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(54) Title: MULTIPLE PASS AND MULTIPLE LAYER FRICTION STIR WELDING AND MATERIAL ENHANCEMENT PROCESSES

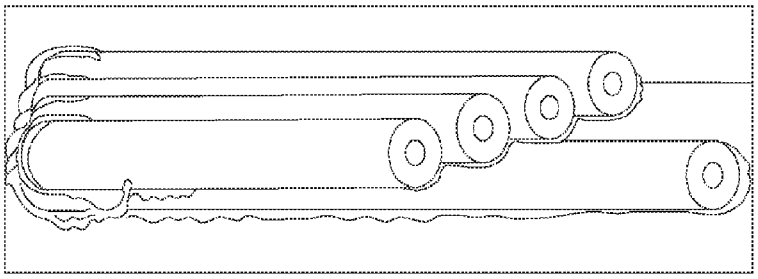

FIG. 9

(57) Abstract: Processes for friction stir welding, typically for comparatively thick plate materials using multiple passes and multiple layers of a friction stir welding tool. In some embodiments a first portion (10) of a fabrication preform and a second portion (12) of the fabrication preform are placed adjacent to each other to form a joint, and there is a groove (22) adjacent the joint. The joint is welded and then, a filler is disposed in the groove, and the seams between the filler and the first and second portions of the fabrication preform may be friction stir welded.

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MULTIPLE PASS AND MULTIPLE LAYER FRICTION STIR WELDING AND MATERIAL ENHANCEMENT PROCESSES

CROSS REFERENCE TO RELATED APPLICATION

This application claims priority to U.S. Patent Application 12/051,972 filed on March 20, 2008, entitled "MULTIPLE PASS AND MULTIPLE LAYER FRICTION STIR WELINDG AND MATERIAL ENHANCEMENT PROCESSES."

GOVERNMENT RIGHTS

[0001] This invention was made with government support under Contract No. DE-AC05-00OR22725 awarded by the U.S. Department of Energy. The government has certain rights in the invention.

FIELD

[0002] This disclosure relates to the field of friction stir welding and material processing. More particularly, this disclosure relates to methods of joining fabrication preforms or portions of a fabrication preform or workpieces and fillers at their edges using friction stir welding, and methods to form new and/or enhanced materials by means of friction stir material processing.

BACKGROUND

[0003] Friction stir welding (FSW) is a welding process in which a cylindrical, shouldered welding tool having a pin protruding from the shouldered surface is rotated and plunged into a joint line between two portions of a fabrication preform. The portions of the fabrication preform are typically of metal, but the process may also be used on various plastics and polymers. Typically the pieces are clamped together to prevent relative motion between the pieces during the welding process. Frictional heat is generated between the pin and the material of the portions of the fabrication preform. This heat causes the adjacent material to soften (generally without reaching its melting point). The tool is then moved relative to the portions of the fabrication preform along a weld line while the shoulder of the tool is pressed against the surface of each portion of the fabrication preform. The softened material is transferred from the leading edge of the pin to the trailing edge of the pin. The shoulder helps form a flat weld that is even with the surface of each portion of the fabrication preform and that, after cooling, bonds the portions of the fabrication preform together.

[0004] The power required to spin a friction stir tool increases significantly when the process is applied to thicker and/or harder materials. Consequently, current friction stir welding processes are generally best suited for welding aluminum or other comparatively soft metals with thicknesses of less than approximately one inch (2.5 cm). What are needed therefore are improved friction stir welding processes that may be applied to thicker and/or harder materials.

SUMMARY

[0005] The present disclosure provides a method of joining a first portion of a fabrication preform and a second portion of the fabrication preform where the portions of the fabrication preform have abutted edges that form a joint and wherein a groove is disposed adjacent at least a portion of the joint. The method includes a step of friction stir welding at least a portion of the joint. The method further includes a step of disposing a filler in at least a portion of the groove, wherein a first seam is formed between the filler and the first portion of the fabrication preform and a second seam is formed between the filler and the second portion of the fabrication preform. The method proceeds with friction stir welding at least a portion of the first seam and friction stir welding at least a portion of the second seam. Additional friction stir weld steps may be applied with fillers to further join portions of the fabrication preform.

[0006] Also provided is a method of forming an enhanced structure from a fabrication preform having a first common surface and a recess below the first common surface. This method has a step of disposing in at least a portion of the recess a filler comprising a composition of material that may be the same or different than at least a portion of the fabrication preform, wherein a first seam and a second seam are formed between the filler and at least a portion of the recess. The method proceeds with friction stir welding at least a portion of the first seam in a first pass of a friction stir welding tool to form a first bond, and friction stir welding at least a portion of the second seam in a second pass of a friction stir welding tool to form a second bond. Additional friction stir weld steps may be applied with fillers to further join portions of the fabrication preform.

[0007] Another embodiment provides a method of forming an enhanced material from a fabrication preform having a first common surface and a recess below the first common surface. This method includes a step of disposing in at least a portion of the recess a filler comprising a composition of material that is different than at least a portion of the fabrication preform, wherein a first seam and a second seam are formed between the filler and at least a portion of the recess. A further step is friction stir mixing at least a portion of the first seam

in a first pass of a friction stir tool to form a first bond, and a further step is friction stir mixing at least a portion of the second seam in a second pass of a friction stir tool to form a second bond. Further friction stir steps may be applied to produce substantially homogeneous materials or materials with improved compositions and/or property gradients.

[0008] Also provided is a method of joining a first portion of a fabrication preform and a second portion of the fabrication preform where the first portion of the fabrication preform has a first planar surface, an opposing second planar surface, and a first edge and the second portion of the fabrication preform has a third planar surface and an opposing fourth planar surface and a second edge. The first edge and the second edge form a seam between the first portion of the fabrication preform and the second portion of the fabrication preform, and the first planar surface and the third planar surface are substantially co-planar and form a first common surface. The second planar surface and the fourth planar surface are substantially co-planar and form a second common surface. The method includes the step of friction stir welding at least a portion of the seam along a first weld path on the first common surface, where the first weld path forms a first weld path plane that is perpendicular to the first common surface. The method also includes the step of friction stir welding at least a portion of the seam on a second weld path on the second common surface, where the second weld path forms a second weld path plane that is perpendicular to the second common surface.

[0009] Another embodiment provides a method of joining a first portion of a fabrication preform having a first thickness and a second portion of the fabrication preform having a second thickness. The method includes a step of disposing a transition piece between the first portion of the fabrication preform and the second portion of the fabrication preform. The transition piece has a first edge and a second edge opposed to the first edge, and the transition piece is configured to vary in thickness from approximately the first thickness at the first edge to approximately the second thickness at the second edge. A first joint is formed between the first portion of the fabrication preform and the transition piece and a second joint is disposed between the transition piece and the second portion of the fabrication

preform. The method also includes the step of friction stir welding at least portions of the first joint, and the step of friction stir welding at least a portion of the second joint.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Various advantages are apparent by reference to the detailed description in conjunction with the figures, wherein elements are not to scale so as to more clearly show the details, wherein like reference numbers indicate like elements throughout the several views, and wherein:

[0011] Figs. 1A – 1Q are somewhat schematic cross-sectional illustrations of steps in friction stir welding processes.

[0012] Figs. 2A – 2M are somewhat schematic cross-sectional illustrations of components and steps used in certain friction stir processes.

[0013] Figs. 3A – 3C are somewhat schematic cross-sectional illustrations of seams between edges of two portions of a fabrication preform that may be joined using friction stir welding.

[0014] Fig. 4 is a somewhat schematic cross-sectional view of two friction stir welding tools performing a friction stir welding operation on the portions of the fabrication preform of Fig. 3B.

[0015] Figs. 5A – 5C depict various features of weld paths and weld planes used in friction stir welding processes.

[0016] Figs. 6A and 6C illustrate a friction stir welding process for joining materials of different thicknesses.

[0017] Figs. 7A and 7C illustrate a friction stir welding process for joining materials of different thicknesses.

[0018] Fig. 8 illustrates an example of a friction stir welding root pass.

[0019] Fig. 9 illustrates an example of a completed multi-pass demonstration friction stir weld.

[0020] Figs. 10A – 10C are photographs of cross-sections of an example of a multi-pass friction stir weld at successive stages of completion.

DETAILED DESCRIPTION

[0021] In the following detailed description of the preferred embodiments, reference is made to the accompanying drawings, which form a part hereof, and within which are shown by way of illustration the practice of specific embodiments of methods of joining a first portion of a fabrication preform and a second portion of the fabrication preform using friction stir welding and embodiments of reinforcing a fabrication preform structure using friction stir welding. Also depicted are various embodiments for producing enhanced structures and materials using stir friction processes. It is to be understood that other embodiments may be utilized, and that structural changes may be made and processes may vary in other embodiments.

[0022] Figures 1A – 1Q illustrate various steps in a multiple-pass and multiple-layer friction stir welding processes. Figure 1A depicts a cross-sectional edge view of a first portion 10 of a fabrication preform and a second portion 12 of a fabrication. In some embodiments the first portion 10 of the fabrication preform is a first workpiece and the second portion 12 of the fabrication preform is a second workpiece that is to be joined with the first workpiece. In other embodiments the first portion 10 of the fabrication preform and the second portion 12 of the fabrication preform are portions of the same workpiece that are to be joined together. In some embodiments the first portion 10 of the fabrication preform and the second portion 12 of the fabrication preform are composed of substantially the same composition of material, and in other embodiments the first portion 10 of the fabrication preform and the second portion 12 of the fabrication preform may be composed of different compositions of material. When referring herein to different compositions of material these differences may be chemical differences and/or physical bulk property differences such as density differences. The first portion 10 of the fabrication preform has a first edge 14 and the second portion 12 of the fabrication preform has a second edge 16. The first edge 14 and the second edge 16 abut and form a joint 18 between the first portion 10 of the fabrication preform and the second portion 12 of the fabrication preform. The joint 18 has a first height 20. A first groove 22 is disposed between the first portion 10 of the fabrication preform and the second

portion 12 of the fabrication preform, adjacent the joint 18. The base of the first groove 22 forms a first common surface 24 of the first portion 10 of the fabrication preform and the second portion 12 of the fabrication preform. The first portion 10 of the fabrication preform and the second portion 12 of the fabrication preform and a portion of the joint 18 form a second common surface 26 that is opposed to the first common surface 24. As used herein, a "common surface" is a generally flat planar surface formed by two or more generally adjacent elements. It is understood that some discontinuities and irregularities may occur in the contour of a common surface provided that they do not prevent the application of a friction stir welding process along a path on the common surface.

[0023] In some embodiments as depicted in Figure 1B, a back support piece 28 may be used to help maintain the structural integrity of the portions of the fabrication preform (e.g., portions of the fabrication preform 10 and 12) during friction stir welding or material enhancement processes. The back support piece 28 typically does not become a portion of the assembly that is formed after friction stir welding.

[0024] Figure 1C illustrates an alternate embodiment wherein a bridge material 30 is disposed between the first portion 10 of the fabrication preform and the second portion 12 of the fabrication preform. The first portion 10 of the fabrication preform and the second portion 12 of the fabrication preform are considered to have abutting edges (14 and 16) even though the bridge material is disposed between the first edge 14 and the second edge 16. The first edge 14 and the second edge 16 and the bridge material 30 form a joint 32 between the first portion 10 of the fabrication preform and the second portion 12 of the fabrication preform. Figure 1D depicts an alternate configuration of bridge material 38 that in part defines a joint 40 between the first portion 10 of the fabrication preform and the second portion 12 of the fabrication preform. At least a portion of the bridge material 38 is configured to be disposed above the first common surface 24 (identified in Figure 1A) and that portion of the bridge helps maintain a flow of bridge material between the first portion 10 of the fabrication preform and the second portion 12 of the fabrication preform during friction stir welding. It should be noted that the joint 32 of Figure 1C and the joint 40 of

Figure 1D (where a filler is disposed between the edges of portions of a fabrication preform), and the joint 18 of Figure 1A the joint 18 (where the joint is a seam between the edges of portions of a preform without an intervening filler) are each defined as "joints" herein.

[0025] The bridge material 30 or 38 may be useful in cases of fabrication preform dimensional variations, and/or to form a first bond between the first portion 10 of the fabrication preform and the second portion 12 of the fabrication preform that has a different composition and/or physical properties from either or both the first and second portions of the fabrication preform (10 and 12). The bridge material 30 or 38 may be composed of substantially the same composition of material as the first portion 10 of the fabrication preform and/or the second portion 12 of the fabrication preform, or the bridge material 30 or 38 may be composed of a composition of material that is different from the composition of material of the first portion 10 of the fabrication preform and different from the composition of material of the second portion 12 of the fabrication preform. In some embodiments the bridge material 30 or 38 is a composite material. As used herein the term "composite material" refers to a plurality of materials with each material being disposed in a separate physical region of the composite material. In many but not all cases the materials have different compositions of material. Examples of a composite material are a metal/metal composite, a cermet composite, a bundle of wires, a package of layered materials, and other aggregations of materials having the same or different compositions. For example, a bundle of wires or rods made of different materials may be consolidated by thermal/mechanical processes to synthesize a composite material for use as the bridge material 30 or 38.

[0026] Figure 1E shows a starting step of a friction stir welding process to join the first portion 10 of the fabrication preform and the second portion 12 of the fabrication preform as configured in Figure 1A. A similar starting step may be used to join the first portion 10 of the fabrication preform and the second portion 12 of the fabrication preform as configured in Figures 1B, 1C, or 1D. Figure 1E illustrates a friction stir welding tool 42 with a pin 44 that protrudes from a shoulder surface 46 of the tool 42. To start the process of friction stir welding, the pin 44 of the tool 42 is rapidly rotated around the axis of the pin and then

typically the pin 44 is plunged into or proximal to the first seam 18 (identified in Figure 1A). In the case of the configuration of Figure 1C the shoulder surface 46 of the tool 42 is pressed against the bottom of the first groove 22 (identified in Figure 1A). In the case of the configuration of Figure 1D the shoulder surface 46 of the tool 42 is pressed against the top of the filler 38. While the tool 42 continues to rotate, the tool 42 is moved laterally along a weld path that follows the joint 18 (or the joint 32 in the configuration of Figure 1C or the joint 40 in the configuration of Figure 1D). This is called a welding pass. The joint 18 (or 32 or 40) and an associated weld path may follow a straight line, a curved line, or a jagged line and may comprise a simple planar surface, a collection of many simple planar surfaces, a non-planar surface, or a collection of many non-planar surfaces. Material from the first portion 10 of the fabrication preform that is adjacent the joint 18 (or 32 or 40) and material from the second portion 12 of the fabrication preform that is adjacent the joint 18 are friction stir welded to form a first bond 48 (as seen in Figure 1F). The welding pass that forms the first friction stir weld (i.e., the first bond 48 in this embodiment) of a multi-pass friction stir weld is referred to herein as the "root pass."

[0027] As labeled in Figure 1G, a first fillet 50 cut into the first portion 10 of the fabrication preform and a second fillet 52 cut into the second portion 12 of the fabrication preform form a second groove 54 between the first portion 10 of the fabrication preform and the second portion 12 of the fabrication preform. The second groove 54 is adjacent the first groove 22 (identified in Figure 1A). Subsequent to the formation of the first bond 48, a first filler 56 is disposed in at least a portion of the first groove 22 between the first portion 10 of the fabrication preform and the second portion 12 of the fabrication preform. Typically the first filler 56 is a solid bar that is inserted into the first groove 22 (identified in Figure 1A) after the first bond 48 is formed and before further friction stir welding is performed. In some embodiments the first filler 56 may be a powder or a paste material. The first filler 56 may be composed of substantially the same composition of material as the first portion 10 of the fabrication preform and/or the second portion 12 of the fabrication preform, or the first filler 56 may be composed of a composition of material that is different from the composition of material of the first portion 10 of the fabrication preform and different from the composition

of material of the second portion 12 of the fabrication preform. In some embodiments the first filler 56 is a composite material, such as metal/metal composite, a cermet composite, or a bundle of wires, layered materials or other forms of mixture of the same or different materials. For example, a bundle of wires or rods made of different materials may be consolidated by thermal/mechanical processes to synthesize the filler 56.

[0028] In the sequence of operations depicted in Figures 1A – 1Q the second groove 54 (identified in Figure 1G) was cut into the first portion 10 of the fabrication preform and the second portion 12 of the fabrication preform before any friction stir welding was performed. However, in alternate embodiments the second groove 54 may, for example, be machined out after the first bond 48 is formed and either before or after the first filler 56 is disposed in at least a portion of the first groove 22.

[0029] Continuing further with Figure 1G, the base of the first fillet 50, the top of the first filler 56 and the base of the second fillet 52 form a third common surface 58. A first seam 64 is formed between the first filler 56 and the first portion 10 of the fabrication preform and a second seam 66 is formed between the first filler 56 and the second portion 12 of the fabrication preform. The first seam 64 and the second seam 66 each have a second height 68, and the second height 68 is different from the first height 20 of the joint 18. Configuring different seam heights may be useful in balancing energy requirements between friction stir welds in a multi-pass friction stir welding process. It is understood that a "seam" as described herein (such as the seam 64 or seam 66) and an associated weld path may follow a straight line, a curved line, or a jagged line and may comprise a simple planar surface, a collection of many simple planar surfaces, a non-planar surface, or a collection of many non-planar surfaces.

[0030] Then as depicted in Figure 1H, a second friction stir tool 70 is used along the first seam 64 (identified in Figure 1G) to form a second bond 80, as seen in Figure 1I. As further depicted in Figure 1H, a source of pre-heating 82 may be applied to the material adjacent the second seam 64 (as identified in Figure 1G). The preheating 82 may, for example, be provided by a laser, an electric arc, an induction heating source, an infrared source, an

ultrasonic source, or a microwave source. The preheating 82 typically softens and may even partially melt the materials being friction stir welded. This typically reduces the energy load required to drive the second friction stir tool 70.

[0031] In Figure 1J the second friction stir tool 70 is used along the second seam 66 (identified in Figure 1G) to form a third bond 84, as seen in Figure 1K. As further depicted in Figure 1J, a source of pre-heating 82 may be applied to the material adjacent the second seam 66 (as identified in Figure 1G). In the embodiment of Figure 1J a portion 86 of the first filler 56 remains substantially unaltered by the friction stir welding process. In alternate embodiments such as depicted in Figure 1K a further pass (or passes) of the friction stir tool 70 may be used to mix the entirety of the first filler 56 with the second bond 80 and the third bond 84 to form a mixed bond 90 as depicted in Figure 1L. In alternate embodiments the entirety of the first filler 56 may be mixed with the second bond 80 and the third bond 84 and with at least portions of the material of the first portion 10 of the fabrication preform, the second portion 12 of the fabrication preform, and the root pass (the first bond 48) to form a mixed bond. For maximum strength of a weld is desirable to mix the materials so that the weld is formed without any voids or discontinuities.

[0032] As further seen in Figure 1L, after completion of the friction stir welding processes of Figure 1J and 1K, a second filler 94 is disposed in at least a portion of the second groove 54 (identified in Figure 1G) between the first portion 10 of the fabrication preform and the second portion 12 of the fabrication preform. A third seam 96 is formed between the second filler 94 and the first portion 10 of the fabrication preform, and a fourth seam 98 is formed between the second filler 94 and the second portion 12 of the fabrication preform.

[0033] Then as seen in Figure 1M, two friction stir tools 110 and 112 are used simultaneously along the third seam 96 and the fourth seam 98 respectively. This forms a fourth bond 114 and a fifth bond 116 as seen in Figure 1N. In the embodiments of Figures 1A – 1N, a portion 118 of the second filler 94 remains substantially unaltered by the friction stir welding processes, as depicted in Figure 1N. As illustrated in Figure 1O, in some embodiments further friction stir welding passes represented by stir tools 130, may be made

through the portion 118 to mix substantially all of the second filler 94 with either or both of the fourth bond 114 and the fifth bond 116. The result may be a partially homogenous surface region 132 depicted in Figure 1P. Further more, by using a friction stir welding tool (such as friction stir welding tool 70) that has a longer pin than the pin of friction stir welding tool 110 or 112, a portion of the second filler 94 may be mixed with the second bond 80, and/or with the portion 92 of the first filler 56, and/or with the third bond 90. Furthermore, as illustrated in Figure 1Q, by using combinations of successive passes a substantially homogenously region 134 may be created to bond the portions of the fabrication preform together. The completed welds in Figures 1N, 1P, and 1Q are examples of "multiple pass" and "multiple layer" friction stir welds.

[0034] It is understood that some or all of the steps described in Figure 1A-1Q may be repeated multiple times to produce a welded structure of virtually unlimited thickness.

[0035] Figures 2A – 2M depict friction stir processes and results performed on a fabrication "preform" in order to form an enhanced structure (article of manufacture) and/or to produce enhanced materials (compositions of material). The enhanced structure or enhanced material may have enhanced chemical, physical, mechanical or electrical properties, or combinations thereof. For example, an enhanced structure or enhanced material may have improved catalytic properties or improved corrosion resistance. An enhanced structure or enhanced material may have (in at least portions of the enhanced structure) modified conductive, semi-conductive, or insulative electrical or thermal properties or different magnetic properties. An enhanced structure or enhanced material may have improved or intentionally diminished strength, or may have a modified coefficient of thermal expansion, or may have a modified melting temperature.

[0036] Figure 2A illustrates a fabrication preform 140 that includes a first piece 142 and a second piece 144. The fabrication preform 140 has a first common surface 146. A gap 148 between the first piece 142 and the second piece 144 forms a recess below the first common surface 146 of the fabrication preform 140. Figure 2B illustrates a fabrication preform 160

formed from a single piece 162. The fabrication preform 160 has a first common surface 164. A channel 166 forms a recess below the first common surface 164.

[0037] In Figure 2C a filler 180 is disposed in at least a portion of the recess (the gap 148 identified in Figure 2A) in the fabrication preform 140 to form a filled preform 182. The filler 180 typically includes a composition of material that is different from the composition of material of the first piece 142 of the fabrication preform 140 and/or that this different from the composition of material of the second piece 144 of the fabrication preform 140. In some embodiments, the filler material 180 is a composite material, such as metal/metal composite, a cermet composite, or a bundle of wires, layered materials or other forms of mixture of the same or different materials. The composite filler 180 may be consolidated or synthesized by the thermal/mechanical deformation and mixing action of the friction stir process to form an enhanced structure and/or to produce enhanced or new materials. In other embodiments, the filler 180 has a composition substantially same as either the first piece 142 or the second piece of 144. A first seam 184 is formed between the filler 180 and the recess (the gap 148) in the fabrication preform 140 and a second seam 186 is formed between the filler 180 and the recess (the gap 148) in the fabrication preform 140. In Figure 2D a filler 200 is disposed in at least a portion of the recess (the channel 166) in the fabrication preform 160 to form a filled preform 202. A first seam 204 is formed between the filler 200 and the recess (channel 166) in the fabrication preform 160 and a second seam 206 is formed between the filler 200 and the recess (channel 166) in the fabrication preform 160.

[0038] Figures 2E – 2L depict friction stir processes and results performed on the filled preform 182 depicted in Figure 2C. Similar friction stir processes and similar results may be achieved using the filled preform 202 depicted in figure 2D, or other similar filled preforms.

[0039] Figure 2E depicts a friction stir tool 220 being used along the first seam 184 (identified in Figure 2C) of filled preform 182 to form a first bond 222, as seen in Figure 2F. Then in Figure 2G the friction stir tool 220 is used along the second seam 186 (identified in Figure 2C) of filled preform 182 to form a second bond 224, as seen in Figure 2H.

[0040] In Figure 2I, a further pass of the friction stir tool 220 is made between the material of the first piece 142 (identified in Figure 2A) and the first bond 222 (identified in Figure 2F). This further pass is referred to as stir mixing and it blends the materials of the first bond 222 and the first piece 142 and forms a first blended bond 226 as depicted in Figure 2J. Such blending may be desirable to form a graded material having more gradual changes in material composition. Additional mixing may be achieved with additional passes between the first blended bond 226 and the first piece 142 to vary the gradient of the material.

[0041] In Figure 2K, a further stir mixing pass of the friction stir tool 220 is made between the material of the second piece 144 (identified in Figure 2A) and the second bond 224 (identified in Figure 2F). This further stir mixing pass blends the materials of the second bond 224 and the second piece 144 and forms a second blended bond 228 as depicted in Figure 2L. The result of these processes is an enhanced structure 230 as depicted in Figure 2L. Additional passes with the friction stir tool 220 may be made through various portions of the enhanced structure 230 in order to further bond or blend the composition of materials.

[0042] In some cases, it may be desirable to process the remaining material with one or more passes between 226 and 228 to form new materials (e.g., composite materials) that combine materials from the first piece 142 and the second piece 144 and the filler 180. This may produce a substantially uniform block of material such as substantially homogenous region 240 of Figure 2M. The properties of substantially homogenous region 240 are typically different from the individual properties of the portions of the fabrication preform and the fillers that were used to produce the substantially homogenous region 240. The substantially homogenous region 240 may be sectioned from the finished assembly as a new composition of material and used to fabricate articles of manufacture. In summary, the substantially homogenous region 240 may be produced by the friction stir bonding and/or blending action on a compound of individual materials, to provide a mechanical synthesis of materials. Such processes may be useful to produce compositions of material that are difficult to combine by other means, such as combinations of copper and steel or copper and aluminum.

[0043] It is understood that the methods described in Figure 1A-1Q may be applied in combination with the methods described in Figure 2A – 2M to produce an enhanced structure and/or to produce enhanced materials of unlimited thickness.

[0044] Figure 3A depicts a first portion 250 of a preform that has a first planar surface 252, a second planar surface 254 and a first edge 256. Figure 3A further depicts a second portion 258 of the fabrication preform having a third planar surface 260 and a fourth planar surface 262 and a second edge 264. In some embodiments the first portion 250 of the fabrication preform is a first workpiece and the second portion 258 of the fabrication preform is a second workpiece that is to be joined with the first workpiece. In other embodiments the first portion 250 of the fabrication preform and the second portion 258 of the fabrication preform are portions of the same workpiece that are to be joined together. The first edge 256 and the second edge 264 form a joint 266 (making a lap joint) between the first portion 250 of the fabrication preform and the second portion 258 of the fabrication preform. In the embodiment of Figure 3A the joint 266 is a seam between the first portion 250 of the preform and the second portion 258 of the preform. In alternate embodiments a joint between the first portion of a preform and the second portion of a preform may include a filler. The first planar surface 252 and the third planar surface 260 are substantially co-planar and form a first common surface 268. The second planar surface 254 and the fourth planar surface 262 are substantially co-planar and form a second common surface 270 that is opposed to the first common surface 268.

[0045] Figure 3B depicts a first portion 300 of a fabrication preform that has a first planar surface 302, a second planar surface 304 and a first edge 306. Figure 3B further depicts a second portion 308 of the fabrication preform having a third planar surface 310 and a fourth planar surface 312 and a second edge 314. In some embodiments the first portion 300 of the fabrication preform is a first workpiece and the second portion 308 of the fabrication preform is a second workpiece that is to be joined with the first workpiece. In other embodiments the first portion 300 of the fabrication preform and the second portion 308 of the fabrication preform are portions of the same workpiece that are to be joined together. The first edge 306

and the second edge 314 form a joint 316 (making a bevel joint) between the first portion 300 of the fabrication preform and the second portion 308 of the fabrication preform. The first planar surface 302 and the third planar surface 310 are substantially co-planar and form a first common surface 318. The second planar surface 304 and the fourth planar surface 312 are substantially co-planar and form a second common surface 320 that is opposed to the first common surface 318.

[0046] Figure 3C depicts a first portion 340 of a fabrication preform that has a first planar surface 342, a second planar surface 344 and a first edge 346. Figure 3C further depicts a second portion 348 of the fabrication preform having a third planar surface 350 and a fourth planar surface 352 and a second edge 354. In some embodiments the first portion 340 of the fabrication preform is a first workpiece and the second portion 348 of the fabrication preform is a second workpiece that is to be joined with the first workpiece. In other embodiments the first portion 340 of the fabrication preform and the second portion 348 of the fabrication preform are portions of the same workpiece that are to be joined together. The first edge 346 and the second edge 354 form a joint 356 (making a butt joint) between the first portion 340 of the fabrication preform and the second portion 348 of the fabrication preform. The first planar surface 342 and the third planar surface 350 are substantially co-planar and form a first common surface 358. The second planar surface 344 and the fourth planar surface 352 are substantially co-planar and form a second common surface 360 that is opposed to the first common surface 358.

[0047] In addition to the embodiments depicted in Figures 3A – 3B other configurations of joints may be used such as those formed by tongue-in-groove joints or interlocking joints, and as previously noted, fillers may be employed.

[0048] Figure 4 depicts a first friction stir tool 380 being used along a portion of the joint 316 (identified in Figure 3B) between the first portion 300 of the fabrication preform and the second portion 308 of the fabrication preform. The first friction stir tool 380 is welding a portion of the joint 316 along a first weld path 382 that is on the first common surface 318 at or at least proximal to where the joint 316 intersects the first common surface 318. The first

weld path 382 forms a first weld path plane 384 that is perpendicular to the first common surface 318.

[0049] Figures 5A – 5C illustrate various embodiments of weld paths and weld planes. Each Figure 5A – 5C depicts a common surface 400. Figure 5A depicts a straight line weld path 402 that is on the common surface 400. Figure 5B depicts a curved line weld path 404 that is on the common surface 400. Figure 5C depicts a jagged weld path 406 that is on the common surface 400. Figure 5A depicts a flat weld plane 408 that is perpendicular to the common surface 400. Figure 5B depicts a curvilinear weld plane 410 that is perpendicular to the common surface 400. Figure 5C depicts a jagged weld plane 712 that is perpendicular to the common surface 400. Thus it seen from Figures 5A – 5C, weld paths may, for example, be straight lines, curved lines or jagged lines, and weld planes may be flat planes, curvilinear planes, or jagged planes. It should also be noted that in Figures 5A – 5C the common surface 400 is a flat surface. In other embodiments the common surface may be a curved surface or a jagged surface. When the common surface is a curved surface or a jagged surface the weld plane is typically still perpendicular to the common surface at each locus of the welding tool along the weld path.

[0050] Returning to Figure 4, a second friction stir welding tool 440 is used along a portion of the joint 316. The second friction stir welding tool 440 is welding a portion of the joint 316 along a second weld path 442 that is on the second common surface 320 at or at least proximal to where the joint 316 intersects the second common surface 320. The second weld path 442 forms a second weld path plane 444 that is perpendicular to the second common surface 320. In the embodiment of Figure 4 the first weld path plane and the second weld path plane are not co-planar. In the embodiment of Figure 4 the first friction stir welding tool 380 and the second friction stir welding tool 440 are welding during substantially the same time interval. In some embodiments the first friction stir welding tool 380 and the second friction stir welding tool 440 may weld during different time intervals. In some embodiments the first friction stir welding tool 380 may be used along the first weld path 382 and then subsequently the same first friction welding tool 380 may be used to friction stir

weld along the second weld path 442. As further depicted in Figure 4, a source of pre-heating 82 is applied to the material adjacent the joint 316 (as identified in Figure 1G).

[0051] Figure 6A depicts cross sections of a first portion 510 of a fabrication preform and a second portion 512 of the fabrication preform with a transition piece 514 disposed between the first portion 510 of the fabrication preform and the second portion 512 of the fabrication preform. In some embodiments the first portion 510 of the fabrication preform is a first workpiece and the second portion 512 of the fabrication preform is a second workpiece that is to be joined with the first workpiece. In other embodiments the first portion 510 of the fabrication preform and the second portion 512 of the fabrication preform are portions of the same workpiece that are to be joined together. The first portion 510 of the fabrication preform and the second portion 512 of the fabrication preform may be fabricated from the same material or from different materials. The transition piece 516 may be fabricated from the same material as the first portion 510 of the fabrication preform or the second portion 512 of the fabrication preform or from a different material than either the first portion 510 of the fabrication preform or the second portion 512 of the fabrication preform. There is a first joint 516 between the first portion 510 of the fabrication preform and the transition piece 514 and a second joint 518 between the transition piece 514 and the second portion 512 of the fabrication preform. The first portion 510 of the fabrication preform has a first thickness 520 and the second portion 512 of the fabrication preform has a second thickness 522 that is different from the first thickness 520. The transition piece 514 has a first edge 524 and a second edge 526 opposed to the first edge 524. The transition piece 514 is configured to vary in thickness from approximately the first thickness 520 at the first edge 524 of the transition piece 514 to approximately the second thickness 522 at the second edge 526 of the transition piece 514. As shown in Figure 6B three friction stir welding tools 550 may be used to weld at least portions of the first joint 516 and the second joint 518.

[0052] Figure 7A depicts cross sections of a first portion 610 of a fabrication preform and a second portion 612 of the fabrication preform with a transition piece 614 disposed between the first portion 610 of the fabrication preform and the second portion 612 of the fabrication

preform. In some embodiments the first portion 610 of the fabrication preform is a first workpiece and the second portion 612 of the fabrication preform is a second workpiece that is to be joined with the first workpiece. In other embodiments the first portion 610 of the fabrication preform and the second portion 612 of the fabrication preform are portions of the same workpiece that are to be joined together. The first portion 610 of the fabrication preform and the second portion 612 of the fabrication preform may be fabricated from the same material or from different materials. The transition piece 614 may be fabricated from the same material as the first portion 610 of the fabrication preform or the second portion 612 of the fabrication preform or from a different material than either the first portion 610 of the fabrication preform or the second portion 612 of the fabrication preform.

[0053] There is a first joint 616 between the first portion 610 of the fabrication preform and the transition piece 614 and a second joint 618 between the transition piece 614 and the second portion 612 of the fabrication preform. The first portion 610 of the fabrication preform has a first thickness 620 and the second portion 612 of the fabrication preform has a second thickness 622 that is different from the first thickness 620. The transition piece 614 has a first edge 624 and a second edge 626 opposed to the first edge 624. The transition piece 614 is configured to vary in thickness from approximately the first thickness 620 at the first edge 624 of the transition piece 614 to approximately the second thickness 622 at the second edge 626 of the transition piece 614. As shown in Figure 7B a first friction stir welding tool 650 may be used to weld at least a portion of the first joint 616 and a second friction stir welding tool 652 may be used to weld at least a portion of the second joint 618.

[0054] Figure 6C illustrates the cross-section of a completed assembly 710 made by the process illustrated in Figure 6B. The completed assembly 710 includes friction stir welds 712, 714 and 716. In the embodiment of Figure 6C a portion 720 of the second joint 518 between the transition piece 514 and the second portion 512 of the fabrication preform (identified in Figure 6A) is not welded. In other embodiments the portion 720 may be welded if, for example, friction stir weld tools are used that have a longer pin than the pin depicted for friction stir weld tools 550 in Figure 6B. Figure 7C illustrates the cross-section

of a completed assembly 750 made by the process illustrated in Figure 7B. The completed assembly 750 includes friction stir welds 752 and 754. The friction stir welds 712, 714, 716, 752 and 754 may be stir mixed with materials from the adjoining portions of the fabrication preform and transition pieces to form mixed bonds that may provide a more gradual gradient of material property changes across the completed assemblies.

[0055] It is understood that the methods described in Figure 1A-1Q may be applied in combination with the methods described in Figure 6A-7C to produce welds of unlimited thickness.

[0056] It should be noted that in most embodiments no flux is used with friction stir welding processes. Generally a protective atmosphere is not used, although a protective atmosphere such as argon or nitrogen may be used to prevent oxidation of the welded materials. Generally the temperatures of the pieces, portions of a fabrication preform, transition pieces, and fillers individually or collectively are maintained at a temperature that is less than their respective melting temperature.

EXAMPLE

[0057] A proof-of-concept test was conducted to demonstrate the feasibility of certain processes described herein using two aluminum alloy portions of a fabrication preform configured like those depicted in Figure 1A. Figure 8 illustrates the portions of the fabrication preform after being joined by a first (root) friction stir welding pass. Figure 9 illustrates the portions of the fabrication preform after four further friction stir welding passes. Figure 10A is a cross-sectional photo of the two portions of the fabrication preform showing the root pass 760 and a cover pass 762. As used herein, the term "cover pass" refers to a welding pass that is made at least in part over a root pass or over a previous cover pass. Figure 10B shows a subsequent cover pass 764. Figure 10C shows the cross section of the completed joint.

[0058] In summary, embodiments disclosed herein provide processes for joining a first portion of a fabrication preform and a second portion of the fabrication preform where the

portions of a fabrication preform have abutted edges that form a first seam and wherein a groove is disposed adjacent at least a portion of the first seam. Also disclosed are embodiments of methods for forming an enhanced structure/material from a fabrication preform that has a first common surface and a recess below the first common surface. Further disclosed are methods of joining a first portion of a fabrication preform and a second portion of the fabrication preform where the first portion of the fabrication preform has a first planar surface, an opposing second planar surface, and a first edge and the second portion of the fabrication preform has a third planar surface and an opposing fourth planar surface and a second edge, and the first edge and the second edge form a seam between the first portion of the fabrication preform and the second portion of the fabrication preform and the first planar surface and the third planar surface are substantially co-planar and form a first common surface and the second planar surface and the fourth planar surface are substantially co-planar and form a second common surface. Also disclosed herein are articles of manufacture made by these processes.

[0059] The foregoing descriptions of embodiments have been presented for purposes of illustration and exposition. They are not intended to be exhaustive or to limit the embodiments to the precise forms disclosed. Obvious modifications or variations are possible in light of the above teachings. The embodiments are chosen and described in an effort to provide the best illustrations of principles and practical applications, and to thereby enable one of ordinary skill in the art to utilize the various embodiments as described and with various modifications as are suited to the particular use contemplated. All such modifications and variations are within the scope of the appended claims when interpreted in accordance with the breadth to which they are fairly, legally, and equitably entitled.

CLAIMS

What is claimed is:

1. A method of joining a first portion of a fabrication preform and a second portion of a fabrication preform, the portions of the fabrication preform having abutted edges that form a joint and wherein a groove is disposed adjacent at least a portion of the joint, the method comprising:

friction stir welding at least a portion of the joint;

disposing a first filler in at least a portion of the groove, wherein a first seam is formed between the first filler and the first portion of the fabrication preform and a second seam is formed between the first filler and the second portion of the fabrication preform;

friction stir welding at least a portion of the first seam; and

friction stir welding at least a portion of the second seam.

2. The method of Claim 1 wherein the filler comprises a composition of material that is different than at least one of the portions of the fabrication preform.

3. The method of Claim 1 wherein the filler comprises a composite material.

4. The method of Claim 1 wherein the first portion of the fabrication preform further comprises a first fillet and the second portion of the fabrication preform comprises a second fillet, the first and second fillet forming a second groove between the first portion of the fabrication preform and the second portion of the fabrication preform and adjacent the first groove, the method further comprising:

disposing a second filler in at least a portion of the second groove forming a third seam between the second filler and the first portion of the fabrication preform and a fourth seam between the second filler and the second portion of the fabrication preform;

friction stir welding at least a portion of the third seam; and

friction stir welding at least a portion of the fourth seam.

5. The method of Claim 1 wherein the first and the second portions of the fabrication preform and the filler establish a first common surface and the first and the second portions of the fabrication preform and the joint form an opposing second common surface, and wherein

the step of friction stir welding at least a portion of the joint is performed at least in part along a first weld path on the second common surface; and

the step of friction stir welding at least a portion of the first seam is performed at least in part along a second weld path on the first common surface.

6. The method of Claim 1 wherein the first and the second portions of the fabrication preform establish a first surface and an opposing second surface, and wherein:

the filler comprises a composition of material that is different than at least one of the portions of the fabrication preform;

the step of friction stir welding at least a portion of the joint is performed at least in part on a first weld path along the second surface;

the step of friction stir welding at least a portion of the first seam is performed at least in part on a second weld path along the first surface; and

the step of friction stir welding at least a portion of the second seam is performed at least in part on a third weld path along the first surface

7. The method of Claim 1 wherein the joint has a first height and the groove has a second height, and the second height is not equal to the first height.

8. The method of Claim 1 further comprising at least one of the following steps:

preheating at least a portion of a material adjacent the joint prior to friction stir welding at least a portion of the first seam;

preheating at least a portion of a material adjacent the first seam prior to friction stir welding at least a portion of the second seam;

preheating at least a portion of a material adjacent the second seam prior to friction stir welding at least a portion of the third seam.

9. An article of manufacture made by the method of Claim 1.

10. A method of forming an enhanced structure from a fabrication preform having a first common surface and a recess below the first common surface, comprising:

disposing in at least a portion of the recess a filler wherein a first seam and a second seam are formed between the filler and at least a portion of the recess;

friction stir welding at least a portion of the first seam in a first pass of a friction stir welding tool, to form a first bond; and

friction stir welding at least a portion of the second seam in a second pass of a friction stir welding tool, to form a second bond.

11. The method of Claim 10 wherein the filler comprises a composition of material that is different than at least a portion of the fabrication preform.

12. The method of Claim 10 wherein the filler comprises a composite material.

13. The method of Claim 10 further comprising stir mixing at least a portion of a material comprising one or more materials from which the first bond or the second bond are formed.

14. The method of Claim 10 wherein the fabrication preform comprises two workpieces and the first seam is formed between the filler and a first workpiece of the two workpieces and a second seam is formed between the filler and a second workpiece of the two workpieces.

15. The method of Claim 10 wherein

the fabrication preform comprises two workpieces and the first seam is formed between the filler and a first workpiece of the two workpieces and a second seam is formed between the filler and a second workpiece of the two workpieces;

the first and the second workpiece establish a second common surface opposed to the first common surface;

the step of friction stir welding at least a portion of the first seam is performed at least in part along a first weld path on the second common surface; and

the step of friction stir welding at least a portion of the second seam is performed at least in part along a second weld path on the first common surface.

16. The method of Claim 10 further comprising at least one of the following steps:

preheating at least a portion of a material adjacent the first seam prior to friction stir welding at least a portion of the first seam;

preheating at least a portion of a material adjacent the second seam prior to friction stir welding at least a portion of the second seam.

17. An article of manufacture made by the process of Claim 10.

18. A method of forming an enhanced material from a fabrication preform having a first common surface and a recess below the first common surface, comprising:

disposing in at least a portion of the recess a filler comprising a composition of material that is different than at least a portion of the fabrication preform, wherein a first seam and a second seam are formed between the filler and at least a portion of the recess;

friction stir mixing at least a portion of the first seam in a first pass of a friction stir tool, to form a first bond; and

friction stir mixing at least a portion of the second seam in a second pass of a friction stir tool, to form a second bond.

19. The method of Claim 18 further comprising stir mixing at least a portion of a material comprising one or more materials from which the first bond or the second bond are formed.

20. A method of joining a first portion of a fabrication preform and a second portion of the fabrication preform, the first portion of the fabrication preform having a first planar surface, an opposing second planar surface, and a first edge and the second portion of the fabrication preform having a third planar surface and an opposing fourth planar surface and a second edge, wherein the first edge and the second edge form a joint between the first portion of the fabrication preform and the second portion of the fabrication preform and the first planar surface and the third planar surface are substantially co-planar and form a first common surface and the second planar surface and the fourth planar surface are substantially co-planar and form a second common surface, the method comprising:

friction stir welding at least a portion of the joint along a first weld path on the first common surface proximal to where the joint intersects the first

common surface, the first weld path forming a first weld path plane perpendicular to the first common surface; and

friction stir welding at least a portion of the joint along a second weld path on the second common surface proximal to where the joint intersects the second common surface, the second weld path forming a second weld path plane perpendicular to the second common surface.

21. The method of Claim 20 wherein the first weld path plane and the second weld path plane are not co-planar.

22. The method of Claim 20 further comprising at least one of the following steps:

preheating a portion of a material adjacent the joint prior to friction stir welding at least a portion of the joint along the first weld path;

preheating a portion of a material adjacent the joint prior to friction stir welding at least a portion of the joint along the second weld path.

23. An article of manufacture made by the process of Claim 20.

24. A method of joining a first portion of a fabrication preform having a first thickness and second portion of the fabrication preform having a second thickness comprising:

disposing a transition piece between the first portion of the fabrication preform and the second portion of the fabrication preform wherein the transition piece has a first edge and a second edge opposed to the first edge and the transition piece is configured to vary in thickness from approximately the first thickness at the first edge to approximately the second thickness at the second edge and wherein a first joint is formed between the first portion of the fabrication preform and the transition piece and a second joint is

formed between the transition piece and the second portion of the fabrication preform;

friction stir welding at least a portion of the first joint; and

friction stir welding at least a portion of the second joint.

25. An article of manufacture made by the process of Claim 24.

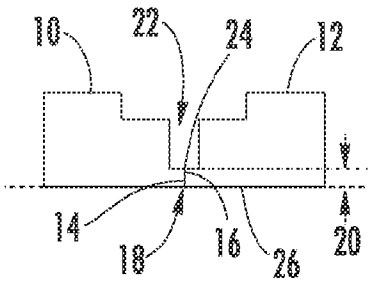

FIG. 1A

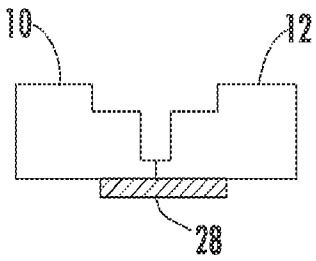

FIG. 1B

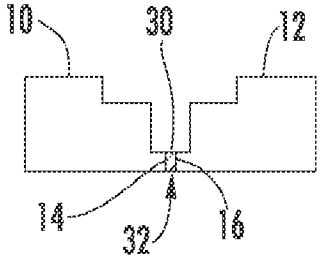

FIG. 1C

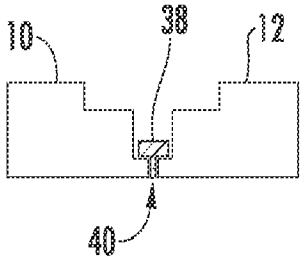

FIG. 1D

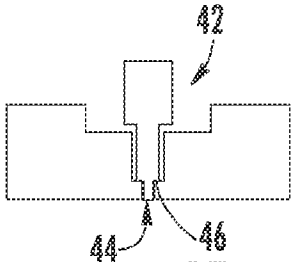

FIG. 1E

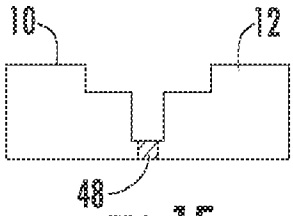

FIG. 1F

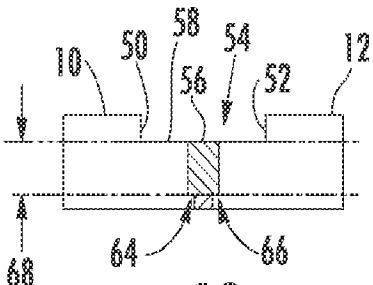

FIG. 1G

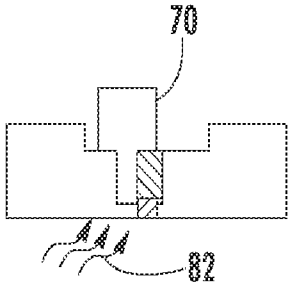

FIG. 1H

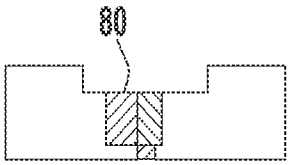

FIG. 1I

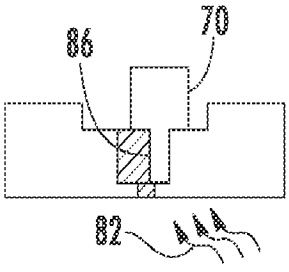

FIG. 1J

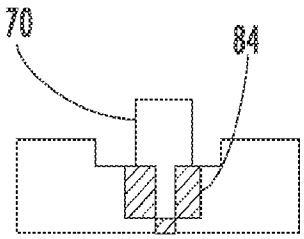

FIG. 1K

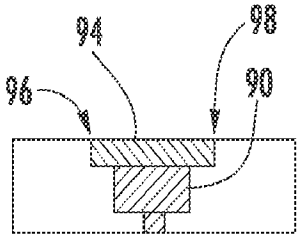

FIG. 1L

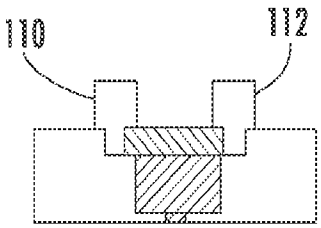

FIG. 1M

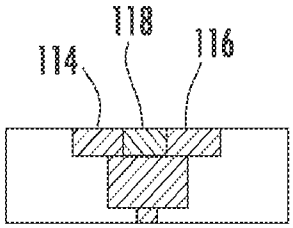

FIG. 1N

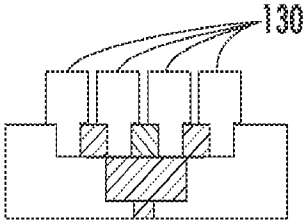

FIG. 1O

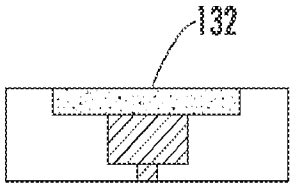

FIG. 1P

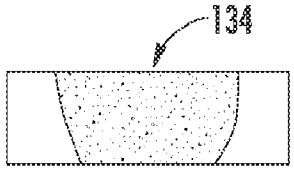

FIG. 1Q

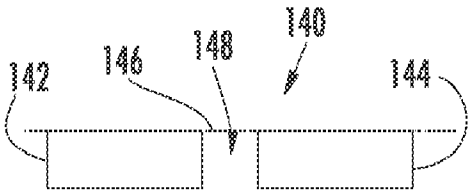

FIG. 2A

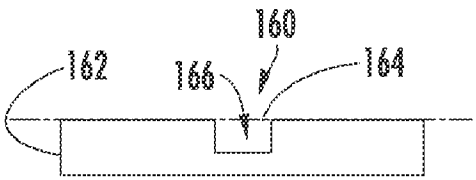

FIG. 2B

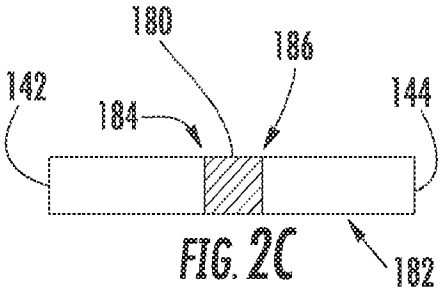

FIG. 2C

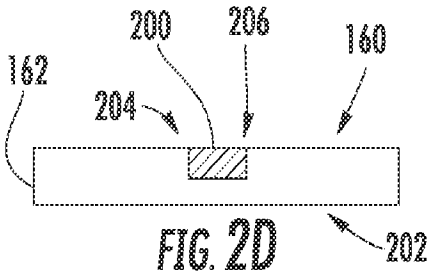

FIG. 2D

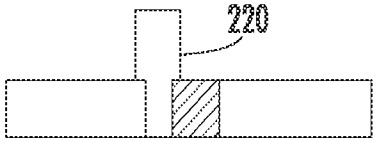

FIG. 2E

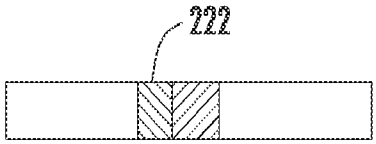

FIG. 2F

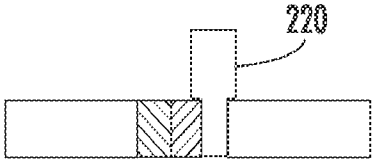

FIG. 2G

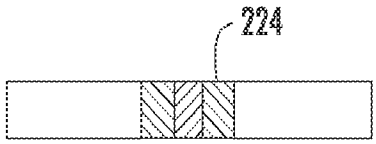

FIG. 2H

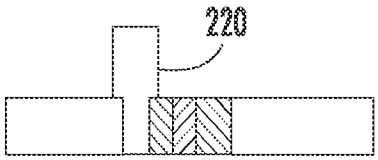

FIG. 2I

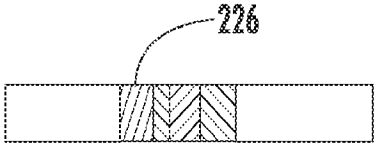

FIG. 2J

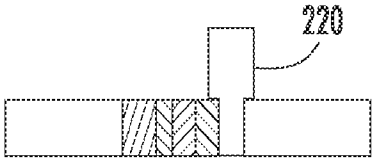

FIG. 2K

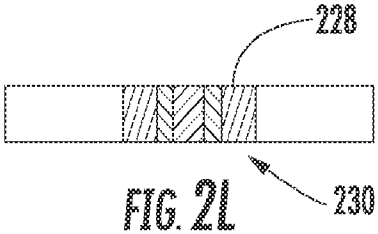

FIG. 2L

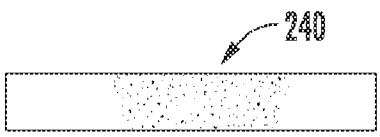

FIG. 2M

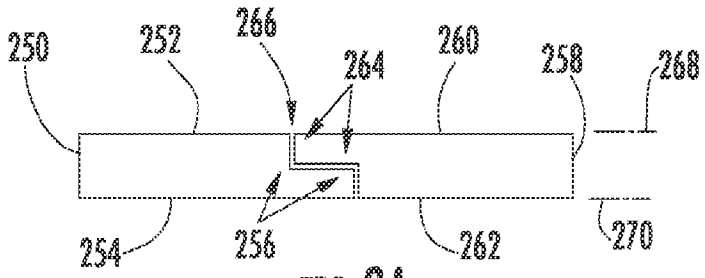

FIG. 3A

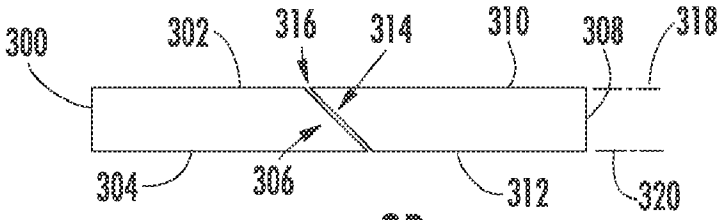

FIG. 3B

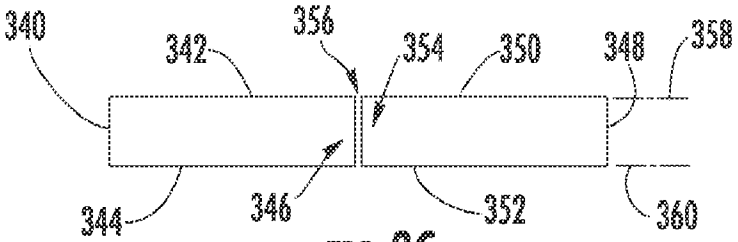

FIG. 3C

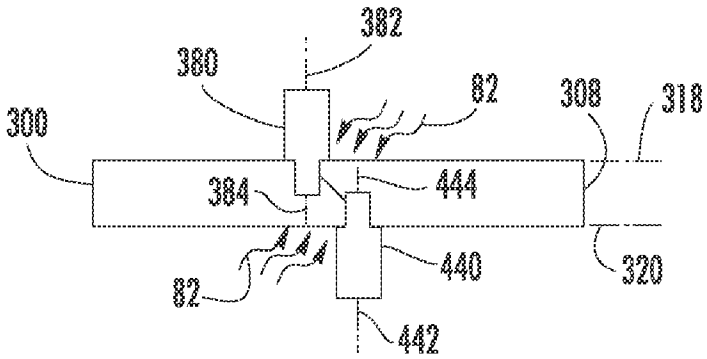

FIG. 4

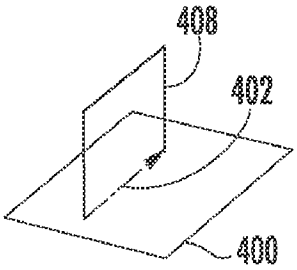

FIG. 5A

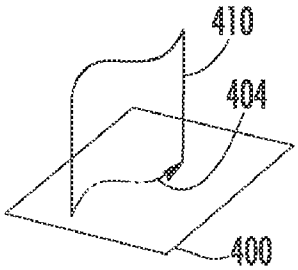

FIG. 5B

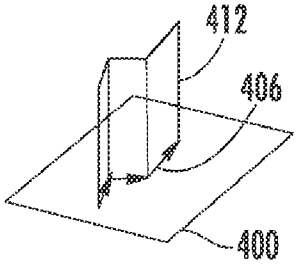

FIG. 5C

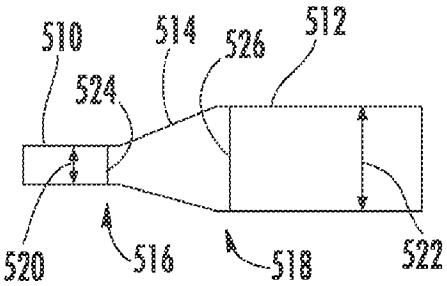

FIG. 6A

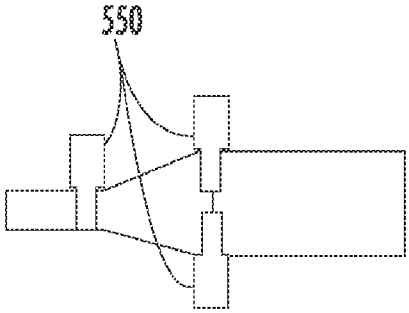

FIG. 6B

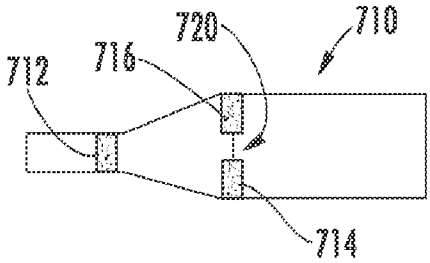

FIG. 6C

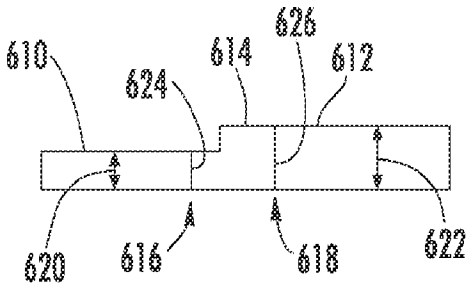

FIG. 7A

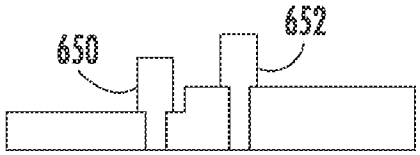

FIG. 7B

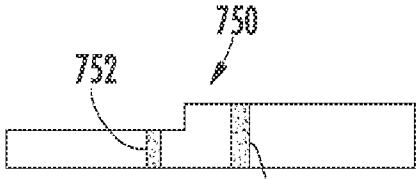

FIG. 7C

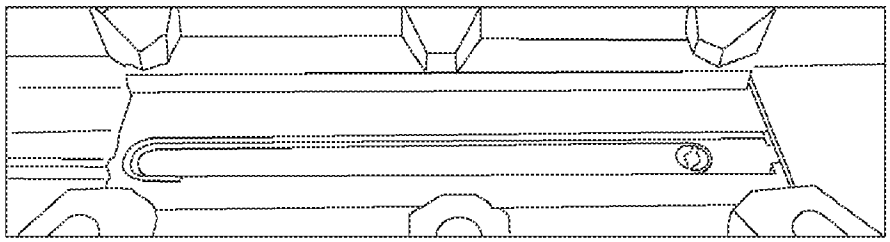

FIG. 8

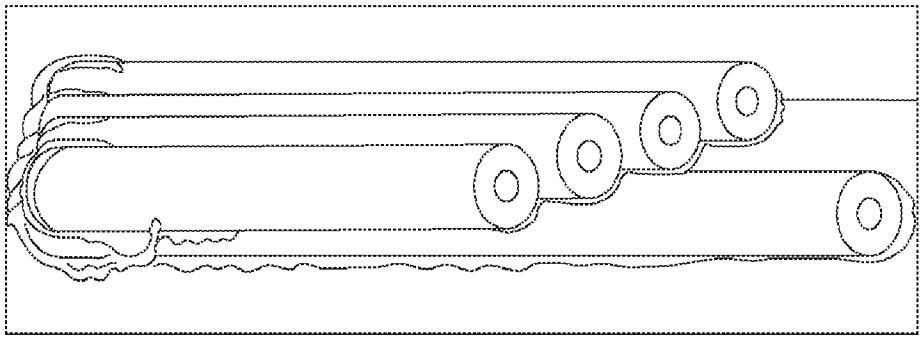

FIG. 9

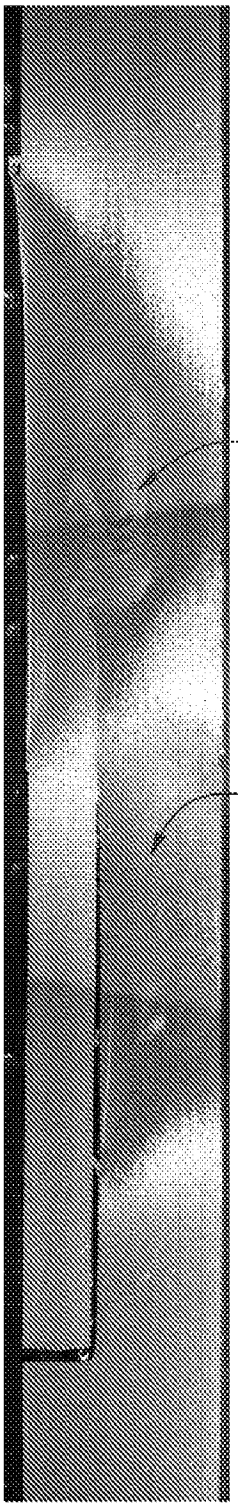

FIG. 10A

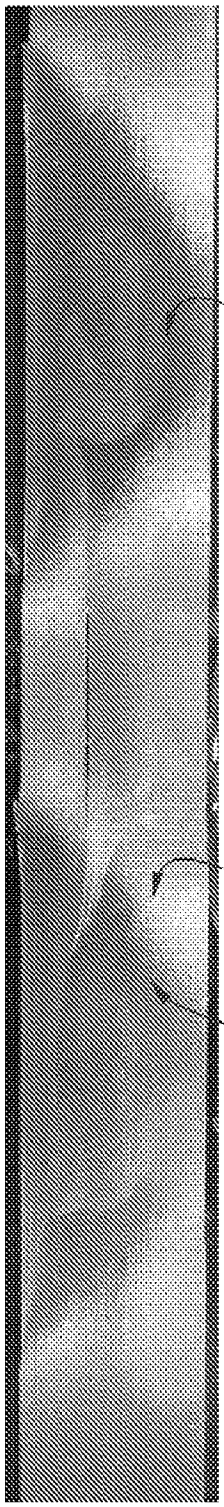

FIG. 10B

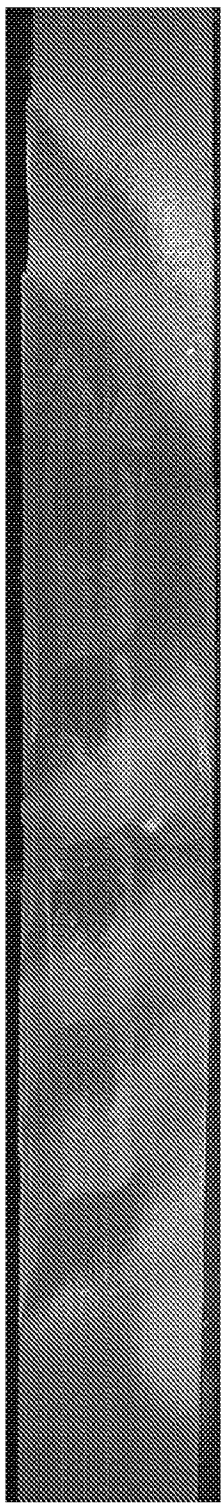

FIG. 10C

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2009/035961

A. CLASSIFICATION OF SUBJECT MATTER
INV. B23K20/12
ADD. B23K101/04 B23K101/18

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)
B23K

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 practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 797 043 A2 (HITACHI LTD [JP]) 24 September 1997 (1997-09-24) column 6, line 27 - column 7, line 3	1,5,7, 9-10, 14-15, 17, 20-21,23
X	JP 11 342481 A (NIPPON LIGHT METAL CO) 14 December 1999 (1999-12-14) abstract; figure 3 paragraph [0006]	1-2,4-7, 9-11, 14-15, 17-18, 20-21, 23-25

-/--

[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 document 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
19 June 2009	11/08/2009

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	Jaeger, Hein

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2009/035961

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 1 057 574 A2 (HITACHI LTD [JP]) 6 December 2000 (2000-12-06) paragraph [0026] - paragraph [0033]	1,5,7, 9-10, 14-15, 17, 20-21,23
X	JP 2000 233284 A (HITACHI LTD; HITACHI KASADO KIKAI CO LTD) 29 August 2000 (2000-08-29) figures 9, 14	1,9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2009/035961

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers allsearchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search reportcovers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

1-2, 4-7, 9-11, 14-15, 17-18, 20-21, 23-25

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-2, 4-7, 9-11, 14-15, 17-18, 20-21, 23-25

Method of friction stir welding thick preforms using a filler comprising a composition of material that is different than a preform.

1.1. claim: 4

Method of friction stir welding thick preforms with several fillers

1.2. claims: 24-25

Method of friction stir welding preforms having different thicknesses

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2. claims: 3, 12

Method of friction stir welding thick preforms using a filler comprising a composite material.

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3. claims: 8, 16, 22

Method of friction stir welding thick preforms using a filler including a heat treatment.

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4. claims: 13, 19

Material enhancement process

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2009/035961

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2009/035961

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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