A process is described that employs what can be termed a friction surface stirring (FSS) process on the surface of a metal object. The FSS process occurs on some or the entire surface of the metal object, at a location(s) separate from a friction stir welded joint. The FSS process on the surface produces a corrosion resistant mechanical conversion “coating” on the object. The “coating” is formed by the thickness of the material of the object that has been FSS processed. In one exemplary application, the process can be applied to a metal strip that is later formed into a tube whereby the “coated” surface resides on the inside of the tube making it highly resistant to corrosive flow such as seawater.
FIG. 2
FRICITION SURFACE STIR PROCESS

FIELD

[0001] This disclosure relates to corrosion resistant metal objects, and to the use of friction surface stirring (FSS) to enhance the corrosion resistance of metal objects.

BACKGROUND

[0002] Most metals, even marine-grade metals, show evidence of corrosion in water environments, including salt, brackish, and fresh water environments. Corrosion is especially pronounced in cold, deep salt water. Over time, the corrosion can be detrimental to long-term operational sustainability of the metal object that is exposed to the water environment.

[0003] The use of friction stir welding (FSW) to join two metallic objects at a weld joint is known. When those objects are exposed to a water environment, it has been observed that at the location of the FSW joint, there is little or no corrosion that occurs, while significant corrosion occurs on the metal objects at locations outside of the FSW joint in the base metal alloy.

SUMMARY

[0004] A process is described that employs what can be termed a friction surface stirring (FSS) process on the surface of a metal object. The FSS occurs on some or the entire surface of the metal object, at a location(s) separate from a FSW welded joint. The FSS process on the surface produces a corrosion resistant, mechanical conversion “coating” on the object. The mechanical conversion “coating” is formed by the thickness of the material of the object that has been FSS processed. The mechanical conversion “coating” can be a portion of the thickness of the metal object or the entire thickness of the object.

[0005] FSS is similar to FSW in that a rotating tool is used to soften or plasticize the metal material. However, FSS occurs over the surface of the metal object, instead of at a joint between two objects. The FSS process can use a conventional FSW tool used to form a FSW weld joint or a conventional FSW tool can be scaled-up in size for use with the larger surfaces subject to FSS.

[0006] The FSS tool can be used in a number of stir paths. For example, the FSS tool can be traversed along linear paths on the metal object stirring in one direction or stirring in 2 directions (i.e. back and forth). In another embodiment, the FSS tool can start in the center and work its way out in a spiral pattern. In another embodiment, the FSS tool can travel in a square or rectangular pattern and work its way out or in on the metal object. Other travel paths are possible.

[0007] The FSS can occur prior to or after machining operations on the metal object. The metal object can have any shape or size, and can be a plate, a bar, a rod, a tube, or other shapes. The FSS can occur on any shape of surface, for example planar or flat surfaces, curved surfaces, or combinations of curved and flat.

[0008] The object subject to FSS can be formed from metal alloys including, but not limited to, aluminum alloys (2xxx, 3xxx, 5xxx, 6xxx, and 7xxx series of alloys) especially marine-grade aluminum alloys (5xxx and 6xxx series), titanium alloys, steel alloys such as stainless steel, and others.

[0009] The resulting FSS mechanical conversion “coating” is significantly thicker than conventional anti-corrosion conversion coatings, for example 5-10 times thicker. Although these FSS coatings are thicker than conventional chemical conversion coatings, they are integral to the parent metals surrounding and underneath the FSS coating stir zone. The parent metal and the FSS coating have very similar, if not identical, thermal properties. Therefore, the FSS coatings possess an advantage over conventional superficial coatings, i.e. there is no de-bonding issue from which the conventional coating processes usually suffer and the thicker FSS coatings yield significantly longer lifetimes in marine and other corrosive environments. The FSS mechanical conversion “coating” is environmentally friendly since separate coating materials are not used. Because the FSS process has dissolved or minimized most of the precipitates, the FSS mechanical conversion “coating” contains fewer and smaller precipitates and cleaner grain boundaries, without impacting the thermal performance or other material properties of the metal object.

[0010] In one exemplary application, the FSS process can be used on an object that is intended for use in water, including salt water, brackish water, and fresh water. For example, but not limited to, the metal object can be an object used in an ocean thermal energy conversion plant, a desalination plant, or a marine vessel. During its intended use, the object can be disposed underneath the water, disposed on the water, disposed above the water but exposed to the water (i.e. splashes, salt fog, or other marine layer environments), or a combination thereof. The FSS process can be employed on a portion of or the entire area of the metal object that in use is exposed to the water and/or marine environment.

[0011] The FSS process, together with FSW, can be used to produce an underwater structure that is formed from a single metal material. For example, in an ocean thermal energy conversion (OTEC) system, the heat exchanger, including the shell, plates and tubing, can be formed entirely from an aluminum alloy, thereby eliminating the use of dissimilar metals or galvanic coupling.

[0012] In one embodiment, a friction surface stir process includes using a friction stir welding tool to friction surface stir at least a portion of a non jointed or FSW-joined surface of a metal object.

[0013] In another embodiment, a process includes friction surface stirring a non jointed surface of a metal object using a friction stir welding tool.

[0014] In another embodiment, a method of increasing corrosion resistance of a metal object includes friction surface stirring at least a portion of a non jointed or FSW-joined surface of the metal object using a friction stir welding tool to produce a mechanical conversion coating.

DRAWINGS

[0015] FIGS. 1A-D illustrate a portion of an object with a surface thereof undergoing FSS.

[0016] FIG. 2 illustrates a portion of an object with a surface thereof undergoing FSS separate from a FSW joint on the object.

[0017] FIGS. 3A-C are side views illustrating another example of FSS on an object together with machining after FSS.

[0018] FIG. 4 is an end view of a tube that has been processed by FSS showing the FSS mechanical conversion “coating”.

[0019] FIGS. 5A-B illustrate an example of FSS of the entire thickness of an object.
FIGS. 6A-C illustrate a process of forming FSS tubes.

FIGS. 7A-B illustrate an alternative process of forming FSS tubes.

FIGS. 8A-C illustrate examples of different FSS tube shapes and FSS tube surfaces that can be formed.

FIGS. 9A-C illustrate examples of FSS objects provided with different surface finishes.

DETAILED DESCRIPTION

The following description describes a process that employs a FSS process on the surface of a metal object. The FSS occurs on some or the entire surface of the metal object, through some portion of or the entire thickness of the object. The metal object can have one or more FSW welded joints, or have no FSW welded joints. The FSS process on the surface produces a corrosion resistant mechanical conversion “coating” on the object which will be referred to hereinafter as just a “coating”. The “coating” is formed by the thickness of the material of the object that has been FSS processed, which is determined by the penetration depth of the rotating tool used in the FSS process.

The FSS process is similar to FSW in that a rotating tool is used to soften or plasticize the material. However, FSS occurs over the surface of the metal object instead of at a joint between two objects as with FSW, and is not used to join two objects together.

With reference now to FIGS. 1A-D, a portion of a metal object 10 that undergoes FSS is illustrated. The object 10 includes a surface 12 which can be planar or curved. A FSS tool 14 is used to perform FSS on the surface 12. In this example, the FSS tool 14 can be identical in construction and operation to a conventional FSW tool used to form a FSW weld joint, or the tool 14 can be similar to a conventional FSS tool but scaled-up in size for use with the larger surface 12 that is subject to FSS.

As would be understood by persons or ordinary skill in the art, the FSS tool 14 rotates at high speeds while in contact with the object’s surface. The tool 14 softens or plasticizes the metal material to a depth determined by the penetration depth of the tool into the object’s surface 12. Once the tool passes the metal, it stirs the metal behind the pin tool and consolidates it under the tool shoulder. The resultant surface “coating” will consist of the metal with very fine equiaxed grains. This operation happens all in the solid state, since there is no melting occurring during the FSS process.

In this example, the FSS tool 14 is moved in the direction of travel 15 shown by the arrow in FIG. 1B along the surface 12 to produce a FSS zone 16 (the FSS zone 16 is illustrated in FIGS. 1B and 1D in dashed lines). As shown in FIG. 1C, after each path is completed, the tool 14 is shifted in the direction of the arrow (or the object is shifted relative to the tool) to complete a new FSS path. This process is repeated for the entire surface area of the object 10 except for the borders as indicated in FIG. 1D, or just a portion of the surface area.

The FSS begins by plunging the FSS tool into the object in FIG. 1A and translating “north” along the long axis of the object and stopping before the tool reaches the end of the object. The FSS tool can then translate back to the original starting position and shift over a sufficient distance to ensure that sufficient overlap of the FSS zones will be achieved. The FSS tool is then again translated “north” along the object, and the shifting operation repeated until the entire object is overlapped with FSS zones. Alternatively, the FSS tool can stop at the end of each path and then shift while the tool is still applying load and spinning. The tool can then begin translating “south” along the object while overlapping the previous FSS zone. The tool can continue welding back-and-forth while shifting at the end of each pass until the entire sheet is FSS, except the borders. Other tool travel patterns are possible including, but not limited to, square, rectangular, or spiral patterns.

In the example illustrated in FIGS. 1A-D, the object 10 does not include any FSW joints.

FIG. 2 illustrates an embodiment where the object 10 is formed by two initially separate portions 18a, 18b that have been joined together along a FSW weld zone or joint 20 by a conventional FSW process. In this embodiment, the tool 14 is traversed across areas of the surface 12 to create the FSS zone(s) 16 at locations separate from the FSW zone 20.

FIGS. 3A-C show cross-sectional views of an object 30 that has been processed by FSS, with FIG. 3A showing one FSS pass and FIG. 3B showing multiple passes. The penetration depth of the FSS tool 14 determines the resulting depth of the “coating”. With reference to FIG. 3B, it can be seen that multiple passes of the FSS tool 14 have sufficient overlap that the resulting stir zones (or friction stir processed (FSP) zones) have a consistent depth “D” across the entire object 30 to form the resulting FSS “coating” 32. The FSS “coating” 32 provides a corrosion resistant barrier that is significantly thicker than conventional anti-corrosion conversion coatings, for example 5-10 times thicker.

After performing the FSS, the surfaces of the object can be machined, fly-cut, sanded, ground and/or polished, if desired, for example to smooth the surface. In one embodiment, FIG. 3C illustrates that the top surface of the overlapped stir zones can be machined, for example machining away a portion of the thickness using a suitable cutting device such as a mill bit, fly-cutter, router, etc. If crevice corrosion is not a concern, then the machining step can be skipped.

The FSS process can be performed on objects having any shape, and on object surfaces of any shape. FIG. 4 illustrates a hollow, cylindrical object or a tube 40 with a hollow interior space 42 and a wall thickness T that extends from an interior surface 44 to an exterior surface 46. FSS is performed on the exterior surface 46 to a depth D to form the FSS “coating” 48. FSS can also be performed on the interior surface 44 as well.

The FSS “coating” 32 can have generally a constant depth on the object or the depth of the coating can vary. For example, with reference to FIGS. 5A and 5B, a side view of an object 50 is illustrated, where the object 50 has been processed by FSS through the entire thickness or depth D of the object 50 which may be beneficial in some applications. In one embodiment, a conventional FSW tool with the pin length comparable to the object’s thickness can be used to achieve full thickness FSS. In another embodiment illustrated in FIG. 5B, the FSS tool 52 is a self-reacting FSS tool with an upper shoulder 54, a lower shoulder 56, and an independent pin 58 extending between the shoulders 54, 56. The pin 58 is exposed between the shoulders 54, 56 and are spaced apart a distance approximately equal to the thickness of the object 50 to obtain full thickness FSS processing.

FIGS. 6A-C illustrate a tube forming process that employs FSS. Starting with FIG. 6A, a plate 60, for example
of an aluminum alloy, is fully FSS processed for the entire depth of the plate and if desired machined as discussed above. As shown in FIG. 6B, the plate 60 is then cut into strips 62a, 62b, . . . 62n to remove the non-FSS processed borders 64. With reference to FIG. 6C, each strip is then rolled into a tube 65 and the edges joined along the seam 64'.

[0037] The edges can be joined using any suitable joining process. In one embodiment, the edges can be joined using a high-frequency resistance welding process known in the art. The result is a tube 65 that is FSS processed on both the internal and external surfaces. Alternatively, as shown in FIGS. 7A-B, the edges can be joined using a conventional FSW process with a FSW tool 66 to create a fully FSS and FSW tube 68 that minimizes or eliminates corrosion on both internal and external surfaces. Alternatively, the edges can be joined using a first type of process, for example a welding process such as electro-resistance or laser welding, and then the joined edges can be FSW down the seam to create a fully FSS and FSW tube that minimizes or eliminates corrosion on both internal and external surfaces.

[0038] FIGS. 8A-C illustrate examples of FSS tube shapes and FSS tube surfaces that can be formed using the processes and techniques described above. These examples illustrate that the process described in FIGS. 6A-C and 7A-B can be used to form tubes having many different shapes and surface enhancements. The surface enhancements can be added prior to or after cutting into strips. In addition, the surface enhancements can occur on some or the entire exterior surface or on some or the entire interior surface of the resulting tube. However, the surface enhancements are not limited to use on tubes and can be provided on any metal object that is subject to FSS processing described herein.

[0039] The surface enhancements can be intended to increase the thermal performance, such as the heat transfer, of the tubes or metal object, or enhance any other property. The surface enhancements can be formed in any manner including, but not limited to, machining, stamping, chemical etching, and the like.

[0040] FIG. 8A shows a cylindrical tube 80. The exterior surface of the tube 80 is also provided with grooves or corrugations 82 that have been machined into the metal after the metal is FSS processed.

[0041] FIG. 8B shows a trapezoidal shaped tube 84, where some or the external exterior surface is machined with grooves 86. In this embodiment, some or the entire interior surface is also machined with grooves 88.

[0042] FIG. 8C shows a rectangular shaped tube 90 where some or the entire exterior surface is machined with grooves 92. In this embodiment, some or the entire interior surface is also machined with grooves 94.

[0043] FIGS. 9A-C illustrate examples of different surface finishes that can be provided on the surfaces (interior and/or exterior) of the tubes or other metal objects that have been FSS processed. FIGS. 9A-C illustrate various embossed surface finishes that can be formed in any manner including, but not limited to, machining, stamping, chemical etching, and the like.

[0044] The FSS process is particularly useful on objects that are used in marine applications and in applications that encounter water, especially salt water. Exemplary applications include, but are not limited to, heat exchangers used in desalination plants or OTEC plants, condensers in power plant systems, and other cooling and liquid-liquid or liquid-air thermal duty exchange applications. The FSS process can also be beneficial for components used on naval or other maritime vessels or aircraft, surface, air or undersea, for example hulls, decks, rotor components, etc.

[0045] The examples disclosed in this application are to be considered in all respects as illustrative and not limiting. The scope of the invention is indicated by the appended claims rather than by the foregoing description; and all changes which come within the meaning and range of equivalency of the claims are intended to be embraced therein.

1. A friction surface stir process, comprising:
   using a friction stir welding tool to friction surface stir at least a portion of a non-jointed surface of a metal object.

2. A process, comprising:
   friction surface stirring a non-jointed surface of a metal object using a friction stir welding tool.

3. A method of increasing corrosion resistance of a surface of a metal object, comprising:
   friction surface stirring at least a portion of a non-jointed surface of the metal object using a friction stir welding tool to produce a mechanical conversion coating.

4. The method of claim 3, comprising surface stirring the entire surface area of the metal object that in its intended use is exposed to water, a marine environment or corrosive environment.

5. The method of claim 3, further comprising after surface stirring, machining, fly-cutting, sanding, grinding or polishing the surface stirred portion of the surface.

6. The method of claim 3, wherein the metal object is formed from a single metal material.

7. The method of claim 3, wherein the non-jointed surface of the metal object is a substantially flat and planar surface.

8. The method of claim 3, wherein the non-jointed surface of the metal object is a curved or non-flat surface.

9. The method of claim 3, wherein the metal object has both curved and flat surfaces.

10. The method of claim 3, wherein the metal object is a plate, bar, rod or tube.

11. The method of claim 3, wherein the metal object is completely friction surface stirred and the friction surface stirring penetrates the entire thickness of the metal object.

12. The method of claim 6, wherein the single metal material comprises an aluminum alloy, a titanium alloy, or stainless steel.

13. The method of claim 12, wherein the aluminum alloy comprises a marine-grade aluminum alloy.

14. The method of claim 4, wherein the metal object is an object used in an ocean thermal energy conversion plant, a desalination plant, or a component of a maritime vessel or aircraft.

15. The method of claim 4, wherein the metal object is a heat exchanger used in an ocean thermal energy conversion plant.

16. The method of claim 11, wherein the metal object is cut into strips.

17. The method of claim 16, wherein after cutting, each of the strips is formed into a tubular object.

18. The method of claim 17, wherein adjoining edges of the tubular object formed by the strip are friction stir welded down the seam to produce a completely friction surface stirred and friction stir welded tube.

19. The method of claim 11, wherein the metal object is machined, stamped or processed to create surface enhancements on at least one surface thereof.
20. The method of claim 19, wherein the metal object is cut into strips.

21. The method of claim 20, wherein after cutting, each of the strips is formed into a tubular object.

22. The method of claim 21, wherein adjoining edges of the tubular object formed by the strip are friction stir welded down the seam to produce a completely friction surface stirred and friction stir welded tube.

23. The method of claim 21, wherein adjoining edges of the tubular object formed by the strip are joined along a seam.

24. The method of claim 23, wherein the joined edges are friction stir welded along the seam to produce a completely friction surface stirred and friction stir welded tubular object.

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