FRICTION STIR WELDING PROCESS HAVING ENHANCED CORROSION PERFORMANCE

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ABSTRACT

A three dimensional joint is formed by coupling (joining) a first structural member and a second structural member. This involves first aligning a first structural member to a second structural member. The first structural member has a channel with which to receive a portion of the second structural member. Certain embodiments may place corrosively inert materials within the mating surfaces to prevent or inhibit corrosion or oxidation. Once aligned, the first structural member and second structural member may be friction stir welded at the channel to plasticize the material adjacent to the channel of both the first structural member and the second structural member to form a friction stir weld joint. Embodiments may then coat the plasticized surfaces of the FSW joint with cold sprayed materials to inhibit corrosion. Should a crack occur within either the plasticized or non-plasticized materials, cold sprayed material may be deposited within and on the crack to retard or arrest the growth of the crack.

100

110

aligning a first structural member to a second structural member

112

friction stir welding at the interface to join the first structural member to the second structural member

114

Cold spraying sacrificial material on the exposed surfaces of the FSW joint

end

FIG. 11
Cold spraying corrosively inert materials on the mating surfaces of the FSW joint

aligning a first structural member to a second structural member

friction stir welding at the interface to join the first structural member to the second structural member

Cold spraying sacrificial material on the exposed surfaces of the FSW joint

start

200

202

204

206

208

end

FIG. 12
200

242

Identify crack within structural member(s)

244

Cold spraying materials on the crack

end

FIG. 14
aligning a first member to a second member

Extrude an in-situ fastener bonded to the substrate (second member) within the shaped cavity

start

260

262

end

FIG. 16
FRICITION STIR WELDING PROCESS HAVING ENHANCED CORROSION PERFORMANCE

TECHNICAL FIELD OF THE INVENTION

[0001] The present invention relates generally to structural joints and more particularly to a method to join two or more members in forming a three-dimensional joint.

BACKGROUND OF THE INVENTION

[0002] Structural beams translate stiffness and other mechanical loads within structures such as buildings, vehicles, and bridges, etc. In one example, structural beams may be used to translate loads associated with the wing of an aircraft. These structural beams may include box beams, I-beams, double I-beams, C-Beams or other like structures that are efficient load carrying members. FIGS. 1A and 1B provide a cross section of a typical I-Beam and C-Beam. Such beams may be used in a variety of applications. I-Beams may be used for long clear spans requiring heavy loads. While C-Beams can be used where design and load requirements allow use of a C-Beam as opposed to an I-Beam, which provides additional support. Additionally a C-Beam may provide one flush surface not present in the I-Beam.

[0003] These beams are typically joined together using fasteners. Structures constructed via bolted and fastened I-beams and C-beams often have problems translating stiffness and loads with minimal weight due to moment continuity. This joining method also requires drilling holes and installing fasteners to attach the members to one another. Such holes often produce localized stresses and mechanical loads that the beams must account for. To account for such localized loads, the structure of the beam may be reinforced resulting in increased weight and loads to be handled by the beams.

[0004] Additionally, set up, tooling and the time required to drill holes may become major drivers in manufacturing as well as issues in quality assurance. The installation of fasteners is also a process prone to quality assurance issues. (i.e. insuring that the proper fasteners are used with the proper torques)

[0005] Friction Stir Welding (FSW) is a joining method, as illustrated in FIG. 2 which has gained acceptance as a means for joining panels together. FSW produces a plasticized region 22 of material by pushing a non-consumable rotating tool 24 into the material of parts 26A and 26B that are to be welded. Then a central pin, or probe, 28 followed by the shoulder 30, is brought into contact with the two parts 26A and 26B to be joined. The rotation of tool 24 heats up and plasticizes the materials that the tool is in contact with. As tool 24 moves along the joint line 32, material from the front of the tool is swept around this plasticized annulus to the rear, so eliminating the interface.

[0006] There are cost advantages if one applies a simple stiffened skin structure that may be produced via FSW to the exterior of a vehicle such as an aircraft. The robustness and automation of the process is very attractive for manufacturing. However, smaller complex three dimensional structures, such as aircraft designs, have not been easily addressed by the application of FSW. The FSW process works best when two pieces abut one another and are clamped tightly together. This is most effectively achieved when the two pieces are forming a single two-dimensional surface. Joining and properly plasticizing three-dimensional surfaces is difficult. Thus it has been difficult to apply FSW processing to complex three-dimensional structures.

[0007] There are problems associated with each of these joining methods. The requirement to drill holes and install fasteners to attach beams to one another requires that the fastened beams be strengthened in order to account for the localized mechanical loads caused by the fasteners. Additionally, mechanical loads within the beams may be localized at the fastener site as opposed to being transferred across the entire joint interface.

[0008] Further limitations and disadvantages of conventional and traditional joining processes and related structures and functionality will become apparent to one of ordinary skill in the art through comparison with the present invention described herein.

SUMMARY OF THE INVENTION

[0009] The present invention provides a means of joining a first structural member and a second structural member that substantially addresses the above identified needs as well as others. Embodiments of the present invention provide a joint formed by coupling (joining) a first structural member and a second structural member. This involves first aligning a first structural member to a second structural member. The first structural member has a channel with which to receive a portion of the second structural member. Certain embodiments may place corrosively inert materials within the mating surfaces to prevent or inhibit corrosion or oxidation. Once aligned, the first structural member and second structural member may be friction stir welded at the channel to plasticize the material adjacent to the channel of both the first structural member and the second structural member to form a friction stir weld joint. Embodiments may then coat the plasticized surfaces of the FSW joint with cold sprayed materials to inhibit corrosion. Should a crack occur within either the plasticized or non-plasticized materials, cold sprayed material may be deposited within and on the crack to retard or arrest the growth of the crack.

[0010] Another embodiment in the present invention provides a method for joining structural members. This involves aligning the first structural member to a second structural member. The first structural member has a channel with which to receive a portion of the second structural member. As in the prior embodiment, this channel serves as a guide with which to position the first structural member relative to the second structural member. For example, the first and second structural member may be an I-beam or C-beam wherein the channel is placed within the horizontal members and not the vertical webs of the I-beam. Certain embodiments may place corrosively inert materials within the mating surfaces to prevent or inhibit corrosion or oxidation. Once fitted together FSW takes place at the channel to join the first structural member to the second structural member. This results in plasticizing and mixing the materials within and adjacent to the channel of both the first and the second structural member to form a single continuous joint at the channel. Cold sprayed materials may then coat the plasticized surfaces of the FSW joint to inhibit corrosion. Should a crack occur within either the plasticized or non-plasticized materials, cold sprayed material may be deposited within and on the crack to retard or arrest the growth of the crack.
Additional embodiments may place an adhesive or barrier material that may both assist in fitting the first structural member to the second structural member prior to the friction stir weld as well as providing a barrier as the adhesive or barrier material is extruded into interface cavities at the friction stir weld joint. This method is particularly useful for structures where weight is a concern, such as an aircraft using aluminum or aluminum alloy structural members. By eliminating the need to reinforce structural components due to the coupling of structural members using traditional fastener methods, the weight associated with these structural members may be greatly reduced.

Another embodiment of the present invention provides a similar method for joining structural members. Again, the first structural member is aligned and fitted to a second structural member wherein a channel within the first structural member receives a portion of the second structural member. In addition to this channel which may be used to fit the first structural member to the second structural member a male connector within either the first structural member and/or second structural member may be received within a female receptacle of the second structural member and/or first structural member. This may further facilitate the setup and alignment process. Certain embodiments may place corrosively inert materials on the mating surfaces to prevent or inhibit corrosion or oxidation. The materials of the male connector and female receptacle may be friction stir welded at the interface to further enhance the joint coupling the first structural member to the second structural member. Additionally, adhesive, barrier, and/or corrosively inert material may be placed at the channel, male connector, and/or female receptacle to assist in fitting, preventing contaminants from entering or penetrating the interface cavities that remain after joining the structural members, and/or inhibit corrosion.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention and the advantages thereof, reference is now made to the following description taken in conjunction with the accompanying drawings in which like reference numerals indicate like features and wherein:

FIG. 1A and 1B provide a cross section of a typical I-Beam and C-Beam;

FIG. 2 illustrates the Friction Stir Welding (FSW) joining method;

FIG. 3 shows a first structural member in the process of being fitted to a second structural member in accordance with an embodiment of the present invention;

FIG. 4 shows a first structural member having a groove or channel operable to receive and align a second structural member in accordance with an embodiment of the present invention;

FIG. 5 provides a schematic diagram of cold spray process;

FIG. 6 shows a first structural member joined to a second structural wherein the FSW joint has been coated with material to enhance the corrosion resistance of the FSW joint in accordance with an embodiment of the present invention;

FIG. 7 shows a first structural member having a groove or channel joined by a FSW to a second structural member in accordance with an embodiment of the present invention;

FIG. 8 shows a first structural member and a second structural member, initially fitted together by male connectors and female receptacles, and then permanently joined by a FSW to in accordance with an embodiment of the present invention;

FIG. 9 shows a first structural member in the process of being fitted to a second structural member in accordance with an embodiment of the present invention wherein corrosively inert material has been placed on the mating surfaces;

FIG. 10 shows a first structural member having a groove or channel operable to receive and align a second structural member in accordance with an embodiment of the present invention wherein corrosively inert material has been placed on the mating surfaces;

FIG. 11 provides a logic flow diagram describing the joining of a first structural member and a second structural member initially fitted together and then permanently joined by a FSW to in accordance with an embodiment of the present invention;

FIG. 12 provides a logic flow diagram describing the joining of a first structural member and a second structural member initially fitted together and then permanently joined by a FSW to in accordance with an embodiment of the present invention;

FIG. 13 shows a structural member having a crack whose growth is retarded or arrested in accordance with an embodiment of the present invention;

FIG. 14 provides a logic flow diagram describing a process to retard or arrest crack propagation or growth with a structural member in accordance with an embodiment of the present invention;

FIG. 15 depicts an alternative way to form an in situ fastener provided by embodiments of the present invention employs friction stir welding and;

FIG. 16 provides a logic flow diagram in accordance with an embodiment of the present invention that uses a forming an in-situ extruded fastener to join a first member to a substrate.

DETAILED DESCRIPTION OF THE INVENTION

Embodiments of the present invention are illustrated in the FIGS., like numerals being used to refer to like and corresponding parts of the various drawings.

The present invention provides a means of joining a first structural member and a second structural member that substantially addresses the above identified needs. A three dimensional joint is formed by coupling (joining) a first structural member and a second structural member. This involves first aligning a first structural member to a second structural member. The first structural member has a channel with which to receive a portion of the second structural member. Certain embodiments may place corrosively inert materials within the mating surfaces to prevent or inhibit corrosion or oxidation. Once aligned, the first structural member and second structural member may be friction stir welded at the channel to plasticize the material adjacent to the channel of both the first structural member and the second structural member to form a friction stir weld joint. Embodiments may then coat the plasticized surfaces of the FSW joint with cold sprayed materials to inhibit corrosion. Should a crack occur within the plasticized or non-plasticized materials, cold sprayed material may be depos-
ited within and on the crack to retard or arrest the growth of the crack. One method of performing friction stir welding to join members is disclosed in U.S. patent application Ser. No. _____ entitled “A FRICTION STIR WELDING PROCESS TO JOIN TWO OR MORE MEMBERS IN FORMING A THREE-DIMENSIONAL JOINT,” which is incorporated by reference in its entirety for all purposes.

[0032] FIG. 3 shows a first structural member. FIG. 3 depicts two I-beams, 50 and 52. These may be similar to the beams discussed with reference to FIGS. 1A and 1B. However, unlike the beams of FIGS. 1A and 1B, I-beam 52 has a channel or groove 54 cut into the horizontal surface operable to receive a portion of the web 56 of I-beam 50 within the channel. In so doing, I-beam 50 is aligned to I-beam 52. FIG. 4 provides a side view of a portion of I-beam 52 wherein grooves 54 have been cut into the horizontal members 58 of I-beam 52. Channels 54 as previously discussed with respect to FIG. 3 may receive a portion of the member to be joined and aligned. Additionally channels 54 assist in fitting and holding member 52 and member 50 during the friction stir weld process. This greatly reduces the time required to setup and align structural members prior to permanently joining the members.

[0033] FIG. 5 provides a schematic diagram of cold spray process. In the cold spray process, energy stored in the high pressure compressed gas supply 52 is used to propel fine particles 54 supplied by a powder feeder 56 at high velocities. The compressed gas may be fed via heating unit 50 to gas 60 where the gas entrains particles 54 and exits through nozzle 62 at a high velocity. Powder particles 54 are accelerated to a certain velocity and heated to a desired temperature within gas 60. Upon impact with substrate 64 particles 54 are deformed and bond to substrate 64, thus forming coating 66. With this process a fine balance exist between particle size, density, temperature, and velocity in achieving a coating having a desired set of properties.

[0034] Embodiments of the present invention may provide a cold spray process where a powder, such as a powered metal, is directly and selectively applied to the exposed surface(s) of the FSW to act as sacrificial layer to protect the FSW joint depicted in the FIGS. Additionally, the impact of the powder during the cold spray process may create a small residual compressive stress which may add superior mechanical properties when compared to conventionally welded and aged joints. The cold spray process depicted in FIG. 5 may be used to apply an aluminum powder to the surface of the FSW joint on both the root and face or just the face as required.

[0035] Through cold spray processes, embodiments of the present invention can apply corrosion coatings to any configuration of a FSW joint to effectively protect exposed surfaces of the FSW joint. For structural members made using 7000 aluminum alloys, this may reduce or eliminate the need for a thermal treatment after FSW. This thermal treatment improves the corrosion resistance of 7000 aluminum alloys, but this sacrifices strength within the 7000 aluminum alloys. Applying cold spray materials to the FSW joint allows the 7000 aluminum alloys to retain their strength while protecting the weld area through the application of a coating via cold spray. Embodiments of the present invention may also provide the ability to apply a layer of coatings (i.e. Commercially Pure Aluminum (CP Al)) to a lapping FSW joint prior to FSW. This will have the result of providing a faying surface that has been effectively clad. Mixing the CP Al into the joint will not affect the strength adversely because of the small addition to the weld.

[0036] The cold spraying process may also be used to form in situ fasteners to metallic materials such as aluminum through composite. One such method is disclosed in U.S. patent application Ser. No. 11/279,970 entitled “PERFORATED COMPOSITES FOR JOINING OF METALLIC AND COMPOSITE MATERIALS,” which is incorporated by reference in its entirety for all purposes. The joint need not be that dissimilar, nor aluminum. Through cold spray processes, embodiments of the present invention can deposit powdered metal directly to the surface of a metal through a hole drilled into the mating member. This will improve the fatigue resistance of the member which has not be through drilled (i.e. the metal). Additionally, a friction stir spot weld of this compacted powder may be performed to further consolidate the cold spray material and providing better “adhesion” to the substrate. Both of these methods may be applied to a drilled hole or channel.

[0037] An alternative way to form an in situ fastener provided by embodiments of the present invention employs friction stir welding. By placing a metallic panel (i.e. Al) on top of a panel with a machined recess such as a hole or channel (could be composite) and using FSW on the surface of the metal, the resulting void will be filled by extruded metal. This has been demonstrated in an Aluminum to composite panel. The main advantage is that the composite can be processed separate and does not require laying up the composite on the metal like COMELD. This process will be further discussed with reference to FIGS. 15 and 16.

[0038] FIGS. 6 and 8 depict a FSW joint such as that discussed in FIG. 2 or a three-dimensional joint such as that discussed with reference to FIG. 3 and FIG. 4 may be used as well. To enhance the corrosion resistance of plasticized region 22 of the FSW joint a cold spray process such as that discussed with reference FIG. 5 may be utilized to deposit a sacrificial material such as an aluminum powder 64 that may bond to the FSW joint surface of the plasticized region of material. This will allow the aluminum powder 64 to form a sacrificial layer 76 on the surface of the friction stir weld joint that corrodes or oxidizes preferentially. Thus, the sacrificial layer 76 extends the life of the FSW joint. Additionally, the small residual compressive stresses may be imported to the surface of the FSW joint. These compressive stresses may improve the static and dynamic properties. This process provides a significant advantage in that cold spray is a relatively inexpensive process that allows precise deposition of material 64 where required. Additionally almost any material can be converted into a powder that can be deposited using cold spray. When compared to other techniques used to improve the corrosion performance application of the material over the entire part is required and does not provide a selective deposition process.

[0039] To further improve the friction stir weld joint of member 50 and 52, an adhesive may be deposited within the channel in order to assist in the fitting. This adhesive may also form a barrier to prevent moisture or other contaminants from penetrating the friction stir weld joint or any spaces (interface cavities) or gaps left following the joining process.

[0040] FIG. 7 provides an isometric view of two members, 50 and 52, in the process of forming a FSW joint. Here a portion of structural member 50 is received within channel 54 cut into the horizontal component 58 of I-beam 52. As previously stated, adhesive or other barrier protection mate-
rial may be placed within the channel to assist in fitting, at least temporarily, member 50 to member 52 prior to the FSW process. Rotating tool 24 inserts probe 28 into the member 52 above channel 54. This probe may also extend into the portion of member 50 contained within channel 54, however this is not required. Rotation of probe 28 and the shoulder 30 of rotating tool 24 will plastizize materials region 60. These materials include both materials within and adjacent to channel 54 from both structural member 50 and 52. This causes the material adjacent to the channel to plastizize as rotating tool 24 follow the path of channel 54. This eliminates the interface and forms a continuous joint that couples structural member 52 to member 50.  

[0041] Unlike prior applications of FSW where two pieces were abutted against each other and friction stir welded to form a single continuous panel. Embodiments of the present invention allow the creation of a three dimensional structure. Additionally, the application of FSW limits any deformation of the vertical portions of the members to be joined. Thus preserving the load bearing capability of the beams.  

[0042] FIG. 8 provides an isometric view of two structural members, structural members 84 and 86. These members are fitted using male portions 82 of structural members 84 that are received within female receptacles 86 and 88 of structural members 86. These male connectors and female receptacles assist in fitting structural members 84 to structural member 86 prior to the FSW process wherein the FSW process plasticizes region 90 that includes both the male connectors and female receptacles, as well as adjacent material within both structural members to form a continuous joint able to better distribute mechanical loads between structural member 84 to structural member 86.  

[0043] In the embodiment presented previously, one can deposit the adhesive or barrier material in the channel 54 of FIGS. 3, 4, and 5 or within receptacle 88 of FIG. 6. This material may then be forced from the receptacles or channels and into interfacing cavities as the material is plastizized. This may fill any free space with the adhesive or barrier material. Filling these spaces prevents penetration of contaminants such as moisture into the FSW joint. Such FSW joints are particularly applicable to structural members made of materials such as aluminum or aluminum alloys used in the fabrication of aircraft. Embodiments of the present invention enable the overall structural requirements and weight of the structural members to be reduced by eliminating localized regions of high structural load caused by drilling holes or other traditional fastener methods. Additionally, the mechanical loads from one structural member may be transferred throughout the continuous joint as opposed to localized fasteners where the two or more structural members meet.  

[0044] These FSW joints may be subject to crevice corrosion of the joint surfaces. One embodiment of the present invention addresses this issue with the addition of a corrosively inert layer applied prior to the FSW process. As shown in FIG. 9 an aluminum metallic (or other corrosively inert material) layer may be applied to selective areas 120 of the components 52 and 50 to be joined. This aluminum metallic layer may be applied using the cold spray process such as that discussed with respect to FIG. 5, kinetic metallization, or other like processes. Through the application of the metallic 120 the aluminum alloy structure may be protected from corrosive attack. This is done in much the same way that cladding would protect the structure. Cladding is a process where by a sheet of material such as a pure aluminum layer is roll bonded onto the surfaces. Addition of the cladding layer to the mating surfaces shown in FIGS. 9 and 10 as areas 120 will inhibit corrosion from moisture entrapment to the same degree cladding does. Friction stir welding through this thin layer of aluminum will not affect the mechanical properties significantly. Additionally embodiments of the present invention would enable the use of a post weld aging to increase the corrosion resistance of the entire structure because the additive aluminum layer would not be affected by thermal post processing. Cold spray technologies.  

[0045] FIG. 11 provides a logic flow diagram that may be used to illustrate various embodiments in the present invention wherein structural members are joined together using FSW joints. Operations 100 began by first aligning and fitting a first structural member to a second structural member in Step 110. This may be achieved by cutting into the first structural member a channel with which to receive a portion of the second structural member. Alternatively, or in combination, male connectors of either the first or second structural member may be aligned to and placed within female receptacles of the second and/or first structural member to fit these members together prior to the FSW. In either case, FSW is performed in Step 112 at the interface of the first and second structural members to join together the first and second structural members. In Step 114, material that preferentially oxidizes or corrodes may be deposited using a cold spray process, kinetic metallization, or other process to the exposed surface(s) of the structure.  

[0046] This will allow in one embodiment, aluminum powder to form a sacrificial layer on the surface of the FSW joint that corrodes or oxidizes preferentially. This sacrificial layer extends the life of the FSW joint. Additionally, the small residual compressive stresses may be imparted to the surface of the FSW joint. These compressive stresses may improve the static and dynamic properties. This process provides a significant advantage in that cold spray is a relatively inexpensive process that allows precise deposition of sacrificial material where required. Additionally almost any material can be converted into a powder that can be deposited using cold spray. When compared to other techniques used to improve the corrosion performance application of the material over the entire part is required and does not provide a selective deposition process.  

[0047] FIG. 12 provides a logic flow diagram that may be used to illustrate an embodiment of the present invention where structural members are joined together using FSW joints. Operations 200 begin in step 202 corrosively inert materials may be deposited using a cold spraying process, kinetic metallization, or other like process on the mating surfaces of the FSW joint. This corrosively inert material applied prior to the friction stir welding will protect the structure from corrosive attack in much the same way cladding does. For example, in one embodiment pure aluminum may be deposited on the mating surfaces of an aluminum alloy structure to be joined. This will inhibit corrosion from moisture entrapment to the same degree that a layer of cladding on the entire structure would. Additionally, when using a FSW joining process the thin layer of corrosively inert material will not affect mechanical properties of the structure significantly. In step 204 a first structural member may then be aligned to a second structural member where the corrosively inert materials have been
deposited on the mating surfaces of one or both the first and second structural members. In step 206 a friction stir welding process may be applied at the interface to join the first and second structural member. Optionally in step 208 a sacrificial material may be cold sprayed or deposited using kinetic metallization on the exposed surfaces of the FSW joint to further inhibit corrosion.

In another embodiment of the present invention as illustrated in FIG. 13, a crack within a Material 220 may be arrested or retarded using a cold spray process such as that described with reference to FIG. 5. As shown in FIG. 13 Material 220 has developed a Crack 222. A layer of Material 224 may be deposited on top of and within Crack 222 to retard or arrest the growth of Crack 222. Additionally other embodiments of the present invention may apply a friction stir weld process to plasticize the material around Crack 222 and then coat the exterior surface with a corrosion inhibiting material as part of Layer 224.

FIG. 14 provides a logic flow diagram in accordance with an embodiment of the present invention wherein cracks within a joined structure or individual structural member may be arrested or retarded via the use of cold spray. In Step 242 a crack is identified within a structural member or joined structural members. In Step 244 materials as applied using a cold spray or kinetic metallization process over the crack. This material may serve to arrest or retard the growth of the crack. Optionally a friction stir weld process may be applied to the material around the crack in order to retard the growth of the crack. This may be done prior to the deposition of the cold spray material or after the cold spray process to plasticize the material adjacent to the crack. The cold spray process can be used to deposit directly to a cracked surface to effectively stop or delay the crack growth for thousands of cycles if not permanently. This allows cracked surfaces to be repaired on site, in the field with minimal access.

Additional steps may require the placing of an adhesive or barrier material within the channel, upon the male connectors, or within the female receptacles. This adhesive or barrier material fills interface cavities to prevent contaminants from entering.

This invention solves prior problems by using the existing structural members, such as I-beams C-beams, that incorporate alignment guides (i.e. channels, connectors, and/or receptacles) to fit and FSW these materials to form three dimensional shapes such as T-joint configurations. By incorporating a groove or channel into the horizontal pieces and inserting the vertical pieces into these alignment guides, both members are joined together without disturbing the radius of the upstanding channel or groove. This joint can be further enhanced through the application of an adhesive or barrier material near the top of the alignment guide which will allow load transfer of material not joined by the FSW. The adhesive or barrier material acts to deny penetration into the joint by moisture or other contaminants. This adhesive facilitates fitting the parts (i.e. structural members), during setup.

The T-grooved or channel T FSW joint provided by embodiments of the present invention has many advantages. First the drilling of holes and fastener installation is eliminated for assembly of structure members. In so doing, the fatigue lives of the structural members are extended through the elimination of localized stresses concentrated by these holes. Stiffness can be distributed over the entire cross section versus 2 or 3 bolts/fasteners interfaces enabling lower overall weight of the structural members and structure. Set up time is reduced by using the adhesive to locate the mating parts. This reduces or eliminates complex tooling requirements. Pull off strength and fatigue life in the finished structure may be improved by the addition of adhesives. The adhesive also fills the interface cavities disallowing water or contaminant entrapment. In so doing crevice corrosion is inhibited. Cold spray and adhesives improve the stiffness and rigidity of the finished assembly by improving the stiffener effectiveness. Nascent adhesive from the weld joint also provides a visual indicator that adhesive material is present in the weld joint, thus simplifying NDE verification.

FIG. 15 depicts an alternative way to form an in situ fastener provided by embodiments of the present invention employs friction stir welding. By placing a metallic panel 252 (i.e. Al) on top of a panel 254 with machined recess(es) 256 such as a hole or channel (could be composite) and using FSW process on the exterior surface of the metallic panel, the resulting void 258 will be filled by extruded metal. This has been demonstrated in an Aluminum to composite panel. The main advantage is that the composite can be processed separate and does not require laying up the composite on the metal.

FIG. 16 provides a logic flow diagram in accordance with an embodiment of the present invention that uses forms an in-situ extruded fastener to join a first member to a substrate similar to that provided in FIG. 15. The first structural member is aligned to a metallic substrate in step 260 wherein the first structural member has a number of shaped or tapered cavities. Protective inserts may be placed within the shaped or tapered cavities. Unlike prior applications of FSW where two metallic pieces were abutted against each other and friction stir welded to form a single continuous panel. Embodiments of the present invention allow the FSW process to be applied to secure composite and metallic pieces without the need for additional fasteners—thus reducing part count and increasing the mechanical bonds. Additionally, the application of FSW limits any deformation of the vertical portions of the members to be joined. Thus preserving the load bearing capability of the beams. In step 262 a FSW tool may be applied to the exterior surface of the metallic substrate, the voids will be filled by extruded metal. This has been demonstrated in an Aluminum to composite panel. The extruded in-situ tapered fasteners which may be used to secure materials such as composite materials to metallic materials. This is achieved without the need drill into the metallic materials. Such an arrangement reduces the setup costs in time and money that are associated with drilling holes, installing fasteners and addressing nonconformance. These setup costs have been determined to be the greatest assembly line cost driver for some advanced aircraft. Further, the issue of hole alignment to fasteners is essentially eliminated. Thus reduce the quality assurance issues associated with nonconformance. By preparing the composite materials off-line, edge distance concerns are greatly reduced.

In summary, embodiments of the present invention provide a three dimensional joint formed by coupling (joining) a first structural member and a second structural member. This involves first aligning a first structural member to a second structural member. The first structural member has a channel with which to receive a portion of the second structural member. Once aligned, the first structural member
and second structural member may be friction stir welded at the channel to plasticize the material adjacent to the channel of both the first structural member and the second structural member to form a FSW joint. One embodiment then coats the plasticized surfaces of the FSW joint with cold sprayed materials to inhibit corrosion. Another embodiment places corrosively inert materials within the mating surfaces to prevent or inhibit corrosion or oxidation. Should a crack occur within either the plasticized or non-plasticized materials, cold sprayed material may be deposited within and on the crack to retard or arrest the growth of the crack.

Although the present invention is described in detail, it should be understood that various changes, substitutions and alterations can be made hereto without departing from the spirit and scope of the invention as described by the appended claims.

What is claimed is:

1. A method for joining structure members, comprising:
   aligning a first structural member to a second structural member;
   the first structural member having a channel to receive a portion of the second structural member;
   friction stir welding (FSW) at the channel to join the first structural member to the second structural member;
   cold spraying material on exposed surfaces of an FSW joint to inhibit corrosion.

2. The method of claim 1, further comprising placing a corrosively inert material at the channel to inhibit crevice crack corrosion.

3. The method of claim 2, further comprising preventing moisture penetration into a FSW joint formed by the first structural member and the second structural member with the corrosively inert material.

4. The method of claim 1, further comprising placing an adhesive material at the channel, the adhesive material operable to fit the first structural member to the second structural member prior to FSW.

5. The method of claim 1, wherein the first structural member and the second structural member are within a vehicle frame.

6. The method of claim 1, wherein the first structural member and the second structural member comprise:
   a box beam;
   an I-beam;
   a double I-beam; or
   a C-Beam.

7. The method of claim 1, wherein the first structural member and the second structural member comprise an aluminum alloy.

8. The method of claim 1, further comprising:
   inserting a male connector of the first structural member and/or second structural member into a female receptacle of the second structural member and/or first structural member;
   friction stir welding materials of the male connector into the female receptacle to create a FSW coupling.

9. A method for joining structural members, comprising:
   aligning a first structural member to a second structural member;
   the first structural member having a channel to receive a portion of the second structural member;
   inserting a male connector of the first structural member and/or second structural member into a female receptacle of the second structural member and/or first structural member;
   friction stir welding (FSW) at the channel and a male connector/female receptacle interface to join the first structural member to the second structural member; and
   cold spraying material on exposed surfaces of an FSW joint to inhibit corrosion.

10. The method of claim 9, further comprising placing a corrosively inert material at the channel to inhibit crevice crack corrosion.

11. The method of claim 10, further comprising preventing penetration of contaminants into a friction stir weld joint formed by the first structural member and the second structural member, the penetration prevented with the corrosively inert material.

12. The method of claim 9, wherein the first structural member and the second structural member are within a vehicle frame.

13. The method of claim 9, wherein the first structural member and the second structural member comprise:
   a box beam;
   an I-beam;
   a double I-beam; or
   a C-Beam.

14. The method of claim 9, wherein the first structural member and the second structural member comprise an aluminum alloy.

15. A friction stir weld joint, comprising:
   a first structural member, the first structural member having a channel;
   at least one second structural member, the channel of the first structural member receives a portion of the at least one second structural member, the materials of the first structural member and at least one second structural member friction stir welded at the interface of the first structural member and at least one second structural member at the channel; and
   cold sprayed material deposited on an exposed surface of the friction stir weld interface operable to inhibit corrosion.

16. The friction stir weld joint of claim 15, wherein the channel is within a horizontal member of the first structural member, the channel receives a vertical member of the second structural member.

17. The friction stir weld joint of claim 15, wherein a barrier material within the channel fills interface cavities at the friction stir weld joint to prevent contamination from entering the friction stir weld joint.

18. The friction stir weld joint of claim 16, wherein the barrier material comprises corrosively inert material.

19. The friction stir weld joint of claim 15, further comprising:
   a male connector of the first structural member and/or second structural member;
   a female receptacle of the second structural member and/or first structural member operable to receive the male connector;
   the materials of the male connector friction stir welded into the female receptacle.

20. The friction stir weld joint of claim 15, wherein an adhesive material at the channel, the male connector, and/or the female receptacle, the adhesive material operable to fit the first structural member to the second structural member prior to friction stir welding.
21. The friction stir weld joint of claim 15, wherein the first structural member and the second structural member are within a vehicle frame.

22. The friction stir weld joint of claim 15, wherein the first structural member and the second structural member comprise:
   a box beam;
   an I-beam;
   a double I-beam; or
   a C-Beam.

23. The friction stir weld joint of claim 15, wherein the first structural member and the second structural member comprise an aluminum alloy.

24. A friction stir weld joint, comprising:
   a first structural member, the first structural member having a channel;
   at least one second structural member, the channel of the first structural member receives a mating surface of the at least one second structural member, the mating surface and/or channel being coated with corrosively inert material, the materials of the first structural member and at least one second structural member friction stir welded at the interface of the first structural member and at least one second structural member at the channel; and
   cold sprayed material deposited on an exposed surface of the friction stir welded interface operable to inhibit corrosion.

25. A friction stir weld joint, comprising:
   a first structural member, the first structural member having a channel; and
   at least one second structural member where the channel of the first structural member receives a mating surface of the at least one second structural member, the mating surface and/or channel being coated with corrosively inert material, the materials of the first structural member and at least one second structural member friction stir welded at the interface of the first structural member and at least one second structural member at the channel.

26. A method for joining structure members, comprising:
   aligning a first structural member to a second structural member, the first structural member having a channel to receive a portion of the second structural member;
   placing a corrosively inert material at the channel to inhibit crevice crack corrosion; and
   friction stir welding (FSW) at the channel to join the first structural member to the second structural member.

27. A method for joining structural members, comprising:
   aligning a first structural member to a second structural member, the first structural member having a channel to receive a mating of the second structural member;
   inserting a male connector of the first structural member and/or second structural member into a female receptacle of the second structural member and/or first structural member;
   placing a corrosively inert material at the channel/mating surface to inhibit crevice crack corrosion;
   placing a corrosively inert material at a male connector/female receptacle interface to inhibit crevice crack corrosion;
   friction stir welding (FSW) at the channel and a male connector/female receptacle interface to join the first structural member to the second structural member.

28. A method for retarding crack growth within a structural member, comprising:
   identifying a crack within the structural member; and
   cold spraying material on/within the crack to retard crack growth.

29. A method for joining a first structural member and a substrate, comprising:
   aligning a first structural member to a metallic substrate;
   the first structural member having at least one shaped cavity; and
   friction stir welding an exterior surface of the metallic substrate proximate to the at least one shaped cavity to extrude metallic material to the at least one shaped cavity.

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