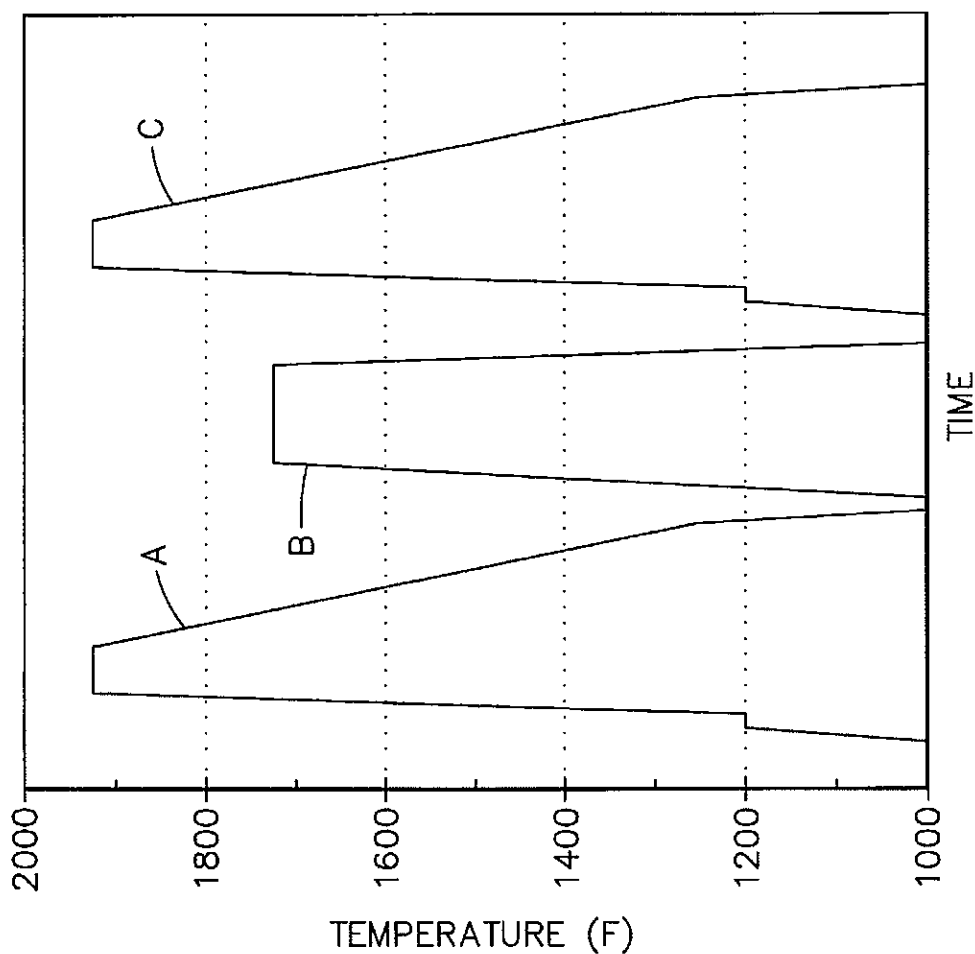


FIG. 2

HEATING APPARATUS FOR A WELDING OPERATION AND METHOD THEREFOR

FIELD OF THE INVENTION

This invention relates to welding apparatuses and methods. More particularly, this invention is directed to an apparatus configured to perform both a welding operation and pre-weld and post-weld heat treatments on a superalloy component.

BACKGROUND OF THE INVENTION

High temperature cobalt and nickel-based superalloys are widely used to form certain components of gas turbine engines, including combustors and turbine vanes and blades. While high-temperature superalloy components are often formed by casting, circumstances exist where superalloy components are preferably or are required to be fabricated by welding. For example, components having complex configurations, such as turbine midframes and shroud support rings, can be more readily fabricated by welding separate castings together. Welding is also widely used as a method for restoring blade tips, and for repairing cracks and other surface discontinuities in superalloy components caused by thermal cycling or foreign object impact. Because the cost of components formed from high-temperature cobalt and nickel-based superalloys is relatively high, restoring/repairing these components is typically more desirable than replacing them when they become worn or damaged.

Superalloy components of gas turbine engines must generally be thermally stress-relieved before welding to relax residual stresses present from engine service, and then stress-relieved after welding to relax residual stresses induced during cool down from the welding operation. Heat treatment also provides stress relief by dissolution of a portion of hardening gamma prime (γ') in γ' -strengthened nickel-base superalloys. Generally, the heat treatment parameters will vary depending on the alloy of interest, the amount of residual stress relief and dissolution required, furnace design, component geometry and many other factors. The ramping rates, soak temperatures, hold times and cooling rates for stress relief and dissolution heat treatments are critical in order to obtain the desired stress relief without adversely affecting the superalloy and its properties.

In the past, pre-weld and post-weld heat treatments have been performed in large batch heat treatment furnaces to ramp and hold a group of components at a suitable heat treatment temperature. Following batch heat treatment, individual components are welded while being maintained at an elevated temperature (e.g., in excess of about 1500° F. (about 815° C.)) to improve welding yields. Welding is often performed in an enclosure containing a controlled atmosphere (e.g., an inert gas) using such welding techniques as tungsten inert gas (TIG) and laser welding processes. Heating is typically performed by induction or with the use of lamps, such as quartz halogen lamps.

While having certain benefits, drawbacks to the use of batch heat treatment processes include long heat treatment times due in part to the mass of the large batch furnace and the mass of the typically large number of components being heat treated. Additionally, long queuing times occur while batches are assembled as individual components are repaired. Therefore, use of batch furnace pre-weld and post-weld stress relief heat treatments represent a time delay to the flow of components through a welding line, and is an inefficient method to metallurgically condition components for welding.

In view of the above, it would be desirable if improved processing efficiency could be achieved for superalloy articles manufactured, restored or repaired by welding.

BRIEF SUMMARY OF THE INVENTION

The present invention generally provides a heating apparatus and method for welding a superalloy article. More particularly, the apparatus and method of this invention provide for pre-weld and post-weld heat treatments to be performed on an article within the same apparatus in which the welding operation is performed.

In view of the criticality of pre-weld and post-weld heat treatments, the invention requires that the welding apparatus be suitably configured to accurately control the temperature of the component being welded. For this reason, the apparatus of this invention generally entails an enclosure adapted for containing a superalloy article, means for welding the article, means for heating the article within the enclosure, and means for sensing the article temperature within the enclosure. The apparatus also works in conjunction with a memory storage device that stores appropriate pre-weld and post-weld heat treatment temperature profiles and a welding temperature profile for the article. Finally, the apparatus includes a control by which the output of the heating means is adjusted based on the article temperature and according to the preestablished pre-weld and post-weld heat treatment temperature and the welding temperature profile.

The method enabled by the apparatus described above generally entails preestablishing the desired pre-weld and post-weld heat treatment temperature profiles and the welding temperature profile for the superalloy article in question, placing the article in the enclosure, and then operating the heating, sensing and controlling means to accurately heat the superalloy article according to the pre-weld heat treatment temperature profile. Once properly heat treated to relieve residual stresses, and without removing the article from the enclosure, the heating, sensing and controlling means are operated to heat the article directly from the pre-weld heat treatment temperature profile to the welding temperature profile, during which the article is welded. Afterwards, and again without removing the article from the enclosure, the heating, sensing and controlling means are operated to heat the article directly from the welding temperature profile to the post-weld heat treatment temperature profile.

In view of the above, it can be appreciated that the present invention eliminates the processing drawbacks known for batch-type pre-weld and post-weld heat treatments of superalloy articles fabricated, restored or repaired by welding. Instead of accumulating a number of articles to simultaneously undergo a single heat treatment, the present invention allows a more streamlined throughput of components by combining the required heat treatments with the welding operation within a single apparatus. The invention also reduces the heat treatment durations required by reducing the thermal mass being heated and cooled during each heat treatment cycle.

Other objects and advantages of this invention will be better appreciated from the following detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic representation of a combination heat treatment and welding apparatus in accordance with this invention; and

FIGS. 2 and 3 are graphs showing the thermal cycles required for heat treating and welding a superalloy article in accordance with the prior art and this invention, respectively.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is generally directed to superalloy articles that undergo a welding operation during their fabrication, restoration or repair. While the advantages of this invention will be described with reference to components of gas turbine engines, the invention is also applicable to a variety of applications in which an article is to be heat treated before and after welding in a manner that will not degrade the properties of the article.

An apparatus 10 for performing the heat treatments and welding operation of this invention is schematically depicted in FIG. 1. The apparatus 10 includes an enclosure 12 generally of a type known for performing a welding operation such as TIG or laser welding in a controlled atmosphere. The apparatus 10 also includes a heating device 14 of a type known for heating the interior of the enclosure 12 during welding. Suitable devices include induction coils, quartz halogen lamps and silicon carbide elements, and may be equipped with cooling elements 16 as shown. The enclosure 12 also includes an inlet 18 through which an inert gas such as argon is fed to the interior of the enclosure 12 to prevent oxidation of the superalloy article while at the elevated processing temperatures of this invention. Also preferably included is an externally-cooled heat shield 20 surrounding the enclosure 12, and an exhaust hood 22 for removing fumes generated during the welding operation.

In the past, before undergoing welding within an enclosure of the type shown in FIG. 1, a superalloy article would first be batch heat treated to relax residual stresses present as a result of the service of the article and, if the article is formed of a γ' -strengthened nickel-base superalloy, to provide alloy softening by dissolution of a portion of the hardening γ' phase. A second batch heat treatment would then be performed after welding to relax residual stresses induced during cool down from welding temperatures. These discrete heat treatment cycles are illustrated in FIG. 2 as curves "A" and "C." Curve "B" in FIG. 2 represents a welding cycle during which the article is maintained at an elevated temperature, generally in excess of about 1500° F. (about 815° C.). The heating and cooling ramp rates, soak temperatures, and hold times for stress relief and dissolution heat treatments are critical to obtaining the desired stress relief without adversely affecting the superalloy and its properties. The heat treatment curves A and C include soak temperatures at which the article is maintained for a duration sufficient to relieve stresses in the article, e.g., about twenty to thirty minutes. Because a post-weld heat treatment is to be performed, the temperature and time profile of the welding operations is not so critically, as long as the article is heated to an acceptable temperature prior to welding. As evidenced by the three discrete temperature profiles of FIG. 2, the article being processed is typically cooled to room temperature between cycles, during which time the article is set aside until enough articles are accumulated to perform a batch heat treatment.

In contrast to the process described above, the welding apparatus 10 of this invention enables control of the temperature and time profile within the enclosure 12, and therefore offers the opportunity to perform pre-weld and post-weld stress relief heat treatments and welding within a single furnace using a single variable-temperature thermal exposure, instead of separate batch and welding furnaces required in the past. Importantly, the preferred process carried out in the welding apparatus 10 does not involve cooling the article between temperature cycles as shown in

FIG. 2, but instead cools the article directly from a pre-weld temperature profile "D" to a welding profile "E," and then heats the article directly from the welding profile F to a post-weld temperature profile "F," as shown in FIG. 3. A comparison of FIGS. 2 and 3 shows that the pre-weld and post-weld profiles D and F in FIG. 3 do not include constant-temperature soaks characteristic of the corresponding profiles A and C, respectively, of FIG. 2. Furthermore, the peak temperatures for the pre-weld and post-weld profiles D and F in FIG. 3 exceed the corresponding soak temperatures for the profiles A and C respectively, of FIG. 2. The result is not only a reduced cycle time by eliminating cool downs to room temperature, but also shorter heat treatment cycles (D and F) before and after welding. However, the profiles D and F of FIG. 3 and this invention could include soaks as shown in FIG. 2; for example, substituting the approximately 1900° F. soaks shown in FIG. 2 for the approximately 2050° F. peaks shown in FIG. 3.

The above operational capabilities are achieved by detecting the temperature of the article within the enclosure 12 with a suitable temperature sensor 24, such as an optical pyrometer or a standard-type K thermocouple. The temperature signal from the sensor 24 is used as input to a programmable temperature controller 26, which compares the signal from the sensor 24 to the desired profiles D, E and F stored in memory 28 for the article. The control signal to the heating device 14 is then regulated based on the difference between the desired temperature profile and the temperature of the article. In this manner, essentially any temperature profile required for a given superalloy article can be programmed and accurately controlled to achieve the objects of this invention.

In view of the above, it can be seen that the present invention provides for the integration of heat treatment and welding cycles within a single apparatus, with the result that what was previously three discrete temperature profiles are consolidated into a single thermal exposure. Advantages include the elimination of batch heat treatments, the elimination of cool downs to room temperature between treatments, and the shortening of the individual treatment profiles. While discussed in terms of certain equipment for the processing of superalloy articles, the apparatus 10 of this invention could also be employed for the treatment and welding of other materials and articles whose processing requires accurate control at elevated temperatures to avoid degradation of the article properties. Therefore, while the invention has been described in terms of a preferred embodiment, it is apparent that other forms could be adopted by one skilled in the art. Accordingly, the scope of the invention is to be limited only by the following claims.

What is claimed is:

1. A method of welding a superalloy article, the method comprising the steps of:

establishing a pre-weld heat treatment temperature profile, a welding temperature profile, and a post-weld heat treatment temperature profile for a superalloy article, wherein the welding temperature profile consists of temperatures below the pre-weld and post-weld heat treatment temperature profiles;

placing the superalloy article in an enclosure having means for heating the article, means for sensing a temperature of the article, and means for controlling the heating means based on the temperature of the article and according to the pre-weld heat treatment temperature profile, the welding temperature profile, and the post-weld heat treatment temperature profile;

operating the heating means, the sensing means and the controlling means to heat the superalloy article according to the pre-weld heat treatment temperature profile;

5

without removing the article from the enclosure, operating the heating means, the sensing means and the controlling means to heat the superalloy article directly from the pre-weld heat treatment temperature profile to the welding temperature profile;

welding the article while maintaining the temperature of the article according to the welding temperature profile; and then

without removing the article from the enclosure, operating the heating means, the sensing means and the controlling means to heat the superalloy article directly from the welding temperature profile to the post-weld heat treatment temperature profile;

wherein at least one of the pre-weld and post-weld heat treatment temperature profiles is characterized by the absence of a constant temperature soak.

6

2. A method as recited in claim 1, wherein both of the pre-weld and post-weld heat treatment temperature profiles are characterized by the absence of a constant temperature soak.

3. A method as recited in claim 1, wherein the temperature of the article is sensed with an optical pyrometer.

4. A method as recited in claim 1, wherein the heating means is selected from the group consisting of quartz halogen lamps, induction coils, and silicon carbide elements.

5. A method as recited in claim 1, wherein the welding step is performed with a welding apparatus selected from the group consisting of tungsten inert gas, plasma transferred arc, and laser beam welders.

* * * * *