

PATENT SPECIFICATION (11)

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(54) METHOD AND APPARATUS FOR APPLYING MOLTEN FILLER MATERIAL

(71) We, GENERAL ELECTRIC COMPANY, a corporation organised and existing under the laws of the State of New York, United States of America, residing at 1, River Road, Schenectady, 12305, State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to welding and repair welding and, more particularly, to improved method and apparatus which provides a weld pool on the workpiece into which filler material is fed for melting and application to the workpiece surface.

In the semi-automatic welding and repair welding of such articles as gas turbine engine alloy components, it is a general practice to add filler material in the form of metal wire, ribbon, for example, which is fed mechanically into a molten weld puddle or pool. As used herein, the term "wire" is intended to include such other equivalent material forms. Such a pool can be provided as a result of an electric arc generated between an electrode and a work surface of the workpiece, a plasma arc or other heating torch means. Relative motion is provided between such electrode and the work surface to enable the arc or torch to traverse that portion of the surface to be welded or repaired.

In many welding applications, the wire has been seen to melt prematurely before it can reach the region of the weld pool and arc, thus causing an accumulation, such as a drop or globule, to form on the end of the wire. This accumulation enlarges and, when it finally reaches the electric arc/weld pool region, results in uneven deposits of filler material. One suggested remedy has been to extend the feed nozzle through which the wire of filler material is fed to provide more chill to the wire. Other suggestions have included reducing the diameter of the wire, or increasing the feed, or sliding the wire along the work surface to provide more chill to the wire through such surface. Such methods

have been found to be only partially successful, and undesirable.

According to one aspect of the invention there is provided a method for applying filler material to a workpiece in which an end of a filler wire of the filler material is melted by a heating torch means providing a heating/molten pool region and the melted filler material is deposited on the workpiece, comprising; feeding the filler wire through a cooling member, separate from the heating torch means, into the heating/molten pool region in a reciprocating manner at a rate of 2—30 cycles per second, alternately to withdraw from and to insert into said region the end of the wire, the end, when withdrawn, being cooled by the cooling member thereby melting the end of the wire intermittently. In a more specific form, the heating pool in generated from an electric arc between an electrode and the workpiece while providing relative surface transverse motion between the workpiece and the electrode, during which the filler material is melted and added to the molten pool as described above.

The invention also provides apparatus for applying filler material to a workpiece, the apparatus including heating torch means, means to direct heating torch means toward a surface of the workpiece to provide a heating/molten pool region and filler wire feed means to feed an end of the filler wire toward said region, the filler wire feed means being provided with a wire cooling member, separate from the heating torch means, through which cooling member the end of the filler wire is fed, and feed varying means acting on the feed means to cause reciprocation of the filler wire at a rate of 2—30 cycles per second alternately to withdraw from and insert into said region the end of the wire while maintaining a net positive feed, the cooling member being positioned with respect to the end of the wire such that, when withdrawn, the end of the wire is cooled by the cooling member thereby to melt the end of the wire intermittently. The apparatus may include means to provide relative surface traversing motion between the heating torch means and a surface

of the workpiece. In one specific form, the filler feed means includes feed drive rolls the direction of rotation of which are reversed from the forward feed direction in a manner in which the forward wire feed distance is always greater than the reverse direction. In another form, the feed means comprises a flexible feed wire guide conduit between constant forward rotation feed rolls and a feed nozzle, the flexible conduit being moved in a reciprocating manner, such as through the use of an eccentric controlled by a motor to provide reciprocating motion to the feed wire.

The invention will now be described in greater detail by way of example with reference to the accompanying drawings, wherein:

Figure 1 is a partially sectional, diagrammatic view of one form of the apparatus associated with the present invention;

Figures 2 and 3 are fragmentary diagrammatic views of alternate positions of the filler wire used in the present invention, within and out of the electric arc/molten weld pool region.

In order to avoid the undesirable, melted accumulation of filler wire material on the end introduced into a heating/weld pool region, the wire end is intermittently thrust or 'dabbed' into and out of such region. As the filler wire is removed from the region, it is cooled sufficiently by a cooling member constituted by a feed nozzle to avoid premature melting and formation of a droplet on its end. Upon reinsertion into the region, which is adjacent or within the electric arc drawn between the electrode and the workpiece, the weld pool, or both, the filler wire again is melted and deposits filler material as desired. The reciprocating movement of the filler wire is repeated continuously at the rate of 2 to 30 cycles per second, to result in a uniform, reproducible deposition of filler material. If higher welding currents are used, the feed nozzle can be adapted to include a cooling means for further chill, for example through the use of a water-cooled jacket around the feed nozzle.

One embodiment of the apparatus associated with the present invention is shown in the partially sectional, diagrammatic view of Fig. 1. Workpiece 10 represents a variety of articles on which it is common practice in the welding art to use the combination of a welding electrode and a filler wire for such purposes as joining members together, build-up of worn surfaces, etc. In the gas turbine engine art, such members frequently are of a material based on such elements as Fe, Co, Ni and Ti. In the particular embodiment more widely evaluated in connection with the present invention, workpiece 10 represents, diagrammatically, a gas turbine engine labyrinth-type seal at least one tooth of which

requires repair through the addition of material for build-up of the tooth area.

Cooperating with workpiece 10 in Fig. 1 is an electrode 12, generally of the non-consumable type, although consumable electrodes can be used as well. An electric arc 14 is drawn between electrode 12 and workpiece 10 through the use of welding current generators of the type commonly used in the art and represented in Fig. 1 by the negative (—) and the positive (+) signs. It should be understood that plasma-type apparatus can be used as a heating torch to provide the necessary heat.

A filler wire feed means or assembly, shown generally at 16 in Fig. 1, delivers a filler wire 18 from a wire source (not shown) through feed rolls 20 and feed nozzle 22 ultimately to weld pool 24 produced on workpiece 10 as a result of electric arc 14 generated between the workpiece 10 and electrode 12. Thus there is defined a heating/molten pool region, in this example an electric arc/weld pool region, shown generally at 23. As is familiar to those skilled in the art, workpiece 10 or the combination of feed nozzle 22 and electrode 12 can be moved or positioned relative one to the other in a variety of ways. For example, it is common practice to use a wire feed accessory manipulator clamped to apparatus which carries electrode 12, to provide a unit, sometimes referred to as a "heating torch means" or a "welding torch", represented by unit 25 in Fig. 1. Such an assembly generally includes means to position feed nozzle 22 in a variety of ways in respect to electrode 12.

One form of the apparatus associated with the present invention to enable practice of its method is disposed, in the embodiment shown in Fig. 1, between feed rolls 20 and feed nozzle 22. Such apparatus includes a flexible feed wire guide conduit 26 which carries filler wire 18 and which is disposed along an arcuate path between feed rolls 20 and feed nozzle 22. The reciprocating motion, represented by double-headed arrow 27 and provided to filler wire 18 as it is displaced generally forwardly toward weld pool 24, i.e. at a net positive feed, is accomplished by applying force at end 28 of conduit 26 which results in conduit 26 changing radius as shown in phantom in Fig. 1. Such displacement or change in radius occurring at the rate of 2—30 times per second, during operation of feed rolls 20 moves filler wire 18 into and out of electric arc/weld pool region 23.

The reciprocating movement of wire 18 can be accomplished in a variety of ways, for example through the use of a cable associated with an eccentric controlled by a motor operating against a biasing means such as spring 30 to produce reciprocating motion. Change in the curvature of the arcuate path or friction between flexible conduit 26

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and filler wire 18, or both, are believed to provide reciprocal motion 27 to filler wire 18. However, it should be understood that a variety of means can be used to bring about such reciprocating or pulsing movement to filler wire 18 superimposed upon its forward movement weld pool 24. For example feed rolls 29 can be periodically reversed in their normal forward direction which is shown by their direction movement arrows in Fig. 1, with the reverse movement being somewhat less than the forward movement. This provides a reciprocating, varying feed rate to filler wire 18 in a manner which displaces the filler wire forward toward the electric arc/weld pool region while at the same time providing it with such reciprocating motion. In another embodiment, such pulsing can be accomplished by a stepping motor with reverse and forward motion, the forward motion being selected to be greater than the reverse motion to "dab" the filler wire into such region.

The apparatus is provided with relative surface traversing motion as indicated diagrammatically by arrows 29. Such motion can be provided by movement of the workpiece, the heating means, or both.

As was indicated before, the constant, direct feed of a filler wire, such as 18, into an electric arc/weld pool region can result in overheating of the wire and premature melting despite the proximity of the weld wire to a feed nozzle such as 22. According to the present invention, such premature melting and accompanying accumulation of droplets on the wire are avoided by reciprocating or pulsing the movement of filler wire 18, as it is fed into the electric arc/weld pool region between the positions shown in Figs. 2 and 3. In Fig. 2, arrow 27a represents the forward motion; in Fig. 3, arrow 27b represents the smaller reverse motion.

Through practice of the present invention, it has been found that the angle of entry of filler wire 18 into the weld pool can be increased from the normal 15° angle to as high as 90° without causing accumulation or droplet problems. Using the prior art methods and apparatus, it has been recognized that at entry angles of between about 15 and 20°, globules begin to form on the end of the wire. In addition, because the apparatus of the present invention can be adapted to move the welding electrode and the filler wire feed nozzle in a variety of directions and positions, wider gaps between members to be processed can be filled. Also, the present invention enables more accurate quality control of the weld pool and the resultant weld build-up through the pulse synchronization of the present invention. Further, operations such as braze can be accomplished using high electric current close to the workpiece. In such a case, it is generally desirable to water cool feed

nozzle 22, such as through the use of water jacket.

In the evaluation of the present invention, reciprocating motion of the filler wire has been evaluated at least up to about 30 cycles per second. Above that rate, vibrations tend to increase to an unsatisfactory level. Below about 2 cycles per second, instability tends to increase. Therefore, it has been found that about 5—15 cycles per second and generally about 8—10 cycles per second are sufficient. Through practice of the present invention, successful butt welds have been made at the rate of up to about 40 inches per minute without undercut.

In one specific example, a gas turbine engine knife edge seal of about 0.03¹¹ thick of a titanium alloy comprising nominally, by weight, about 6% Al, 4% V with the balance Ti, sometimes referred to as Ti-6-6 alloy, was repaired using the present invention. Although filler wire of that same titanium-base alloy and having a diameter of about 0.03¹¹ normally is used in such a repair operation, through practice of the present invention, a larger, less expensive wire, in this example 0.045¹¹ Ti-6-4 alloy was used and easily controlled in the gas tungsten arc welding method well known in the art, using a thoriated tungsten non-consumable electrode. Although the positive wire feed rate has been evaluated in the range of from about 2 inches per minute to about 25 inches per minute, this example used a positive feed rate of about 3—4 inches per minute with a reciprocating rate of about 8 cycles per second. Weld additions as high as about 0.15¹¹ have been accomplished in about 7 passes of the combination electrode/filler wire feed system over the workpiece surface. Through coordination of the feed wire movement and the movement of the electrode, a weld pool can be created prior to introduction of the filler material, in the sequential movement of the combination over the surface of a workpiece.

Other articles such as gas turbine engine seals made of commercially available nickel-base superalloys, for example Inco 718 alloy, have been repaired in a similar manner using nickel-based filler wire. This is representative of the repair of typical gas turbine engine articles made of alloys based on Fe, Co or Ni using compatible filler wire, as with the Ti-base alloy articles above.

Thus, the present invention provides significant advantages over prior methods and apparatus. For example, filler wire or ribbon addition is more uniform. Also, deeper penetration with narrower welds results because the welding arc can be used to first melt the workpiece metal without the intervening effect of the filler. Then, after proper heating of the base metal, filler material can be added to achieve reinforcement. The result of practice of the method of the present invention results

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in less shrinkage, lower distortion, higher welding speeds and more uniform welds. A further advantage is that the filler wire can be fed vertically or at very steep angles, thus permitting better access and welding in any direction without the necessity of swivelling the feed nozzle in the direction of the seam being produced. As was indicated before, larger diameter, less expensive filler wire can be used. Because the present invention provides increased control of penetration and fusion, semi-automatic welding of joints can be accomplished with variable gaps.

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10 By modifying such variables as filler wire stroke length, forward dwell time, retract dwell time, transit velocity and nozzle proximity to the tip of the wire in the various positions, melting of the filler wire can be varied over a range from solid to near liquid when the top of the filler wire enters the weld pool. Through similar controls, it is possible according to the present invention to braze weld by melting filler of a lower melting point without melting the base metal and still achieving a sound bond. As will be appreciated by those skilled in the art, the reciprocating, "dabbing" function of the present invention can be used with both cold and hot wire feed systems and with such methods as the gas tungsten arc and plasma welding processes. If further control is desired, melting of the wire can be controlled by synchronizing the weld current level to the filler wire position. By pulsing the current upward while the wire is retracted, less heating of the wire will occur. Since the variables can be adjusted such that the filler wire can enter the weld pool at a lower current level, heat from the pool itself will provide the energy to melt the filler wire and in so doing will help solidify and control the weld pool temperature, shape and fluidity. Thus, although the present invention has been described in connection with specific examples and embodiments, it will be recognized by those skilled in the art the wide variety of variations and modifications of which the present invention is capable without varying from its scope. It is intended to include within the scope of the appended claims such variations and modifications.

WHAT WE CLAIM IS:—

55 1. A method for applying filler material to a workpiece in which an end of a filler wire of the filler material is melted by a heating torch means providing a heating/molten pool region and the melted filler material is deposited on the workpiece, comprising:
60 feeding the filler wire through a cooling member, separate from the heating torch means, into the heating/molten pool region in a reciprocating manner at a rate of 2—30 cycles per second, alternately to withdraw

from and to insert into said region the end of the wire, the end, when withdrawn, being cooled by the cooling member thereby melting the end of the wire intermittently.

2. The method of claim 1 in which the heating torch means includes an electrode which generates an electric arc for the provision of heat and the cooling member is associated with a wire feed nozzle to cool the feed nozzle, including providing relative surface traversing motion between the heating torch means and the workpiece; while feeding the filler wire through the cooled feed nozzle and into the heating/molten pool region in the reciprocating manner during the traversing motion.

3. The method of claim 2 in which, the filler wire is of a material based on an element selected from the group consisting of Fe, Co, Ni and Ti; the electric arc is generated between a non-consumable electrode and the workpiece to provide an electric arc/molten pool region; and the filler wire is reciprocated into and from said region at the rate of 5—15 cycles per second.

4. Apparatus for applying filler material to a workpiece, the apparatus including heating torch means, means to direct the heating torch means toward a surface of the workpiece to provide a heating/molten pool region, and filler wire feed means to feed an end of the filler wire toward said region, the filler wire feed means being provided with a wire cooling member, separate from the heating torch means, through which cooling member the end of the filler wire is fed, and feed varying means acting on the feed means to cause reciprocation of the filler wire at a rate of 2—30 cycles per second alternately to withdraw from and insert into said region the end of the wire while maintaining a net positive feed, the cooling member being positioned with respect to the end of the wire such that, when withdrawn, the end of the wire is cooled by the cooling member thereby to melt the end of the wire intermittently.

5. The apparatus of claim 4 in which the filler wire feed means includes wire feed rolls, and in which apparatus means rotates the feed rolls alternatively in the forward feed and in the reverse feed directions, the forward feed being greater than the reverse feed to provide a net positive feed to feed the end of the filler wire toward the heating/molten pool region, and a fluid/cooled wire feed nozzle to direct the filler wire toward said region.

6. The apparatus of claim 5 including in addition, means to provide relative surface traversing motion between the heating torch means and the workpiece surface to move the heating/molten pool region along said surface.

7. A method substantially as herein-



in less shrinkage, lower distortion, higher welding speeds and more uniform welds. A further advantage is that the filler wire can be fed vertically or at very steep angles, thus permitting better access and welding in any direction without the necessity of swivelling the feed nozzle in the direction of the seam being produced. As was indicated before, larger diameter, less expensive filler wire can be used. Because the present invention provides increased control of penetration and fusion, semi-automatic welding of joints can be accomplished with variable gaps.

By modifying such variables as filler wire stroke length, forward dwell time, retract dwell time, transit velocity and nozzle proximity to the tip of the wire in the various positions, melting of the filler wire can be varied over a range from solid to near liquid when the top of the filler wire enters the weld pool. Through similar controls, it is possible according to the present invention to braze weld by melting filler of a lower melting point without melting the base metal and still achieving a sound bond. As will be appreciated by those skilled in the art, the reciprocating, "dabbing" function of the present invention can be used with both cold and hot wire feed systems and with such methods as the gas tungsten arc and plasma welding processes. If further control is desired, melting of the wire can be controlled by synchronizing the weld current level to the filler wire position. By pulsing the current upward while the wire is retracted, less heating of the wire will occur. Since the variables can be adjusted such that the filler wire can enter the weld pool at a lower current level, heat from the pool itself will provide the energy to melt the filler wire and in so doing will help solidify and control the weld pool temperature, shape and fluidity. Thus, although the present invention has been described in connection with specific examples and embodiments, it will be recognized by those skilled in the art the wide variety of variations and modifications of which the present invention is capable without varying from its scope. It is intended to include within the scope of the appended claims such variations and modifications.

WHAT WE CLAIM IS:—

1. A method for applying filler material to a workpiece in which an end of a filler wire of the filler material is melted by a heating torch means providing a heating/molten pool region and the melted filler material is deposited on the workpiece, comprising: feeding the filler wire through a cooling member, separate from the heating torch means, into the heating /molten pool region in a reciprocating manner at a rate of 2—30 cycles per second, alternately to withdraw

from and to insert into said region the end of the wire, the end, when withdrawn, being cooled by the cooling member thereby melting the end of the wire intermittently.

2. The method of claim 1 in which the heating torch means includes an electrode which generates an electric arc for the provision of heat and the cooling member is associated with a wire feed nozzle to cool the feed nozzle, including providing relative surface traversing motion between the heating torch means and the workpiece; while feeding the filler wire through the cooled feed nozzle and into the heating/molten pool region in the reciprocating manner during the traversing motion.

3. The method of claim 2 in which, the filler wire is of a material based on an element selected from the group consisting of Fe, Co, Ni and Ti; the electric arc is generated between a non-consumable electrode and the workpiece to provide an electric arc/molten pool region; and the filler wire is reciprocated into and from said region at the rate of 5—15 cycles per second.

4. Apparatus for applying filler material to a workpiece, the apparatus including heating torch means, means to direct the heating torch means toward a surface of the workpiece to provide a heating/molten pool region, and filler wire feed means to feed an end of the filler wire toward said region, the filler wire feed means being provided with a wire cooling member, separate from the heating torch means, through which cooling member the end of the filler wire is fed, and feed varying means acting on the feed means to cause reciprocation of the filler wire at a rate of 2—30 cycles per second alternately to withdraw from and insert into said region the end of the wire while maintaining a net positive feed, the cooling member being positioned with respect to the end of the wire such that, when withdrawn, the end of the wire is cooled by the cooling member thereby to melt the end of the wire intermittently.

5. The apparatus of claim 4 in which the filler wire feed means includes wire feed rolls, and in which apparatus means rotates the feed rolls alternatively in the forward feed and in the reverse feed directions, the forward feed being greater than the reverse feed to provide a net positive feed to feed the end of the filler wire toward the heating/molten pool region, and a fluid/cooled wire feed nozzle to direct the filler wire toward said region.

6. The apparatus of claim 5 including in addition, means to provide relative surface traversing motion between the heating torch means and the workpiece surface to move the heating/molten pool region along said surface.

7. A method substantially as herein-

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before described with reference to the accompanying drawings.

8. Apparatus for applying filler material to a workpiece with reference to and as
5 illustrated in the accompanying drawing.

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