Bobbin-Tool Friction-Stir Welding of Thick-Walled Aluminum Alloy Pressure Vessels

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Previous thick-walled Al alloy 2219 pressure vessels were assembled by gas-tungsten-arc welding using alloy 2319 filler. Testing with progressively-larger explosive charges resulted in rapid disassembly of the welds that attached the cylindrical end-sections to the spherical center section. Failure of these welds was determined to be related to the large amounts of fine porosity, about 10-15 % by volume, resulting in welds with 2% tensile ductility when the calculated strain-demand was about 3-4%.

To avoid formation of solidification-related porosity and solidification- cracking in welds in future vessels, it was decided to use a completely solid-state joining-process, friction-stir welding in the fabrication of additional vessels. Extensive friction-stir welding-parameter studies were conducted on 1.0” and 1.5” thick 2219 Al alloy plate. Starting conditions of the plate were the fully-heat-treated (-T62) and in the annealed (-O) conditions. The former condition was chosen with the intent of using the welds in either the “as welded” condition or after a simple low-temperature aging treatment. Since preliminary stress-analyses showed that stresses in and near the welds would probably exceed the yield-strength of both “as welded” and welded and aged weld-joints, a post-weld solution-treatment, quenching, and aging treatment was also examined.

For the purposes of examining many combinations of friction-stir weld-process parameters, welds were made in flat plates using a conventional pin-tool and an ESAB friction-stir welding machine. Weld-quality was evaluated by visual examination and metallography. Mechanical properties were evaluated by room-temperature tensile testing conducted across the weld-joint. In addition to the usual tensile properties, i.e. ultimate and yield strengths and elongation at failure, the true strain at failure was determined from the reduction in area. These true strain values were compared with the outputs of extensive stress-analyses to determine if the ductility of the weld-joint was adequate in terms of the strain-demands as calculated by these analyses.

Once a suitable set of welding and post-weld heat-treatment parameters was established, the project divided into two parts. The first part concentrated on developing the necessary process information to be able to make defect-free friction-stir welds in 1.5” thick Al alloy 2219 in the from of circumferential welds that would join two hemispherical forgings with a 40” inside diameter. This necessitated going to a bobbin-tool welding-technique to simplify the tooling-needed to react the large forces generated in friction-stir welding. The bobbin-tool technique was demonstrated on both flat-plates and plates that were bent to the curvature of the actual vessel. An additional issue was termination of the weld, i.e. closing out the hole left at the end of the weld by withdrawl of the friction-stir welding tool. This was accomplished by friction-plug welding a slightly-oversized Al alloy 2219 plug into the termination-hole, followed by machining the plug flush with both the inside and outside surfaces of the vessel.

The second part of the project involved demonstrating that the welds were fit for the intended service. This involved determining the room-temperature uniaxial and biaxial tensile, elastic-plastic fracture-toughness, and low-cycle fatigue properties of the bobbin-tool friction-stir welds after a post-weld solution-treatment, quenching, and aging heat-treatment. These mechanical properties were used with standard elastic-plastic and linear-elastic fracture-mechanics codes to determine a range of "critical flaw sizes". Phased-array and conventional ultrasonic non-destructive examination was used to demonstrate that no flaws that match or exceed the calculated critical flaw-sizes exist in or near the friction-stir welds

It was demonstrated that it is possible to make defect-free friction-stir welds in a high-strength Al alloy in thicknesses and topologies that had not been previously demonstrated. This was done through use of a bobbin-tool method and friction-plug welding to close out the weld. Use of post-weld heat-treatment restored the mechanical properties of the friction-stir weld to nearly those of the forged base-metal, i.e. to almost "100% joint efficiency". It is planned to extend the use of bobbin-tool friction-stir welding to the development and manufacture of similar pressure vessels in other high-strength Al alloys. The reason for adapting friction-stir welding over conventional fusion-welding processes for the joining of high-strength Al alloys has been successfully demonstrated.

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