[00021] HAZ cracking in Inconel 738 was related to an incipient melting of low temperature eutectics, carbides and other precipitations along grain boundaries during welding followed by a propagation of cracks due to high level of residual tensile stresses into the HAZ. Lack of low temperature eutectics and rapid cooling did not allow full crack back filling during welding as was shown by Alexandrov B.T., Hope A.T., Sowards J.W., Lippold J.C., and McCracken S.S, in the publication titled: Weldability Studies of High-Cr, Ni-base Filler Metals for Power Generation Applications, Welding in the World, Vol. 55, n. 3/4, pp. 65 – 76, 2011 (Doc. IIW-2111, ex Doc. IX-2313 -09).

[00022] The post weld heat treatment (PWHT) of these welds resulted in an additional strain-aging cracking in the HAZ. Some cracks propagated into the welds.

[00023] Therefore, currently only preheating to temperatures exceeding 900° C allows crack free welding on Inconel 738, Inconel 713, GDT 111, GDT 222, Rene 80, Mar M247 and other precipitation hardening polycrystalline and directionally solidified high gamma-prime superalloys, as well as Mar M 247, Rene 80, CMSX 4, CMSX 10, Rene N5 and other single crystal materials.

[00024] However, preheating of turbine engine components prior to welding increases the cost and reduces the productivity of welding operations.

[00025] ~~Therefore, one of major objectives~~ Embodiments of the present invention ~~is~~ disclose the development of a new cost effective method for welding and cladding on polycrystalline, directionally

solidified and single crystal superalloys at an ambient temperature that will allow self healing of cracks during welding and post weld heat treatment.

[00021] ~~Additionally it is another objective~~Embodiments of the present invention seek to develop parameters for a post weld heat treatment (PWHT) for the self healing of cracks during a PWHT.

Brief Description of the Invention

According to an aspect of the present invention, there is provided a method of cladding and fusion welding of superalloys comprises the steps of: application of a composite filler powder that comprises 5-50% by weight brazing powder which includes melting point depressants, and 50-95% by weight high temperature welding powder, to a superalloy base material; simultaneous heating of the base material and the composite filler powder by a welding heat source that is movable relative to the base material, to a temperature that fully melts the brazing powder and at least partially melts the high temperature welding powder and also melts a surface layer of the base material, thereby forming a welding pool; cooling of the welding pool with a sufficient speed such that upon solidification and cooling, a composite structure that comprises an interconnected framework of high melting temperature dendrites produced by the high temperature welding powder and an interdendritic eutectic matrix in the weld bead is formed by the brazing powder and the welding powder and the base material; and post weld heat treatment at a temperature exceeding a solidus temperature of the brazing powder and below a solidus temperature of the high temperature welding powder, that results in at least a partial re-melting of the eutectic that fills cracks in the weld bead and the base material by capillary action followed by cooling and consolidation of the weld bead.

~~The~~An embodiment of the method of cladding and fusion welding includes the steps of an application of a composite filler powder containing 5-50% brazing powder

and 50-95% high temperature welding powder to a base material and simultaneously heating the base material and a composite filler powder by a local welding heat source. The filler powder is heated to a temperature that will fully melt the brazing powder and at least partially melt the high temperature welding powder and also a surface layer of the base material producing a heterogeneous or homogeneous welding pool depending on welding parameters followed by a subsequent solidification and cooling of a weld pool forming a heterogeneous weld bead comprising of a continuous interconnected framework of high temperature dendrites and interdendritic eutectics matrix. This matrix, together with a post weld heat treatment at a temperature exceeding the solidus temperature of the brazing powder but below of the solidus temperature of the base material allows self healing of cracks by capillary forces, while the weld bead geometry is supported by the continuous interconnected framework of dendrites produced by the high temperature welding powder.

[00028] The article repaired using the ~~preferable~~ embodiment comprises an originally manufactured defect free base material with a damaged area being removed prior to a repair and replaced with the composite weld material comprising of a continuous framework of a high temperature dendrites produced during solidification of a welding pool and a braze based matrix containing melting point depressants.

[00029] To ensure required chemical composition and microstructure of welds the welding pool during welding is heated to a temperature exceeding the melting temperature of the brazing powder but below approximately 1.2 times the melting temperature of the high temperature welding powder using one or more passes depending on the required size of the weld build up.

[00030] In accordance with other ~~preferable~~ embodiments the crack healing is made by local heating of the weld bead using a welding source preferably in a combination with a full heat treatment of the article at a temperature below the solidus temperature of the brazing powder but above 500° C allowing at least a partial stress relief of the base material.

[00031] As per another embodiment to ensure crack healing a post weld heat treatment is made within a solidus liquidus range of a weld bead material but below the solidus temperature of the high temperature welding powder. The solidus liquidus range is found by an experiment.

[00032] Welding results in the accumulation of residual stresses while crack healing during high temperature heat treatment reduces mechanical properties of a base material. Therefore, further embodiments of the current invention based on performance requirements

of base materials and service conditions may include annealing, aging or combination of annealing followed by aging.

[00033] Aiming to reduce distortion, residual stresses and cold cracking in accordance with the another embodiment the post weld heat treatment is made after application of 2 – 10 weld passes.

[00034] Welding as per the ~~preferable~~ embodiment is made either using premixed brazing and welding powders with the required ratio using one powder hopper or mixing these powders during heating with welding sources using two separate powder hoppers. The welding sources are selected among laser, electron beam, electric arc or plasma.

[00035] Due to improve weldability depending on chemical composition and condition of the base material, the article prior to welding is subjected to a stress relief, aging or annealing heat treatment.

[00036] In accordance with the ~~preferable~~ embodiment crack free welds are produced for example when the ratio of the welding pool length to the welding speed is 0.002 – 0.02.

[00037] Repair of an article by welding can be made at an ambient temperature without preheating of the base material or with the preheating of the article to a required temperature using similar welding powder with approximately the same chemical composition as the base material, or with a dissimilar welding powder with a different composition as the base material and brazing powders which include from 1 to 10 wt. % of Si or from 0. 2 to 4 wt.% of B or mixture of Si and B as a melting temperature depressants from 1.2 to 10 wt.% with a total content of B not more than 4 wt.%

[00038] In other ~~preferable~~ embodiments the composite welding materials includes high temperature welding powder and brazing powder is used to produce a buttering pass followed by welding using a high temperature welding powder to produce a weld build up with the required geometry.

[00039] ~~The invented~~Embodiments of the method can be used for joining of at least two articles, manufacturing, repair and dimensional restoration of structural components, casings, nozzle guide vanes, compressor and turbine blades manufactured of polycrystalline, directionally solidified, single crystal and composite materials.

[00040] The following advantages were observed.

[00041] ~~This~~An embodiment of the method has been found to produce crack free welds at ambient temperature on most polycrystalline, directionally solidified and single crystal superalloys with a high content of gamma-prime phase and carbon, reducing the cost, increasing productivity and improving the health and safety of the work conditions.

[00042] ~~The~~An embodiment of the method results in formation of a heterogeneous composite weld bead structure consisting of a continuous framework of a high temperature and high strength dendrites and a ductile matrix. This produces weld beads with mechanical properties and oxidation resistance exceeding properties of brazed and classical homogenous welded joints.

[00043] The formation of the heterogeneous composite structure in welds produced using optimized welding parameters occurs despite the melting of brazing and welding powders and base material within the same welding pool.

[00044] Welds deposited by an embodiment of this method exhibit self healing of cracks during a post weld heat treatment eliminating necessity of costly rework.

[00045] They also exhibit superior oxidation resistance that exceeds the oxidation resistance of base and high temperature welding materials.

[00046] Advantageously there is also a wide window of optimal welding parameters that simplify process control.

[00047] ~~The present concept~~Disclosed herein is a method of cladding and fusion welding of superalloys comprises the steps of:

a) application of a composite filler powder that comprises 5-50% by weight brazing powder which includes melting point depressants, and 50-95% by weight high temperature welding powder, to a superalloy base material;

b) simultaneous heating of the base material and the composite filler powder by a welding heat source that is movable relative to the base material, to a temperature that will fully melt the brazing powder and at least partially melt the high temperature welding powder and also melt a surface layer of the base material, thereby forming a weld pool;

c) such that upon solidification and cooling of the weld pool, there is coalescence between a weld bead and the base material.

[00048] ~~Preferably wherein~~In an embodiment, the method of welding is applied to an article consisting of the base material, and further includes the step selected from among, joining articles together, cladding the article for dimensional restoration, manufacturing the article and repair of the article.

[00049] ~~Preferably such that~~In an embodiment, upon solidification and cooling, a composite structure in the weld bead is formed that comprises an interconnected framework of high melting temperature dendrites and an interdendritic eutectic matrix.

[00050] ~~Preferably such that~~In an embodiment, upon heating a heterogeneous weld pool forms.

[00051] ~~Preferably such that~~In an embodiment, upon heating a homogenous weld pool forms.

[00052] ~~Preferably further including~~An embodiment further includes the step of a post weld heat treatment.

[00053] ~~Preferably wherein~~In an embodiment, a post weld heat treatment is made at a temperature exceeding a solidus temperature of the brazing powder and below the solidus temperature of the high temperature welding powder, wherein at least a partial re-melting of the matrix and a filling of cracks with the eutectic by a capillary action occurs.

[00021] ~~Preferably wherein~~In an embodiment, the post weld heat treatment is made at a temperature below the solidus temperature of the brazing powder but above 500° C such that at least a partial stress relief of the weld bead and the base material occurs.

[00022] ~~Preferably wherein~~In an embodiment, the post weld heat treatment is made locally by a heating of the weld bead by the welding heat source.

[00023]

BRIEF DISCRIPTION DRAWINGS

[00024] FIGURE 1 is the micrograph of cross (a) and longitudinal (b) sections of Mar M247 – AWS A5.8 BNi-9 clad welds produced on Inconel 738 using micro plasma welding after heat treatment.

[00025] FIGURE 2 is the typical macrostructure of three pass laser beam clad weld (LBW) made on Inconel 738 with Inconel 738 - AWS A5.8 BNi-9 filler material, wherein (a) - longitudinal samples in as welded condition, (b) - longitudinal samples after heat treatment (b).

[00026] FIGURE 3 depicts the microstructure of the crack healing in the HAZ prior to a heat treatment (a) and macro structure of the three passes clad weld after PWHT at 1200° C (b).

Claims:

1. A method of cladding and fusion welding of superalloys comprises the steps of:

   a. application of a composite filler powder that comprises 5-50% by weight brazing powder which includes melting point depressants, and 50-95% by weight high temperature welding powder, to a superalloy base material;

   b. simultaneous heating of the base material and the composite filler powder by a welding heat source that is movable relative to the base material, to a temperature that fully melts the brazing powder and at least partially melts the high temperature welding powder and also melts a surface layer of the base material, thereby forming a welding pool;

   c. cooling of the welding pool with a sufficient speed such that upon solidification and cooling, a composite structure that comprises an interconnected framework of high melting temperature dendrites produced by the high temperature welding powder and an interdendritic eutectic matrix in the weld bead is formed by the brazing powder and the welding powder and the base material; and

   d. post weld heat treatment at a temperature exceeding a solidus temperature of the brazing powder and below a solidus temperature of the high temperature welding powder, that results in at least a partial re-melting of the eutectic that fills cracks in the weld bead and the base material by capillary action followed by cooling and consolidation of the weld bead.

2. Method of cladding and fusion welding as per claim 1, wherein the ratio of the length of the welding pool to the welding speed is selected to fall between 0.002 - 0.02.

3. Method of cladding and fusion welding as per claim 1, wherein the brazing powder is fully melted while the high temperature welding powder is heated to a temperature below its liquidus temperature.

4. Method of cladding and fusion welding as per claim 1, wherein the composite filler powder is heated during welding by the heat source to a temperature exceeding the melting temperature of the brazing powder but below 1.2 times the melting temperature of the high temperature welding powder.

5. Method of cladding and fusion welding as per claim 3, wherein the composite filler powder is heated during welding by the heat source to a temperature exceeding the melting temperature of the brazing powder but below 1.2 times the melting temperature of the high temperature welding powder.

6. Method of cladding and fusion welding as per claim 1, wherein the high temperature welding powder consists of in wt. % the following chemical elements:

Co 9-15%;

Al 3-6.5%;

C 0.1-0.2%;

Ti, Zr and Hf with a total content from 1 to 8.5%;

Ta and Nb with a total content from 0.5 to 8.5%;

W and Mo with a total content from 7 to 20 %;

Cr and Re with a total content from 6.5 to 18.5 %;

Fe and Mn with a total content from 0.1 to 1 %;

Ni and impurities to balance.

7. Method of cladding and fusion welding as per claim 1 wherein the post weld heat treatment includes an additional second step of an aging heat temperature of the base material.

8. Method of cladding and fusion welding as per claim 1, wherein the melting point depressant in the brazing powder consists of Si in the amount of approximately 1 to 10 weight % of the brazing powder.

9. Method of cladding and fusion welding as per claim 1, wherein the melting point depressant in the brazing powder consists of B in the amount of approximately 0.2 to 4 weight % of the brazing powder.

10. Method of cladding and fusion welding as per claim 1, wherein the melting point depressant in the brazing powder consists of a preselected mixture B and Si in the amount of approximately 1.2 to 10 weight % of the brazing powder wherein the B content remains less than approximately 4 weight %.

Claims:

1. A method of cladding and fusion welding of superalloys comprises the steps of:

   a) application of a composite filler powder that comprises 5-50% by weight brazing powder which includes melting point depressants, and 50-95% by weight high temperature welding powder, to a superalloy base material;
   b) simultaneous heating of the base material and the composite filler powder by a welding heat source that is movable relative to the base material, to a temperature that will fully melt the brazing powder and at least partially melt the high temperature welding powder and also melt a surface layer of the base material, thereby forming a weld pool;
   c) such that upon solidification and cooling of the weld pool, there is coalescence between a weld bead and the base material.

2. The method of cladding and fusion welding as per claim 1 wherein the method of welding is applied to an article consisting of the base material, and further includes the step selected from among, joining articles together, cladding the article for dimensional restoration, manufacturing the article and repair of the article.

3. The method of cladding and fusion welding as per claim 1 such that upon solidification and cooling, a composite structure in the weld bead is formed that comprises an interconnected framework of high melting temperature dendrites and an interdendritic eutectic matrix.

4. The method of cladding and fusion welding as per claim 1 such that upon heating a heterogeneous weld pool forms.

5. The method of cladding and fusion welding as per claim 1 such that upon heating a homogenous weld pool forms.

6. The method of cladding and fusion welding as per claim 1further including the step of a post weld heat treatment.

7. Method of cladding and fusion welding as per claim 1 and 3, wherein a post weld heat treatment is made at a temperature exceeding a solidus temperature of the brazing powder and below the solidus temperature of the high temperature welding powder, wherein at least a partial re-melting of the matrix and a filling of cracks with the eutectic by a capillary action occurs.

8. Method of cladding and fusion welding as per claim 6, wherein the post weld heat treatment is made at a temperature below the solidus temperature of the brazing powder but above 500° C such that at least a partial stress relief of the weld bead and the base material occurs.

9. Method of cladding and fusion welding as per claim 6, wherein the post weld heat treatment is made locally by a heating of the weld bead by the welding heat source.

10. Method of cladding and fusion welding as per claim 6, wherein the post weld heat treatment is made at an annealing temperature of the base material.

11. Method of cladding and fusion welding as per claim 6 wherein the post weld heat treatment is made at an aging temperature of the base material.

12. Method of cladding and fusion welding as per claim 6, wherein the post weld heat treatment comprises annealing followed by aging heat treatments.

13. Method of cladding and fusion welding as per claim 6, wherein the post welding heat treatment is made in the solidus to liquidus range of the weld bead material but below the solidus temperature of the high temperature welding powder.

14. Method of cladding and fusion welding as per claim 13, wherein the solidus to liquidus range of the weld bead material is found by an experiment.

15. Method of cladding and fusion welding as per claim 1, wherein the composite filler powder is heated during welding by the heat source to a temperature exceeding the melting temperature of the brazing powder but below 1.2 times the melting temperature of the high temperature welding powder.

16. Method of cladding and fusion welding as per claim 1, wherein the application of the composite welding powder to the base material is made using at least two consecutive passes.

17. Method of cladding and fusion welding as per claim 6, wherein the post weld heat treatment is made after the application of at least two weld passes.

18. Method of cladding and fusion welding as per claim 1, wherein the brazing and welding powders are fully melted prior to solidification and cooling.

19. Method of cladding and fusion welding as per claim 1, wherein the brazing powder is fully melted while the high temperature welding powder is heated to a temperature below its liquidus temperature.

20. Method of cladding and fusion welding as per claim 1, prior to the heating step, further including the step of premixing a preselected ratio of the brazing powder and the high temperature welding powder, and further feeding the premixed powders into the weld pool from a single powder hopper.

21. Method of cladding and fusion welding as per claim 1, further including the step of mixing the brazing powder and the high temperature welding powder during the heating step just prior to entering into the weld pool and further feeding the powders into the weld pool from at least two powder hoppers.

22. Method of cladding and fusion welding as per claim 1, wherein the ratio of the length of the weld pool to the welding speed is selected to fall between 0.002 - 0.02.

23. Method of cladding and fusion welding as per claim 1, further including the step of an annealing heat treatment which is carried out prior to welding.

24. Method of cladding and fusion welding as per claim 1, further including the step of a stress relief heat treatment which is carried out prior to welding.

25. Method of cladding and fusion welding as per claim 1, further including the step of aging is which carried out prior to welding.

26. Method of cladding and fusion welding as per claim 1, wherein the melting point depressant consists of Si in the amount of approximately 1 to 10 weight % of the brazing powder.

27. Method of cladding and fusion welding as per claim 1, wherein the melting point depressant consists of B in the amount of approximately 0.2 to 4 weight % of the brazing powder.

28. Method of cladding and fusion welding as per claim 1, wherein the melting point depressant consists of a preselected mixture B and Si in the amount of approximately 1.2 to 10 weight % of the brazing powder wherein the B content remains less than approximately 4 weight %.

29. Method of cladding and fusion welding as per claim 1, wherein the high temperature welding powder is selected from among nickel based alloys, nickel based superalloys, cobalt based alloys, cobalt based superalloys, iron based alloys, and iron based superalloys.

30. Method of cladding and fusion welding as per claim 1 and 29, wherein the high temperature welding powder consists of in wt. % the following chemical elements:

Co 9 – 15%;

Al 3-6.5%;

C 0.1 – 0.2%;

Ti, Zr and Hf with a total content from 1 to 8.5%;

Ta and Nb with a total content from 0.5 to 8.5%;

W and Mo with a total content from 7 to 20 %;

Cr and Re with a total content from 6.5 to 18.5 %;

Fe and Mn with a total content from 0.1 to 1 %;

Ni and impurities to balance.

31. Method of cladding and fusion welding as per claim 1, wherein the high temperature welding powder has approximately the same composition as the base material.

32. Method of cladding and fusion welding as per claim 1, wherein the high temperature welding powder has a different composition than the base material.

33. Method of cladding and fusion welding as per claim 1, wherein the welding heat source is selected from among laser beam, electron beam, electric arc, and plasma.

34. Method of cladding and fusion welding as per claim 1, wherein the composite filler powder is used to produce a buttering welding pass only.

35. Method of cladding and fusion welding as per claim 1, wherein the welding is carried out at an ambient temperature without preheating of the base material.

36. Method of cladding and fusion welding as per claim 1, wherein prior to welding the base material is preheated to a temperature exceeding the stress relieve temperature but below of the solidification temperature of the base material.

37. Method of cladding and fusion welding as per claim 2, wherein the article is a turbine blade.

38. Method of cladding and fusion welding as per claim 37, wherein the material of turbine blade is selected from among a polycrystalline material, a directionally solidified material, and a single crystal material.

39. Method of cladding and fusion welding as per claim 2, wherein the article is selected from among a nozzle guide vane, a structural turbine engine component, a turbine casing, and a compressor blade.

40. Method of cladding and fusion welding as per claim 2, wherein the article is manufactured of a composite material.

41. Method of cladding and fusion welding as per claim 1 further includes the initial step of removing a damaged area from an originally manufactured article which consists of the base material, to carry out repair of the article.