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(54) Title: REPAIR OF SIGMATIZED STAINLESS STEELS

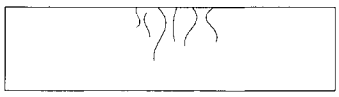

FIG. 1A

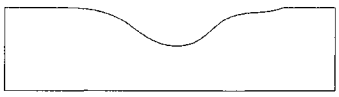

FIG. 1B

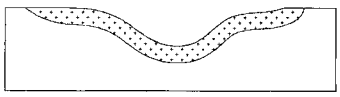

FIG. 1C

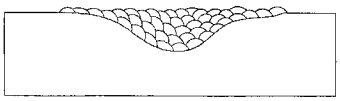

FIG. 1D

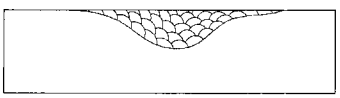

FIG. 1E

(57) Abstract: The present invention relates to compositions and methods for repairing stainless steel, comprising the steps: a) providing a stainless steel body have a body surface, wherein at least a portion of the body surface comprises a surface defect and sigma phase precipitate; b) removing the body surface portion comprising the surface defect to expose a repair zone surface portion; c) heat treating the repair zone surface; d) forming a compressive stress field in the repair zone surface; and e) after forming the compressive stress field, welding a weld repair material to the repair zone surface to form a weld repair

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REPAIR OF SIGMATIZED STAINLESS STEELS

BACKGROUND

[0001] Stainless steels and their welds are known to be susceptible to formation of iron-chromium compound, known as sigma phase embrittlement. These sigma phase precipitates form in stainless steels as a consequence of extended exposure to temperatures between 538°C to 927°C. The adverse effect of sigma phase precipitation is most pronounced once the steel has cooled to temperatures below 260°C, where the alloy can suffer a complete loss of toughness. As a result, sigmatized stainless steels can crack during regular repair procedures such as grinding and re-welding. Moreover, sigma phase precipitation can also lead to reduction in creep and thermal fatigue resistance.

[0002] Currently, many sigma phase problems occur in connection with difficult weld repairs, which are often ultimately unsuccessful. Furthermore, conventional weld repair procedures have limited efficacy and can actually lead to additional defects in the areas adjacent to the repaired area. For example, the aggressive nature of normal grinding and re-welding process can produce residual stresses that lead to the additional damage.

[0003] Accordingly, there remains a need for improved weld repairs and method for repairing stainless steel.

SUMMARY

[0004] In accordance with the purpose(s) of the invention, as embodied and broadly described herein, the invention, in one aspect, relates to a method for repairing stainless steel. In an exemplary aspect, the invention relates to a method comprising the steps: a) providing a stainless steel body have a body surface, wherein at least a portion of the body surface comprises a surface defect and sigma phase precipitate; b) removing the body surface portion comprising the surface defect to expose a repair zone surface portion; c) heat treating the repair zone surface; d) forming a compressive stress field in the repair zone surface; and e) after forming the compressive stress field, welding a weld repair material to the repair zone surface to form a weld repair.

[0005] In another exemplary aspect, the invention relates to a method, comprising the steps: a) providing a stainless steel body have a body surface, wherein at least a portion of the body surface comprises a surface defect and sigma phase precipitate; b) removing the body surface portion comprising the surface defect and sigma phase precipitate to expose a repair zone surface portion; c) forming a compressive stress field in the repair zone surface; d) buttering at least a portion of the repair zone surface; and e) after buttering and after forming the compressive stress field, welding a weld repair material to the repair zone surface to form a weld repair.

[0006] In another exemplary aspect, the invention relates to a stainless steel body repaired by a process comprising: a) removing a portion of a body surface of the stainless steel body to expose a repair zone surface portion; wherein the removed portion comprises a surface defect and sigma phase precipitate; b) heat treating the repair zone surface; c) forming a compressive stress field in the repair zone surface; and d) after forming the compressive stress field, welding a weld repair material to the repair zone surface to form a weld repair.

[0007] In another exemplary aspect, the invention relates to a stainless steel body repaired by a process comprising: a) removing a portion of a body surface of the stainless steel body to expose a repair zone surface portion; wherein the removed portion comprises a surface defect and sigma phase precipitate; b) forming a compressive stress field in the repair zone surface; c) buttering at least a portion of the repair zone surface; and d) after buttering and after forming the compressive stress field, welding a weld repair material to the repair zone surface to form a weld repair.

[0008] In still further aspects, the invention also relates to articles comprising the disclosed repaired stainless steel and methods for repairing stainless steel.

BRIEF DESCRIPTION OF THE FIGURES

[0009] The accompanying figures, which are incorporated in and constitute a part of this specification, illustrate several aspects and together with the description serve to explain the principles of the invention.

[0010] Figure 1 shows a diagram illustrating an exemplary weld repair process according to the present invention. FIG. 1A shows a stainless steel body with damage in the form of

surface defects and sigma phase precipitate. FIG. 1B shows the stainless steel body after removing the damaged body surface portion to expose a repair zone surface portion. FIG. 1C shows the stainless steel body after the repair zone surface has been shot-peened to induce a compressive stress field. FIG. 1D shows the stainless steel body after a weld repair material has been welded to the repair zone surface to form a weld repair. FIG. 1E shows the stainless steel body after smoothing a surface of the weld repair to a uniform surface similar to that of the surrounding surface portion of the stainless steel body.

[0011] Additional advantages of the invention will be set forth in part in the description which follows, and in part will be obvious from the description, or can be learned by practice of the invention. The advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims. It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

DESCRIPTION

[0012] The present invention can be understood more readily by reference to the following detailed description of the invention and the Examples included therein.

[0013] Before the present compounds, compositions, articles, systems, devices, and/or methods are disclosed and described, it is to be understood that they are not limited to specific synthetic methods unless otherwise specified, or to particular reagents unless otherwise specified, as such may, of course, vary. It is also to be understood that the terminology used herein is for the purpose of describing particular aspects only and is not intended to be limiting. Although any methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, example methods and materials are now described.

[0014] All publications mentioned herein are incorporated herein by reference to disclose and describe the methods and/or materials in connection with which the publications are cited. The publications discussed herein are provided solely for their disclosure prior to the filing date of the present application. Nothing herein is to be construed as an admission that the present invention is not entitled to antedate such publication by virtue of prior invention.

Further, the dates of publication provided herein can be different from the actual publication dates, which can require independent confirmation.

A. Definitions

[0015] As used in the specification and the appended claims, the singular forms "a," "an" and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "a weld material," includes mixtures of two or more such weld materials, and the like.

[0016] Ranges can be expressed herein as from "about" one particular value, and/or to "about" another particular value. When such a range is expressed, a further aspect includes from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent "about," it will be understood that the particular value forms a further aspect. It will be further understood that the endpoints of each of the ranges are significant both in relation to the other endpoint, and independently of the other endpoint. It is also understood that there are a number of values disclosed herein, and that each value is also herein disclosed as "about" that particular value in addition to the value itself. For example, if the value "10" is disclosed, then "about 10" is also disclosed. It is also understood that each unit between two particular units are also disclosed. For example, if 10 and 15 are disclosed, then 11, 12, 13, and 14 are also disclosed.

[0017] As used herein, the terms "optional" or "optionally" means that the subsequently described event or circumstance can or cannot occur, and that the description includes instances where said event or circumstance occurs and instances where it does not.

[0018] Unless otherwise expressly stated, it is in no way intended that any method set forth herein be construed as requiring that its steps be performed in a specific order. Accordingly, where a method claim does not actually recite an order to be followed by its steps or it is not otherwise specifically stated in the claims or descriptions that the steps are to be limited to a specific order, it is no way intended that an order be inferred, in any respect. This holds for any possible non-express basis for interpretation, including: matters of logic with respect to arrangement of steps or operational flow; plain meaning derived from grammatical organization or punctuation; and the number or type of embodiments described in the specification.

[0019] Disclosed are the components to be used to prepare the compositions of the invention as well as the compositions themselves to be used within the methods disclosed herein. These and other materials are disclosed herein, and it is understood that when combinations, subsets, interactions, groups, etc. of these materials are disclosed that while specific reference of each various individual and collective combinations and permutation of these compounds cannot be explicitly disclosed, each is specifically contemplated and described herein. For example, if a particular compound is disclosed and discussed and a number of modifications that can be made to a number of molecules including the compounds are discussed, specifically contemplated is each and every combination and permutation of the compound and the modifications that are possible unless specifically indicated to the contrary. Thus, if a class of molecules A, B, and C are disclosed as well as a class of molecules D, E, and F and an example of a combination molecule, A-D is disclosed, then even if each is not individually recited each is individually and collectively contemplated meaning combinations, A-E, A-F, B-D, B-E, B-F, C-D, C-E, and C-F are considered disclosed. Likewise, any subset or combination of these is also disclosed. Thus, for example, the sub-group of A-E, B-F, and C-E would be considered disclosed. This concept applies to all aspects of this application including, but not limited to, steps in methods of making and using the compositions of the invention. Thus, if there are a variety of additional steps that can be performed it is understood that each of these additional steps can be performed with any specific embodiment or combination of embodiments of the methods of the invention.

[0020] As used herein, the term or phrase "effective," "effective amount," or "conditions effective to" refers to such amount or condition that is capable of performing the function or property for which an effective amount is expressed. As will be pointed out below, the exact amount or particular condition required will vary from one aspect to another, depending on recognized variables such as the materials employed and the processing conditions observed. However, it should be understood that an appropriate effective amount will be readily determined by one of ordinary skill in the art using only routine experimentation.

[0021] As used herein, the terms "repair zone" or "repair zone surface" refers to any opening or void space defined by the at least one connecting surface of an outer wall of a body as disclosed herein. Exemplary "repair zones" include, without limitation, holes, apertures, leaks, cavities, recesses, dents, openings, bores, slits, slots, notches, and other void

spaces formed within one or more bodies. In some aspects, a repair zone can be defined within a single body. However, in other aspects, it is contemplated that two or more bodies can cooperate to define the repair zone.

[0022] Each of the materials disclosed herein are either commercially available and/or the methods for the production process thereof are known to those of ordinary skill in the art.

[0023] It is understood that the compositions disclosed herein have certain functions. Disclosed herein are certain structural requirements for performing the disclosed functions, and it is understood that there are a variety of structures that can perform the same function that are related to the disclosed structures, and that these structures will typically achieve the same result.

B. METHODS OF REPAIRING STAINLESS STEEL

[0024] As briefly described above, the present disclosure relates, in various aspects, to a method of repairing stainless steel. In one aspect, the present disclosure provides a method comprising the steps: a) providing a stainless steel body have a body surface, wherein at least a portion of the body surface comprises a surface defect and sigma phase precipitate; b) removing the body surface portion comprising the surface defect to expose a repair zone surface portion; c) heat treating the repair zone surface; d) forming a compressive stress field in the repair zone surface; and e) after forming the compressive stress field, welding a weld repair material to the repair zone surface to form a weld repair.

[0025] Also disclosed herein is a method, comprising the steps: a) providing a stainless steel body have a body surface, wherein at least a portion of the body surface comprises a surface defect and sigma phase precipitate; b) removing the body surface portion comprising the surface defect and sigma phase precipitate to expose a repair zone surface portion; c) forming a compressive stress field in the repair zone surface; d) buttering at least a portion of the repair zone surface; and e) after buttering and after forming the compressive stress field, welding a weld repair material to the repair zone surface to form a weld repair.

[0026] In a further aspect, the method involves sigma phase precipitate. In a further aspect the sigma phase precipitate is formed from exposure to temperatures in the range of from about 538°C to about 927°C. In a still further aspect, the method involves a surface

defect. In a yet further aspect, the surface defect comprises brittle fracture, stress corrosion cracking, fatigue, thermal shock, or a combination thereof.

[0027] In a further aspect, the method comprises heat treating the stainless steel, for example, the repair zone surface. In a still further aspect, heat treating comprises solution annealing. In various aspects, it is believed that the heat treatment, for example, by solution annealing, a more homogeneous microstructure can be provided, and intergranular carbides and sigma phase precipitates can be removed. In a further aspect, heat treatment comprises heating the material to an annealing temperature followed by rapid quenching. In a still further aspect, the heat treating or solution annealing is performed at a temperature in a range of from about 800 to about 1100 °C. In some aspects, the exposed repair zone surface portion is heat treated prior to forming the compressive stress field.

[0028] In a further aspect, the methods comprise at least one removing step. In a still further aspect, the removing step is performed under conditions effective to prevent growth of surface defects in the body surface surrounding the repair zone surface. In a still further aspect, the removing step comprises cutting, grinding, or machining, or combinations thereof. In a yet further aspect, the removing step comprises low stress grinding, cutting or machining, or combinations thereof. In an even further aspect, the removing is performed using a carbide cutting tool.

[0029] In a further aspect, the method comprises forming a compressive stress field. In a still further aspect, the compressive stress field is formed by shot peening. In various aspects, it is believed that the surface compression stress strengthens the metal, ensuring that the finished part will resist fatigue failures, corrosion fatigue and cracking, and galling and erosion from cavitation. In one aspect, the compressive stress field has a thickness greater than 0.1 mm. In a further aspect, the compressive stress field has a thickness in the range of from greater that 0 to about 1 mm.

[0030] In various aspects, the method can comprise any shot peening process appropriate for the materials to be treated. In a further aspect, the shot peeing process can use a standard industry protocol or approach. In an exemplary aspect, shot peening involves bombarding the surface of the part to be finished with small spherical shots. In a further aspect, the shot acts like a peen hammer, dimpling the surface and causing compression stresses under the dimple.

As the media continues to strike the part, it forms multiple overlapping dimples throughout the metal surface being treated.

[0031] In a further aspect, the shot peening step can have any desired frequency, and will vary based on the specific application. In a still further aspect, the shot peening step can have any desired hammer size, and will vary based on the given application.

[0032] In a further aspect, the method can comprise any weld process appropriate for the materials to be welded. In a further aspect, the weld process can use the standard industry protocol or approach. In one aspect, the weld process can be any weld process appropriate for the repair of a stainless steel body. In a further aspect, the welding comprises arc welding. In a yet further aspect, the welding step is performed under weld conditions effective to increase ductility of the weld material. In a yet further aspect, the method can further comprise subjecting a surface of the weld repair to a finishing step. In a still further aspect, the finishing step comprises smoothing a surface of the weld repair to a uniform surface similar to that of the surrounding surface portion of the stainless steel body.

[0033] In various aspects, the stainless steel utilized in the present method can comprise any desired stainless steel. In a further aspect, the stainless steel is an austenitic stainless steel, ferritic stainless steel, or martensitic stainless steel, or a combination thereof. In a still further aspect, the stainless steel is duplex stainless steel. In a yet further aspect, the stainless steel is stainless steel wrought metal, weld metal, or casting, or a combination thereof. In a some aspects, the stainless steel is an iron-chromium-nickel alloy, for example, HK alloy. In other aspects, the staineless steel is an iron-nickel-chromium alloy, for example, HP alloy. In a further aspect, the stainless steel is a 300 or 400 series stainless steel. In a yet further aspect, the stainless steel is a stainless steel selected from 304, 316, 347, 321 310, 430, and 440. In a further aspect, the stainless steel has a chromium content of at least 11 wt%, for example, at least about 12, 13, 14 or 15 wt% chromium. In a still further aspect, the stainless steel has at least a 10 wt% ferrite phase content.

[0034] In various aspects, the method comprises a weld material. In a further aspect, the weld material can comprise any desired material capable of restoring structural integrity to the repaired body. In a still further aspect, the weld material comprises a corrosion resistant material or a cracking resistant material, or a combination thereof. In an even further aspect,

the weld material can comprise a material that will restore ductility to the weld-repaired stainless steel body. In some aspects, the weld material comprises nickel. In other aspects, the weld material comprises the same material as the stainless steel body.

[0035] In some aspects, the method can comprise a buttering step. In a further aspect, the buttering step comprises adding weld material on at least one portion of the repair zone surface. In a still further aspect, the adding step provides a build-up of weld material on at least one portion of the repair zone surface. In a yet further aspect, the build-up comprises a transition weld deposit for the subsequent completion of the repair weld or joint.

C. STAINLESS STEEL COMPOSITIONS

[0036] Also disclosed herein are stainless steel bodies repaired by the disclosed methods. In one aspect, the inventions provides a stainless steel body repaired by a process comprising: a) removing a portion of a body surface of the stainless steel body to expose a repair zone surface portion; wherein the removed portion comprises a surface defect and sigma phase precipitate; b) heat treating the repair zone surface; c) forming a compressive stress field in the repair zone surface; and d) after forming the compressive stress field, welding a weld repair material to the repair zone surface to form a weld repair.

[0037] In another aspect, disclosed herein is a stainless steel body repaired by a process comprising: a) removing a portion of a body surface of the stainless steel body to expose a repair zone surface portion; wherein the removed portion comprises a surface defect and sigma phase precipitate; b) forming a compressive stress field in the repair zone surface; c) buttering at least a portion of the repair zone surface; and d) after buttering and after forming the compressive stress field, welding a weld repair material to the repair zone surface to form a weld repair.

[0038] In a further aspect, the sigma phase precipitate is formed from exposure to temperatures in the range of from about 538°C to about 927°C. In a still further aspect, the surface defect comprises brittle fracture, stress corrosion cracking, fatigue, thermal shock, or a combination thereof.

[0039] In a further aspect, the heat treating comprises solution annealing. In a further aspect, heat treatment comprises heating the material to an annealing temperature followed by

rapid quenching. In a still further aspect, heat treating or solution annealing is performed at a temperature in a range of from about 800 to about 1100 °C. In some aspects, the exposed repair zone surface portion is heat treated prior to forming the compressive stress field.

[0040] In a further aspect, the removing step is performed under conditions effective to prevent growth of surface defects in the body surface surrounding the repair zone surface. In a still further aspect, the removing step comprises cutting, grinding, or machining, or combinations thereof. In a yet further aspect, the removing step comprises low stress grinding, cutting or machining, or combinations thereof. In an even further aspect, the removing is performed using a carbide cutting tool.

[0041] In a further aspect, the compressive stress field is formed by shot peening. In one aspect, the compressive stress field has a thickness greater than 0.1 mm. In a further aspect, the compressive stress field has a thickness in the range of from greater that 0 to about 1 mm.

[0042] In various aspects, shot peeing can comprise any shot peening process appropriate for the materials to be treated. In a further aspect, the shot peeing process can use a standard industry protocol or approach. In an exemplary aspect, shot peening involves bombarding the surface of the part to be finished with small spherical shots. As noted above, the shot peening step can have any desired frequency, and will vary based on the specific application. Likewise, the shot peening step can have any desired hammer size, and will vary based on the given application.

[0043] In a further aspect, welding can comprise any weld process appropriate for the materials to be welded. In a further aspect, the weld process can use the standard industry protocol or approach. In one aspect, the weld process can be any weld process appropriate for the repair of a stainless steel body. In a further aspect, the welding comprises arc welding. In a further aspect, the welding step is performed under weld conditions effective to increase ductility of the weld material. In a yet further aspect, can be further subjecting a surface of the weld repair can be subjected to a finishing step. In a still further aspect, the finishing step comprises smoothing a surface of the weld repair to a uniform surface similar to that of the surrounding surface portion of the stainless steel body.

[0044] In various aspects, the stainless steel utilized in the present method can comprise any desired stainless steel. In a further aspect, the stainless steel is an austenitic stainless

steel, ferritic stainless steel, or martensitic stainless steel, or a combination thereof. In a still further aspect, the stainless steel is duplex stainless steel. In a yet further aspect, the stainless steel is stainless steel wrought metal, weld metal, or casting, or a combination thereof. In a some aspects, the stainless steel is an iron-chromium-nickel alloy, for example, HK alloy. In other aspects, the staineless steel is an iron-nickel-chromium alloy, for example, HP alloy. In a further aspect, the stainless steel is a 300 or 400 series stainless steel. In a yet further aspect, the stainless steel is a stainless steel selected from 304, 316, 347, 321 310, 430, and 440. In a further aspect, the stainless steel has a chromium content of at least 11 wt%, for example, at least about 12, 13, 14 or 15 wt% chromium. In a still further aspect, the stainless steel has at least a 10 wt% ferrite phase content.

[0045] In a further aspect, the weld material can comprise any desired material capable of restoring structural integrity to the repaired body. In a still further aspect, the weld material comprises a corrosion resistant material or a cracking resistant material, or a combination thereof. In an even further aspect, the weld material can comprise a material that will restore ductility to the weld-repaired stainless steel body. In some aspects, the weld material comprises nickel. In other aspects, the weld material comprises the same material as the stainless steel body.

[0046] In some aspects, the repaired stainless steel body can comprise a buttering step. In a further aspect, the buttering step comprises adding weld material on at least one portion of the repair zone surface. In a still further aspect, the adding step provides a buildup of weld material on at least one portion of the repair zone surface. In a yet further aspect, the build-up comprises a transition weld deposit for the subsequent completion of the repair weld or joint.

[0047] FIG. 1 illustrates an exemplary weld repaired according to the inventive methods of the present invention. FIG. 1A shows a stainless steel body with damage in the form of surface defects and sigma phase precipitate. FIG. 1B shows the stainless steel body after removing the damaged body surface portion to expose a repair zone surface portion. FIG. 1C shows the stainless steel body after the repair zone surface has been shot-peened to induce a compressive stress field. FIG. 1D shows the stainless steel body after a weld repair material has been welded to the repair zone surface to form a weld repair. FIG. 1E shows the stainless steel body after smoothing a surface of the weld repair to a uniform surface similar to that of the surrounding surface portion of the stainless steel body.

D. ASPECTS

[0048] The disclosed compositions and methods include at least the following aspects.

[0049] Aspect 1: A method comprising the steps:

a. providing a stainless steel body have a body surface, wherein at least a portion of the body surface comprises a surface defect and sigma phase precipitate;

b. removing the body surface portion comprising the surface defect to expose a repair zone surface portion;

c. heat treating the repair zone surface;

d. forming a compressive stress field in the repair zone surface; and

e. after forming the compressive stress field, welding a weld repair material to the repair zone surface to form a weld repair.

[0050] Aspect 2: The method of aspect 1, wherein the sigma phase precipitate is formed from exposure to temperatures in the range of from about 538 °C to about 927 °C.

[0051] Aspect 3: The method of aspect 1 or 2, wherein the surface defect comprises brittle fracture, stress corrosion cracking, fatigue, thermal shock, or a combination thereof.

[0052] Aspect 4: The method of aspects 1-3, wherein heat treating comprises solution annealing.

[0053] Aspect 5: The method of aspects 1-4, wherein the exposed repair zone surface portion is heat treated prior to forming the compressive stress field.

[0054] Aspect 6: The method of aspect 4, wherein the solution annealing is performed at a temperature in a range of from about 800 to about 1100 °C.

[0055] Aspect 7: The method of aspects 1-6, wherein the removing step is performed under conditions effective to prevent growth of surface defects in the body surface surrounding the repair zone surface.

[0056] Aspect 8: The method of aspects 1-7, wherein the removing step comprises cutting, grinding, or machining, or combinations thereof.

[0057] Aspect 9: The method of aspects 1-8, wherein the removing step comprises low stress grinding, cutting or machining, or combinations thereof.

[0058] Aspect 10: The method of aspects 1-9, wherein the removing step is performed using using a carbide cutting tool.

[0059] Aspect 11: The method of aspects 1-10, wherein the compressive stress field is formed by shot peening.

[0060] Aspect 12: The method of aspects 1-11, wherein the compressive stress field has a thickness greater that 0.1 mm.

[0061] Aspect 13: The method of aspects 1-12, wherein the compressive stress field has a thickness in the range of from greater that 0 to about 1 mm.

[0062] Aspect 14: The method of aspects 1-13, wherein the welding step is performed under weld conditions effective to increase ductility of the weld material.

[0063] Aspect 15: The method of aspects 1-14, further comprising subjecting a surface of the weld repair to a finishing step.

[0064] Aspect 16: The method of aspect 15, wherein the finishing step comprises smoothing a surface of the weld repair to a uniform surface similar to that of the surrounding surface portion of the stainless steel body.

[0065] Aspect 17: The method of aspect 1, wherein the stainless steel is an austenitic stainless steel, ferritic stainless steel, or martensitic stainless steel, or a combination thereof.

[0066] Aspect 18: The method of aspect 1, wherein the stainless steel is duplex stainless steel.

[0067] Aspect 19: The method of aspect 1, wherein the stainless steel is stainless steel wrought metal, weld metal, or casting, or a combination thereof.

[0068] Aspect 20: The method of aspect 1, wherein the stainless steel is an HK or HP alloy.

[0069] Aspect 21: The method of aspect 1, wherein the stainless steel is a 300 or 400 series stainless steel.

[0070] Aspect 22: The method of aspect 1, wherein the stainless steel is a stainless steel selected from 304, 316, 347, 321 310, 430, and 440.

[0071] Aspect 23:The method of aspect 1, wherein the stainless steel has at least a 10 wt% ferrite phase content.

[0072] Aspect 24: The method of aspect 1, wherein the stainless steel has a chromium content of at least 11 wt%.

[0073] Aspect 25: The method of aspects 1-24, wherein the weld material comprises nickel.

[0074] Aspect 26: The method of aspects 1-24, wherein the weld material comprises the same material as the stainless steel body.

[0075] Aspect 27: The method of aspects 1-26, wherein the weld material comprises a corrosion resistant material or a cracking resistant material, or a combination thereof.

[0076] Aspect 28: The method of aspects 1-27, wherein the weld-repaired stainless steel body exhibits improved ductility.

[0077] Aspect 29: A method, comprising the steps:

a. providing a stainless steel body have a body surface, wherein at least a portion of the body surface comprises a surface defect and sigma phase precipitate;

b. removing the body surface portion comprising the surface defect and sigma phase precipitate to expose a repair zone surface portion;

c. forming a compressive stress field in the repair zone surface;

d. buttering at least a portion of the repair zone surface; and

e. after buttering and after forming the compressive stress field, welding a weld repair material to the repair zone surface to form a weld repair.

[0078] Aspect 30: The method of aspect 29, wherein the removing step is performed under conditions effective to prevent growth of surface defects in the body surface surrounding the repair zone surface.

[0079] Aspect 31: The method of aspect 29 or 30, wherein the removing step comprises cutting, grinding, or machining, or combinations thereof.

[0080] Aspect 32: The method of aspects 29-31, wherein the removing step comprises low stress grinding, cutting or machining, or combinations thereof.

[0081] Aspect 33: The method of aspects 29-32, wherein the removing is performed using using a carbide cutting tool.

[0082] Aspect 34: The method of aspects 29-33, wherein the compressive stress field is formed by shot peening.

[0083] Aspect 35: The method of aspects 29-34, wherein the compressive stress field has a thickness greater that 0.1 mm.

[0084] Aspect 36: The method of aspects 29-35, wherein the compressive stress field has a thickness in the range of from greater that 0 to about 1 mm.

[0085] Aspect 37: The method of aspects 29-36, wherein the welding step is performed under weld conditions effective to increase ductility of the weld material.

[0086] Aspect 38: The method of aspects 29-37, further comprising subjecting a surface of the weld repair to a finishing step.

[0087] Aspect 39: The method of aspect 38, wherein the finishing step comprises smoothing a surface of the weld repair to a uniform surface similar to that of the surrounding surface portion of the stainless steel body.

[0088] Aspect 40: The method of aspect 29, wherein the stainless steel is an austenitic stainless steel, ferritic stainless steel, or martensitic stainless steel, or a combination thereof.

[0089] Aspect 41: The method of aspect 29, wherein the stainless steel is duplex stainless steel.

[0090] Aspect 42: The method of aspect 29, wherein the stainless steel is stainless steel wrought metal, weld metal, or casting, or a combination thereof.

[0091] Aspect 43: The method of aspect 29, wherein the stainless steel is an HK or HP alloy.

[0092] Aspect 44: The method of aspect 29, wherein the stainless steel is a 300 or 400 series stainless steel.

[0093] Aspect 45: The method of aspect 29, wherein the stainless steel is a stainless steel selected from 304, 316, 347, 321, 310, 430, and 440.

[0094] Aspect 46: The method of aspect 29, wherein the stainless steel has at least a 10 wt% ferrite phase content.

[0095] Aspect 47: The method of aspect 29, wherein the stainless steel has a chromium content of at least 11 wt%.

[0096] Aspect 48: The method of aspects 29-47, wherein the weld material comprises nickel.

[0097] Aspect 49: The method of aspects 29-47, wherein the weld material comprises the same material as the stainless steel body.

[0098] Aspect 50: The method of aspects 29-49, wherein the weld material comprises a corrosion resistant material or a cracking resistant material, or a combination thereof.

[0099] Aspect 51: The method of aspects 29-50, wherein the weld-repaired stainless steel body exhibits improved ductility.

[00100] Aspect 52: The method of aspects 29-51, wherein the buttering step comprises adding weld material on at least one portion of the repair zone surface.

[00101] Aspect 53: The method of aspect 52, wherein the adding step provides a buildup of weld material on at least one portion of the repair zone surface.

[00102] Aspect 54: The method of aspect 54, wherein the buildup comprises a transition weld deposit for the subsequent completion of the joint.

[00103] Aspect 55: A stainless steel body repaired by a process comprising:

a. removing a portion of a body surface of the stainless steel body to expose a repair zone surface portion; wherein the removed portion comprises a surface defect and sigma phase precipitate;

b. heat treating the repair zone surface;

c. forming a compressive stress field in the repair zone surface; and

d.after forming the compressive stress field, welding a weld repair material to the repair zone surface to form a weld repair.

[00104] Aspect 56: A stainless steel body repaired by a process comprising:

a. removing a portion of a body surface of the stainless steel body to expose a repair zone surface portion; wherein the removed portion comprises a surface defect and sigma phase precipitate;

b. forming a compressive stress field in the repair zone surface;

c. buttering at least a portion of the repair zone surface; and

d. after buttering and after forming the compressive stress field, welding a weld repair material to the repair zone surface to form a weld repair.

[00105] Aspect 57: The stainless steel body of aspect 55, wherein heat treating comprises solution annealing.

[00106] Aspect 58: The stainless steel body of aspect 55, wherein the exposed repair zone surface portion is heat treated prior to forming the compressive stress field.

[00107] Aspect 59: The stainless steel body of aspect 57, wherein the solution annealing is performed at a temperature in a range of from about 800 to about 1100 °C.

[00108] Aspect 60: The stainless steel body of aspect 55 or 56, wherein the removing step is performed under conditions effective to prevent growth of surface defects in the body surface surrounding the repair zone surface.

[00109] Aspect 61: The stainless steel body of aspect 55 or 56, wherein the removing step comprises cutting, grinding, or machining, or combinations thereof.

[00110] Aspect 62: The stainless steel body of aspect 55 or 56, wherein the removing is performed using using a carbide cutting tool.

[00111] Aspect 63: The stainless steel body of aspect 55 or 56, wherein the compressive stress field is formed by shot peening.

[00112] Aspect 64: The stainless steel body of aspect 55 or 56, wherein the welding step is performed at weld conditions effective to increase ductility of the weld material.

[00113] Aspect 65: The stainless steel body of aspect 55 or 56, further comprising subjecting a surface of the weld repair to a finishing step.

[00114] Aspect 66: The stainless steel body of aspect 65, wherein the finishing step comprises smoothing a surface of the weld repair to a uniform surface similar to that of the surrounding surface portion of the stainless steel body.

[00115] Aspect 67: The stainless steel body of aspect 55 or 56, wherein the stainless steel is an austenitic stainless steel, ferritic stainless steel, or martensitic stainless steel, or a combination thereof.

[00116] Aspect 68: The stainless steel body of aspect 55 or 56, wherein the stainless steel is duplex stainless steel.

[00117] Aspect 69: The stainless steel body of aspect 55 or 56, wherein the stainless steel is stainless steel wrought metal, weld metal, or casting, or a combination thereof.

[00118] Aspect 70: The stainless steel body of aspect 55 or 56, wherein the stainless steel is an HK or HP alloy.

[00119] Aspect 71: The stainless steel body of aspect 55 or 56, wherein the stainless steel is a 300 or 400 series stainless steel.

[00120] Aspect 72: The stainless steel body of aspect 55 or 56, wherein the stainless steel is a stainless steel selected from 304, 316, 347, 321, 310, 430, and 440.

[00121] Aspect 73: The stainless steel body of aspect 55 or 56, wherein the stainless steel has a chromium content of at least 11 wt%.

[00122] Aspect 74: The stainless steel body of aspect 55 or 56, wherein the weld material comprises nickel.

[00123] Aspect 75: The stainless steel body of aspect 55 or 56, wherein the weld material comprises the same material as the stainless steel body.

[00124] Aspect 76: The stainless steel body of aspect 55 or 56, wherein the weld material comprises comprise a corrosion resistant material or a cracking resistant material, or a combination thereof.

[00125] Aspect 77: The stainless steel body of aspect 55 or 56, wherein the weld-repaired stainless steel body exhibits improved ductility.

[00126] Aspect 78: The stainless steel body of aspect 55 or 56, wherein the stainless steel has at least a 10 wt% ferrite phase content.

[00127] While aspects of the present invention can be described and claimed in a particular statutory class, such as the system statutory class, this is for convenience only and one of skill in the art will understand that each aspect of the present invention can be described and claimed in any statutory class. Unless otherwise expressly stated, it is in no way intended that any method or aspect set forth herein be construed as requiring that its steps be performed in a specific order. Accordingly, where a method claim does not specifically state in the claims or descriptions that the steps are to be limited to a specific order, it is no way. Appreciably intended that an order be inferred, in any respect. This holds for any possible non-express basis for interpretation, including matters of logic with respect to arrangement of steps or

operational flow, plain meaning derived from grammatical organization or punctuation, or the number or type of aspects described in the specification.

[00128] Throughout this application, various publications are referenced. The disclosures of these publications in their entireties are hereby incorporated by reference into this application in order to more fully describe the state of the art to which this pertains. The references disclosed are also individually and specifically incorporated by reference herein for the material contained in them that is discussed in the sentence in which the reference is relied upon. Nothing herein is to be construed as an admission that the present invention is not entitled to antedate such publication by virtue of prior invention. Further, the dates of publication provided herein can be different from the actual publication dates, which can require independent confirmation.

CLAIMS

What is claimed is:

1. A method comprising the steps:
   a. providing a stainless steel body have a body surface, wherein at least a portion of the body surface comprises a surface defect and sigma phase precipitate;
   b. removing the body surface portion comprising the surface defect to expose a repair zone surface portion;
   c. heat treating the repair zone surface;
   d. forming a compressive stress field in the repair zone surface; and
   e. after forming the compressive stress field, welding a weld repair material to the repair zone surface to form a weld repair.

2. The method of claim 1, wherein the sigma phase precipitate is formed from exposure to temperatures in the range of from about 538 °C to about 927 °C.

3. The method of claim 1 or 2, wherein the surface defect comprises brittle fracture, stress corrosion cracking, fatigue, thermal shock, or a combination thereof.

4. The method of claims 1-3, wherein heat treating comprises solution annealing.

5. The method of claims 1-4, wherein the exposed repair zone surface portion is heat treated prior to forming the compressive stress field.

6. The method of claim 4, wherein the solution annealing is performed at a temperature in a range of from about 800 to about 1100 °C.

7. The method of claims 1-6, wherein the removing step is performed under conditions effective to prevent growth of surface defects in the body surface surrounding the repair zone surface.

8. The method of claims 1-7, wherein the removing step comprises cutting, grinding, or machining, or combinations thereof.

9. The method of claims 1-8, wherein the removing step comprises low stress grinding, cutting or machining, or combinations thereof.

10. The method of claims 1-9, wherein the removing step is performed using using a carbide cutting tool.

11. The method of claims 1-10, wherein the compressive stress field is formed by shot peening.

12. The method of claims 1-11, wherein the compressive stress field has a thickness greater that 0.1 mm.

13. The method of claims 1-12, wherein the compressive stress field has a thickness in the range of from greater that 0 to about 1 mm.

14. The method of claims 1-13, wherein the welding step is performed under weld conditions effective to increase ductility of the weld material.

15. The method of claims 1-14, further comprising subjecting a surface of the weld repair to a finishing step.

16. The method of claim 15, wherein the finishing step comprises smoothing a surface of the weld repair to a uniform surface similar to that of the surrounding surface portion of the stainless steel body.

17. The method of claim 1, wherein the stainless steel is an austenitic stainless steel, ferritic stainless steel, or martensitic stainless steel, or a combination thereof.

18. The method of claim 1, wherein the stainless steel is duplex stainless steel.

19. The method of claim 1, wherein the stainless steel is stainless steel wrought metal, weld metal, or casting, or a combination thereof.

20. The method of claim 1, wherein the stainless steel is an HK or HP alloy.

21. The method of claim 1, wherein the stainless steel is a 300 or 400 series stainless steel.

22. The method of claim 1, wherein the stainless steel is a stainless steel selected from 304, 316, 347, 321 310, 430, and 440.

23. The method of claim 1, wherein the stainless steel has at least a 10 wt% ferrite phase content.

24. The method of claim 1, wherein the stainless steel has a chromium content of at least 11 wt%.

25. The method of claims 1-24, wherein the weld material comprises nickel.

26. The method of claims 1-24, wherein the weld material comprises the same material as the stainless steel body.

27. The method of claims 1-26, wherein the weld material comprises a corrosion resistant material or a cracking resistant material, or a combination thereof.

28. The method of claims 1-27, wherein the weld-repaired stainless steel body exhibits improved ductility.

29. A method, comprising the steps:
    a. providing a stainless steel body have a body surface, wherein at least a portion of the body surface comprises a surface defect and sigma phase precipitate;
    b. removing the body surface portion comprising the surface defect and sigma phase precipitate to expose a repair zone surface portion;

c. forming a compressive stress field in the repair zone surface;

d. buttering at least a portion of the repair zone surface; and

e. after buttering and after forming the compressive stress field, welding a weld repair material to the repair zone surface to form a weld repair.

30. The method of claim 29, wherein the removing step is performed under conditions effective to prevent growth of surface defects in the body surface surrounding the repair zone surface.

31. The method of claim 29 or 30, wherein the removing step comprises cutting, grinding, or machining, or combinations thereof.

32. The method of claims 29-31, wherein the removing step comprises low stress grinding, cutting or machining, or combinations thereof.

33. The method of claims 29-32, wherein the removing is performed using using a carbide cutting tool.

34. The method of claims 29-33, wherein the compressive stress field is formed by shot peening.

35. The method of claims 29-34, wherein the compressive stress field has a thickness greater that 0.1 mm.

36. The method of claims 29-35, wherein the compressive stress field has a thickness in the range of from greater that 0 to about 1 mm.

37. The method of claims 29-36, wherein the welding step is performed under weld conditions effective to increase ductility of the weld material.

38. The method of claims 29-37, further comprising subjecting a surface of the weld repair to a finishing step.

39. The method of claim 38, wherein the finishing step comprises smoothing a surface of the weld repair to a uniform surface similar to that of the surrounding surface portion of the stainless steel body.

40. The method of claim 29, wherein the stainless steel is an austenitic stainless steel, ferritic stainless steel, or martensitic stainless steel, or a combination thereof.

41. The method of claim 29, wherein the stainless steel is duplex stainless steel.

42. The method of claim 29, wherein the stainless steel is stainless steel wrought metal, weld metal, or casting, or a combination thereof.

43. The method of claim 29, wherein the stainless steel is an HK or HP alloy.

44. The method of claim 29, wherein the stainless steel is a 300 or 400 series stainless steel.

45. The method of claim 29, wherein the stainless steel is a stainless steel selected from 304, 316, 347, 321, 310, 430, and 440.

46. The method of claim 29, wherein the stainless steel has at least a 10 wt% ferrite phase content.

47. The method of claim 29, wherein the stainless steel has a chromium content of at least 11 wt%.

48. The method of claims 29-47, wherein the weld material comprises nickel.

49. The method of claims 29-47, wherein the weld material comprises the same material as the stainless steel body.

50. The method of claims 29-49, wherein the weld material comprises a corrosion resistant material or a cracking resistant material, or a combination thereof.

51. The method of claims 29-50, wherein the weld-repaired stainless steel body exhibits improved ductility.

52. The method of claims 29-51, wherein the buttering step comprises adding weld material on at least one portion of the repair zone surface.

53. The method of claim 52, wherein the adding step provides a buildup of weld material on at least one portion of the repair zone surface.

54. The method of claim 54, wherein the buildup comprises a transition weld deposit for the subsequent completion of the joint.

55. A stainless steel body repaired by a process comprising:
    a. removing a portion of a body surface of the stainless steel body to expose a repair zone surface portion; wherein the removed portion comprises a surface defect and sigma phase precipitate;
    b. heat treating the repair zone surface;
    c. forming a compressive stress field in the repair zone surface; and
    d. after forming the compressive stress field, welding a weld repair material to the repair zone surface to form a weld repair.

56. A stainless steel body repaired by a process comprising:
    a. removing a portion of a body surface of the stainless steel body to expose a repair zone surface portion; wherein the removed portion comprises a surface defect and sigma phase precipitate;
    b. forming a compressive stress field in the repair zone surface;
    c. buttering at least a portion of the repair zone surface; and
    d. after buttering and after forming the compressive stress field, welding a weld repair material to the repair zone surface to form a weld repair.

57. The stainless steel body of claim 55, wherein heat treating comprises solution annealing.

58. The stainless steel body of claim 55, wherein the exposed repair zone surface portion is heat treated prior to forming the compressive stress field.

59. The stainless steel body of claim 57, wherein the solution annealing is performed at a temperature in a range of from about 800 to about 1100 °C.

60. The stainless steel body of claim 55 or 56, wherein the removing step is performed under conditions effective to prevent growth of surface defects in the body surface surrounding the repair zone surface.

61. The stainless steel body of claim 55 or 56, wherein the removing step comprises cutting, grinding, or machining, or combinations thereof.

62. The stainless steel body of claim 55 or 56, wherein the removing is performed using using a carbide cutting tool.

63. The stainless steel body of claim 55 or 56, wherein the compressive stress field is formed by shot peening.

64. The stainless steel body of claim 55 or 56, wherein the welding step is performed at weld conditions effective to increase ductility of the weld material.

65. The stainless steel body of claim 55 or 56, further comprising subjecting a surface of the weld repair to a finishing step.

66. The stainless steel body of claim 65, wherein the finishing step comprises smoothing a surface of the weld repair to a uniform surface similar to that of the surrounding surface portion of the stainless steel body.

67. The stainless steel body of claim 55 or 56, wherein the stainless steel is an austenitic stainless steel, ferritic stainless steel, or martensitic stainless steel, or a combination thereof.

68. The stainless steel body of claim 55 or 56, wherein the stainless steel is duplex stainless steel.

69. The stainless steel body of claim 55 or 56, wherein the stainless steel is stainless steel wrought metal, weld metal, or casting, or a combination thereof.

70. The stainless steel body of claim 55 or 56, wherein the stainless steel is an HK or HP alloy.

71. The stainless steel body of claim 55 or 56, wherein the stainless steel is a 300 or 400 series stainless steel.

72. The stainless steel body of claim 55 or 56, wherein the stainless steel is a stainless steel selected from 304, 316, 347, 321, 310, 430, and 440.

73. The stainless steel body of claim 55 or 56, wherein the stainless steel has a chromium content of at least 11 wt%.

74. The stainless steel body of claim 55 or 56, wherein the weld material comprises nickel.

75. The stainless steel body of claim 55 or 56, wherein the weld material comprises the same material as the stainless steel body.

76. The stainless steel body of claim 55 or 56, wherein the weld material comprises comprise a corrosion resistant material or a cracking resistant material, or a combination thereof.

77. The stainless steel body of claim 55 or 56, wherein the weld-repaired stainless steel body exhibits improved ductility.

78. The stainless steel body of claim 55 or 56, wherein the stainless steel has at least a 10 wt% ferrite phase content.

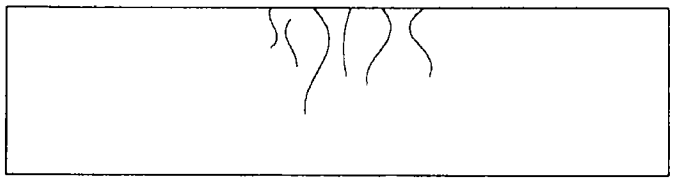

FIG. 1A

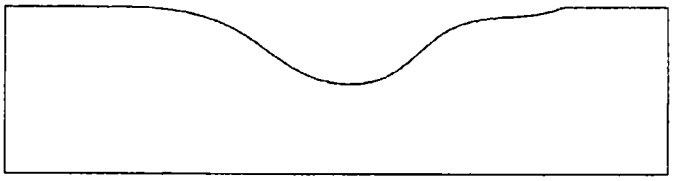

FIG. 1B

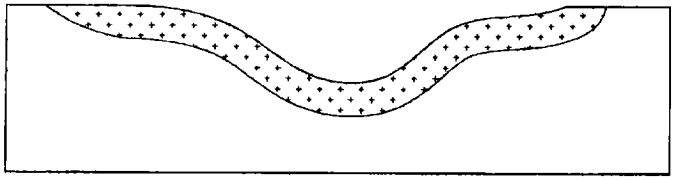

FIG. 1C

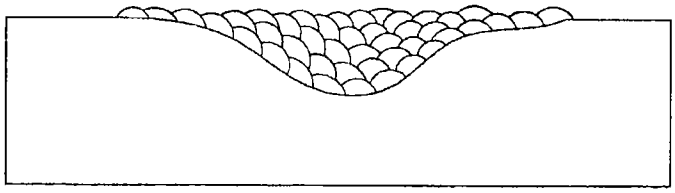

FIG. 1D

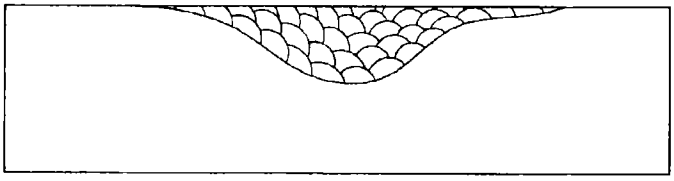

FIG. 1E

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2015/001752

A. CLASSIFICATION OF SUBJECT MATTER
INV. B23P6/00 B23P6/04 B23K103/04
ADD. C21D7/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B23P B23K C21D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 102 009 279 A (BEIJING INST AERONAUTICAL MATERIALS AVIAT INDUSTRY CORP CHINA) 13 April 2011 (2011-04-13)	55-67, 69,77
A	abstract	1-54

X	JP 2001 170823 A (NIPPON KOKAN KK; KANMETA ENG KK) 26 June 2001 (2001-06-26)	55-67, 69,71,72
A	abstract	1-54

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A	abstract; figures	1-54

X	EP 1 287 936 A1 (TOSHIBA KK [JP]) 5 March 2003 (2003-03-05)	55-67,75
A	paragraph [0021]; claim 1; figures	1-54

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
9 December 2015	18/12/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Plastiras, Dimitrios

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2015/001752

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/248071 A1 (KIUCHI KIYOSHI [JP] ET AL) 13 October 2011 (2011-10-13)	55-67, 71,72,76
A	paragraphs [0081], [0095]	1-54
X	EP 0 296 861 A1 (WESTINGHOUSE ELECTRIC CORP [US]) 28 December 1988 (1988-12-28)	55-67, 71-73
A	page 1, line 41 - line 43; figure 1 page 3, line 35 - line 48	1-54
X	CN 101 559 524 A (JINGLEI SCIENCE AND TECHNOLOGY [CN]) 21 October 2009 (2009-10-21) abstract	55-68,78
X	DATABASE WPI Week 197836 Thomson Scientific, London, GB; AN 1978-64208A XP002751962, -& JP S53 87944 A (NIPPON STEEL CORP) 2 August 1978 (1978-08-02) abstract	55,56,74
X	JP S59 222527 A (KUBOTA LTD) 14 December 1984 (1984-12-14)	55,56,75
A	abstract; figures	1
X	WO 2010/070548 A1 (CSIR [ZA]; ESKOM [ZA]; VAN ROOYEN CORNEY [ZA]; BURGER HERMAN [ZA]; DOU) 24 June 2010 (2010-06-24)	55,56, 71,72
A	page 5, line 1 - line 3; claims; figures	1-54
X	The International Nickel Companny INC: "Cast Heat-Resistant Alloys", , 1 July 1974 (1974-07-01), XP055234940, Retrieved from the Internet: URL:http://www.nickelinstitute.org/~/Media/Files/TechnicalLiterature/CastHeat_ResistantAlloys_1196_.pdf [retrieved on 2015-12-09] table 1	55,56,70
A	US 5 002 839 A (QURESHI JAVAID I [US] ET AL) 26 March 1991 (1991-03-26) column 2, line 52 - column 5, line 18; figures	1-54
A	US 2004/245323 A1 (OFFER HENRY P [US] ET AL) 9 December 2004 (2004-12-09) claims 1,3,8,9; figures	1-54

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2015/001752

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JP 2001170823 A	26-06-2001	NONE	
JP S58151987 A	09-09-1983	JP S6225065 B2	01-06-1987
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