Friction Plug Weld Repair for the Space Shuttle External Tank

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Lockheed Martin Space Systems, Michoud Operations in New Orleans, LA is the manufacturer of the External Fuel Tanks (ET) for the Space Transportation System (STS). The ET contains and delivers the propellants used by the Orbiters three main engines. Additionally, it also serves as the structural backbone for the Orbiter and the two Solid Rocket Boosters (SRB), which combined, constitute the STS. In 1994, NASA established that in order to launch the International Space Station, the performance of the STS must be improved. One option was to reduce the weight of the ET, which would enable sufficient increase in performance. With the development of the Weldalite® series of Al-Cu-Li alloys in the late 1980's, Lockheed Martin was postured to replace the current Al2219 fuel tanks with the high strength, light weight Al2195 alloy. With the use of Al2195 and some component redesign, the weight of the Super Lightweight (SLWT) ET was reduced by approximately 7,000 pounds, which added as much capability to the Space Shuttle. Since June 1998, seven STS missions have been successful with the use of the SLWT ET's. (Figure 1)

Al2195 offers a 5% density improvement and a 20% increase in strength as compared to Al2219, however these benefits are offset with some manufacturing challenges. While the Al2195 alloying elements increased the base metal properties, it adversely affected the oxidation and risk of weld cracking, especially during repair and rework. Although these challenges have been met with manufacturing improvements such as the introduction of backside shielding to mitigate oxidation and the use of a softer filler wire (Al2319 was replaced with Al4043), additional enhancements are desirable to improve through-put time.

The ET is comprised of 36,000 inches of fully automated fusion arc welds, primarily Variable Polarity Plasma Arc and Soft Plasma Arc. The tank is made up of four primary weld joint configurations, longitudinal welds for the barrels, complex contour welds for the domes and ogives, circular welds for the dome caps and circumferential welds for the barrel to barrel and barrel to dome welds. Weld integrity is verified through visual, penetrant and radiographic inspection. When defects, which exceed specification requirements, are repaired using the manual Tungsten Inert Gas (TIG) process. After all assembly and inspection is complete, both tanks are proof tested, re-inspected and then further processed prior to shipment to Cape Canaveral for mating with the Orbiter and the SRB's.

In 1995, The Welding Institute (TWI) in Cambridge, UK introduced a solid state welding process, Friction Plug Welding (FPW), to Lockheed Martin for consideration as a productivity enhancement for the ET. FPW is a derivative of Friction Taper Plug Welding which was originally developed as a solid state repair method for steels. Friction plug welding is an innovative weld repair technique whereby a tapered hole is drilled through the weld at the location of the defect. A rotating plug, with a taper similar to the hole, is then welded into the tapered hole. The complete conical section of the tapered plug is welded to the matching surface of the hole almost simultaneously. (Figures 2a and b) Excess plug protruding from the repaired hole is removed and the surface is prepared for non-destructive inspection. For weld defects that cannot be consumed with a single plug, a stitch welding process is employed whereby a series of interconnecting tapered plugs welds is made. (Figure 3) The advantages of the process are as follows

- Simple mechanical and energy efficient process
- Solid state process with no base metal melting, resulting in low residual stress and distortion
- Improved mechanical properties, fatigue, fracture toughness and ductility
- Improved cycle time and reliability

Upon completing the initial development at TWI, engineers at Lockheed Martin and the NASA Marshall Space Flight Center in Huntsville, AL began optimization of the weld process. Unlike the currently employed fusion weld repair process used on the ET's, FPW has fewer parameters which promote a more robust process. The primary weld parameters are plug rotation speed, forging and heating force, and plug displacement (the total distance the plug travels during the process). Also of primary importance are the plug and hole angle and diameter. The process has been developed for Al2195 and Al2219, both of which use a plug machined from Al2195-T8 extruded rod. Although the process has been demonstrated on thickness' ranging from 0.140 through 1 inch, it has been optimized for 0.200, 0.230 and 0.320 gages. In optimizing the process a combination of high strength and fracture toughness and a low occurrence of weld defects was achieved. Calculated design allowables have been established and demonstrate that friction plug weld repairs have a 20% strength increase over convention TIG heat repairs and have demonstrated exceptional fracture toughness characteristics. Perhaps one of the most attractive things about the process is that it is successful in eliminating defects the first time; unlike heat repairs that may require several iterations of "grind and fill" before the defect is removed. This results in a substantial reduction in repair time and subsequently overall tank cost. Although mission success is the single most important aspect of our business, cost reductions, especially those that improve tank integrity are embraced.

In determining the implementation logic for FPW, two basic drivers were identified that would ultimately reduce tank cycle time and subsequently cost. The first was to determine the type of hardware component that could benefit most from an alternate repair process and the second was the tooling schedule and cost impact. The production quality database indicated that the domes not only had the highest occurrence of defects, but that the defects lent themselves to the self-imposed tooling limitations; simple and robust. The bottom of the domes where the Al2195 gore panels are joined to the Al2219 extruded frames was selected for the initial implementation. A two-stage approach was determined for the domes. The first was the design and fabrication of a large prototype c-clamp tool, which captures all defects around the bottom of the domes. The tool, which is equipped with a hydraulic welding unit supplied by Ramstud USA Inc. of Marietta, GA was effectively demonstrated on full scale LH_2 and LO_2 ET domes in mid 1999. This successful demonstration program has led to the fabrication and certification of a production c-clamp tool which is planned for implementation this summer. (Figure 4).

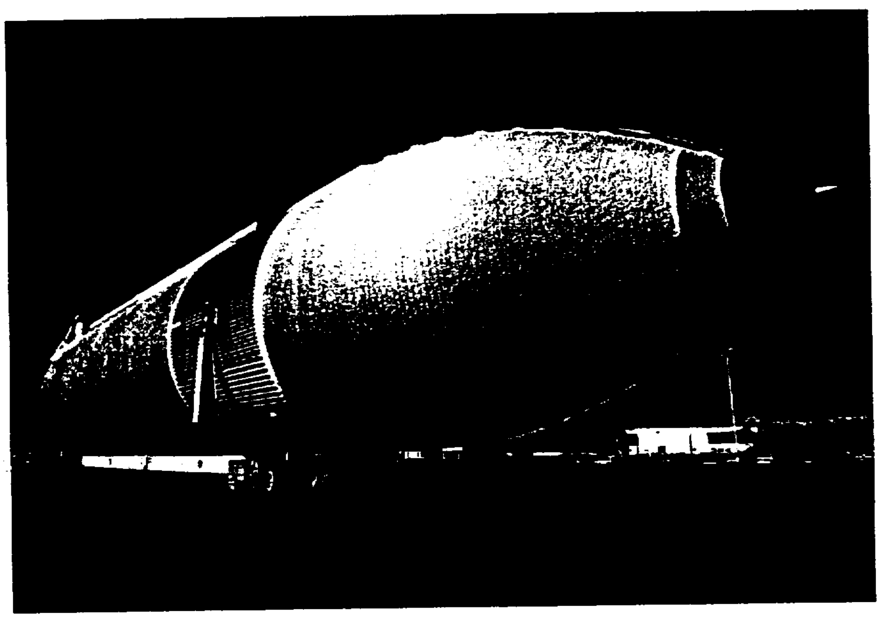

Figure 1

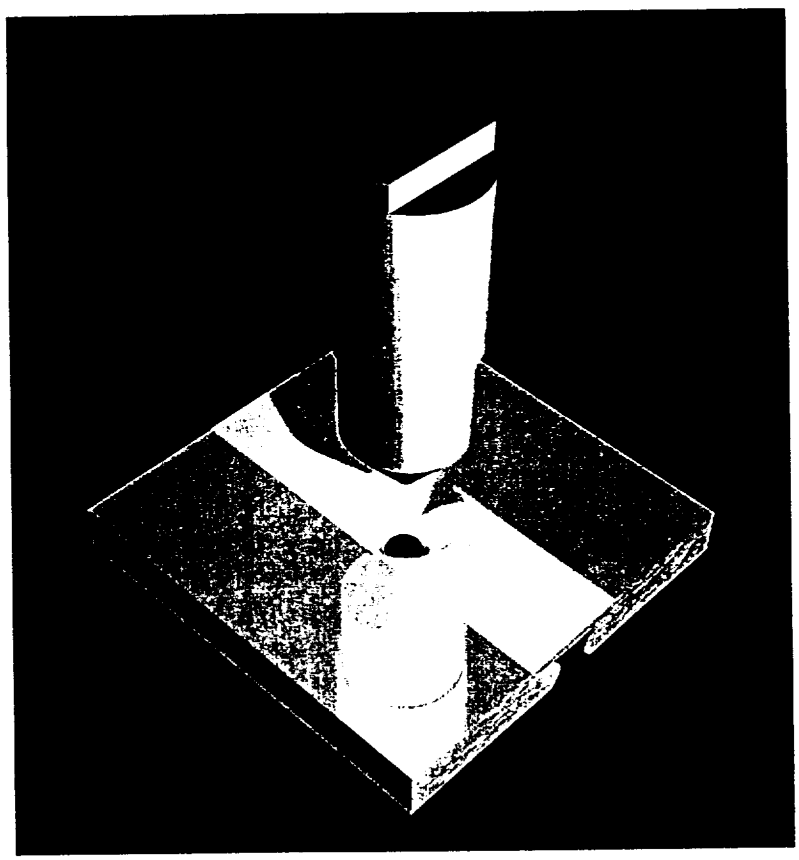

Figure 2a

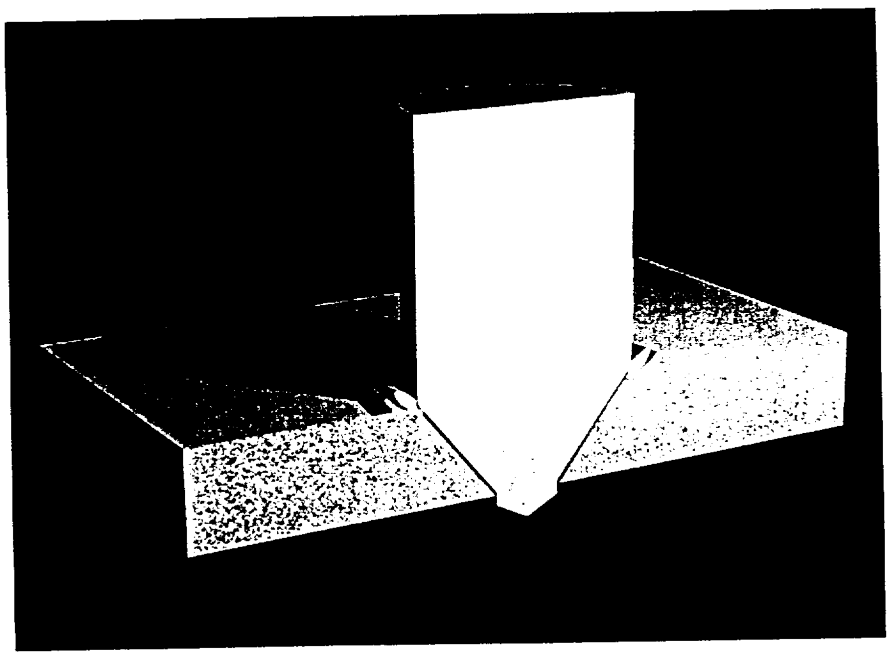

Figure 2 b

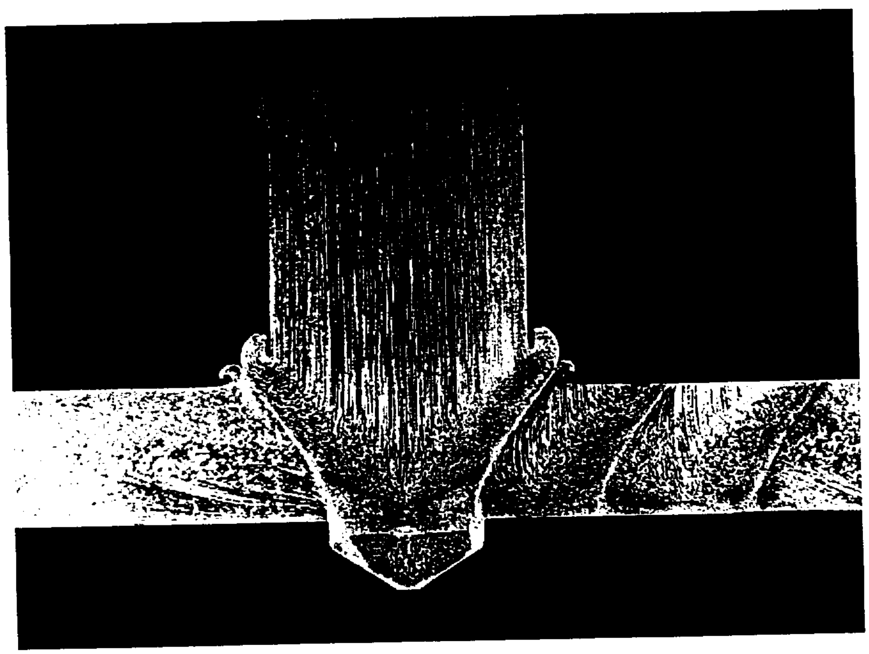

Figure 3

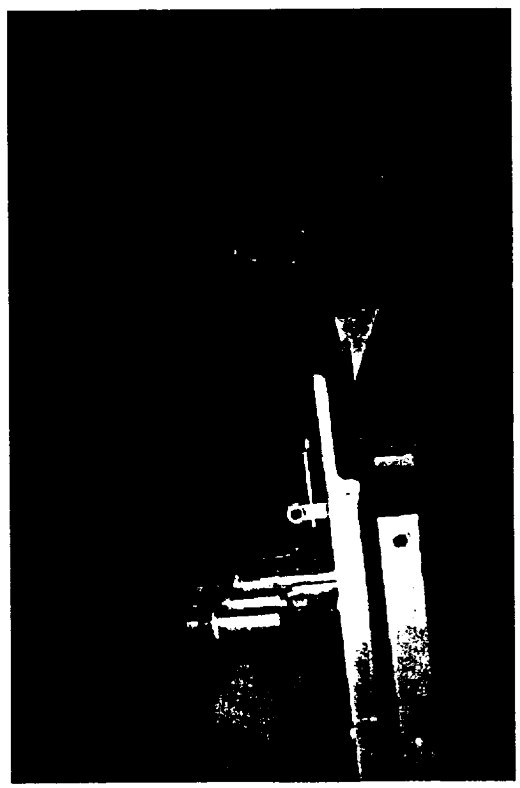

Figure 4