Space Shuttle
Technology Summary

Friction Stir Welding

Friction Stir Welding is the most recent upgrade to the Space Shuttle's gigantic External Tank, the largest element of the Space Shuttle and the only element not reusable. The new welding technique—being marketed to industry—utilizes frictional heating combined with forging pressure to produce high-strength bonds virtually free of defects. Friction Stir Welding transforms the metals from a solid state into a "plastic-like" state, and then mechanically stirs the materials together under pressure to form a welded joint.

Invented and patented by The Welding Institute, a British research and technology organization, the process is applicable to aerospace, shipbuilding, aircraft and automotive industries. One of the key benefits of this new technology is that it allows welds to be made on aluminum alloys that cannot be readily fusion arc welded, the traditional method of welding.

In 1993, NASA challenged Lockheed Martin Laboratories in Baltimore, Md., to develop a high-strength, low-density, lighter-weight replacement for aluminum alloy Al 2219–used on the original Space Shuttle External Tank. Lockheed Martin, Reynolds Aluminum and the labs at Marshall Space Flight Center in Huntsville, Ala., were successful in developing a new alloy known as Aluminum Lithium Al-Li 2195, which reduced the weight of the External Tank by 7,500 pounds (3,402 kilograms). Today, the External Tank project uses the new alloy to build the Shuttle's Super Lightweight Tanks.

The lithium in the new lighter-weight material—aluminum lithium alloy Al-Li 2195—made the initial welds of the External Tank far more complex. The repair welds were difficult to make and the joint strength of the External Tank had much lower mechanical properties. This drove up production cost on the tank. In an effort to mitigate the increased production cost and regain the mechanical properties of the earlier Al 2219 External Tank the project began researching alternative welding techniques. Because Friction Stir Welding produces stronger welds—that are easier to make—the External Tank Project Managers chose to use the process on its Super Light Weight Tank, which is made from Al-Li 2195. The Friction Stir Welding process produces a joint stronger than the fusion arc welded joint, obtained in the earlier Light Weight Tank program.

A significant benefit of Friction Stir Welding is that it has significantly fewer process elements to control. In a Fusion weld, there are many process factors that must be controlled–such as purge gas, voltage and amperage, wire feed, travel speed, shield gas, arc gap. However, in Friction Stir Weld there are only three process variables to control: rotation speed, travel speed and pressure, all of which are easily controlled. The increase in joint strength combined with the reduction in process variability provides for an increased safety margin and high degree of reliability for the External Tank.

How does Friction Stir Welding work? First, a dowel is rotated between 180 to 300 revolutions per minute, depending on the thickness of the material. The pin tip of the dowel is forced into the material under 5,000 to 10,000 pounds per square inch (775 to 1550 pounds per square centimeter) of force. The pin continues rotating and moves forward at a rate of 3.5 to 5 inches per minute (8.89 to 12.7 centimeters per minute). As the pin rotates, friction heats the surrounding material and rapidly produces a softened "plasticized" area around the pin. As the pin travels forward, the material behind the pin is forged under pressure from the dowel and consolidates to form a bond. Unlike fusion welding, no actual melting occurs in this process and the weld is left in the same fine-grained condition as the parent metal.

One of the early drawbacks to the friction stir process was the fixed pin, because it limited welding to materials with a constant thickness. The Shuttle's External Tank project developed a through-spindle retractable pin tool that can retract or expand its pin tip within the material. This allows for changes in thickness such as on the tank's longitudinal barrel.

The viability of the technology was demonstrated when NASA's Marshall Center used the retractable pin tool to weld a full-scale External Tank hydrogen barrel. The External Tank project will implement Friction Stir Welding on the longitudinal barrel welds on both the liquid oxygen and hydrogen tanks. External Tank 134—scheduled to fly in January 2005—will be the first tank to incorporate the process.

The Marshall Center is NASA's lead center for development of space transportation and propulsion systems, including the development of the Space Shuttle's External Tank, Solid Rocket Boosters, Reusable Solid Rocket Motors and Main Engines.

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