

Innovative Tools Advance Revolutionary Weld Technique

Originating Technology/NASA Contribution

The iconic, orange external tank of the space shuttle launch system not only contains the fuel used by the shuttle's main engines during liftoff but also comprises the shuttle's "backbone," supporting the space shuttle orbiter and solid rocket boosters. Given the tank's structural importance and the extreme forces (7.8 million pounds of thrust load) and temperatures it encounters during launch, the welds used to construct the tank must be highly reliable.

Variable polarity plasma arc welding, developed for manufacturing the external tank and later employed for building the International Space Station, was until 1994 the best process for joining the aluminum alloys used during construction. That year, Marshall Space Flight Center engineers began experimenting with a relatively new welding technique called friction stir welding (FSW), developed in 1991 by The Welding Institute, of Cambridge, England. FSW differs from traditional fusion welding in that it is a solid-state welding technique, using frictional heat and motion to join structural components without actually melting any of the material. The weld is created by a shouldered pin tool that is plunged into the seam of the materials to be joined. The tool traverses the line while rotating at high speeds, generating friction that heats and softens—but does not melt—the metal. (The heat produced approaches about 80 percent of the metal's melting temperature.) The pin tool's rotation crushes and stirs the "plasticized" metal, extruding it along the seam as the tool moves forward. The material cools and consolidates, resulting in a weld with superior mechanical properties as compared to those weld properties of fusion welds.

The innovative FSW technology promises a number of attractive benefits. Because the welded materials are not melted, many of the undesirables associated with fusion welding—porosity, cracking, shrinkage, and distortion of the weld—are minimized or avoided. The process is

more energy efficient, safe (no toxic smoke or shielding gas, liquid metal splatter, arcing, dangerous voltage, or radiation), and environmentally sound (no consumables, fumes, or noise) than fusion welding. Under computer control, an automated FSW machine can create welds with high reproducibility, improving efficiency and overall quality of manufactured materials. The process also allows for welding dissimilar metals as well as those metals considered to be "unweldable" such as the 7xxx series aluminum alloys. Its effectiveness and versatility makes FSW useful for aerospace, rail, automotive, marine, and military applications.

A downside to FSW, however, is the keyhole opening left in the weld when the FSW pin tool exits the weld joint. This is a significant problem when using the FSW process to join circumferential structures such as pipes and storage containers. Furthermore, weld joints that taper in material thickness also present problems when using the conventional FSW pin tool, because the threaded pin rotating within the weld joint material is a fixed length. There must be capability for the rotating pin to both increase and decrease in length in real time while welding the tapered material. (Both circumferential and tapered thickness weldments are found in the space shuttle external tank.) Marshall engineers addressed both the keyhole and tapered material thickness problems by developing the auto-adjustable pin tool. This unique piece of equipment automatically withdraws the pin into the tool's shoulder for keyhole closeout. In addition, the auto-adjustable pin tool retracts, or shortens, the rotating pin while welding a weld joint that tapers from one thickness to a thinner thickness. This year, the impact of the Marshall innovation was recognized with an "Excellence in Technology Transfer Award" from the Federal Laboratory Consortium.

Partnership

In the late 1990s, Nova-Tech Engineering LLC, a machine design, aerospace tooling, and manufacturing



The retractable pin tool developed at Marshall Space Flight Center fully enables friction stir welding (FSW) for circumferential and tapered thickness welds, like those needed to assemble the space shuttle's external tank.

systems company, based in Lynnwood, Washington, provided Marshall with stir welding machine retrofits that employed the retractable pin tool, for use during the center's FSW research on longitudinal and circumferential welds for the space shuttle's external tank. In 2003, Nova-Tech acquired the FSW equipment and process capabilities of Seattle, Washington firm MCE Technologies Inc., which was co-licensee of the 2001 NASA license for the Marshall FSW technology. After acquiring MCE, Nova-Tech applied for and received a co-exclusive license for the auto-adjustable pin tool for friction stir welding.

Product Outcome

The Marshall adjustable pin tool technology is featured on nearly all of Nova-Tech Engineering's stir

welding systems, including the first three FSW weld heads delivered to the Marshall Space Flight Center in the late 1990s. Nova-Tech supplies a wide range of stir welding machine configurations including circumferential and vertical stir welders for rocket tank assembly; large, five-axis horizontal and vertical stir welders for combat vehicle construction; and multi-axis stir welders for research and development use.

“There are some distinct advantages to the retractable pin,” says Don Holman, FSW product manager for Nova-

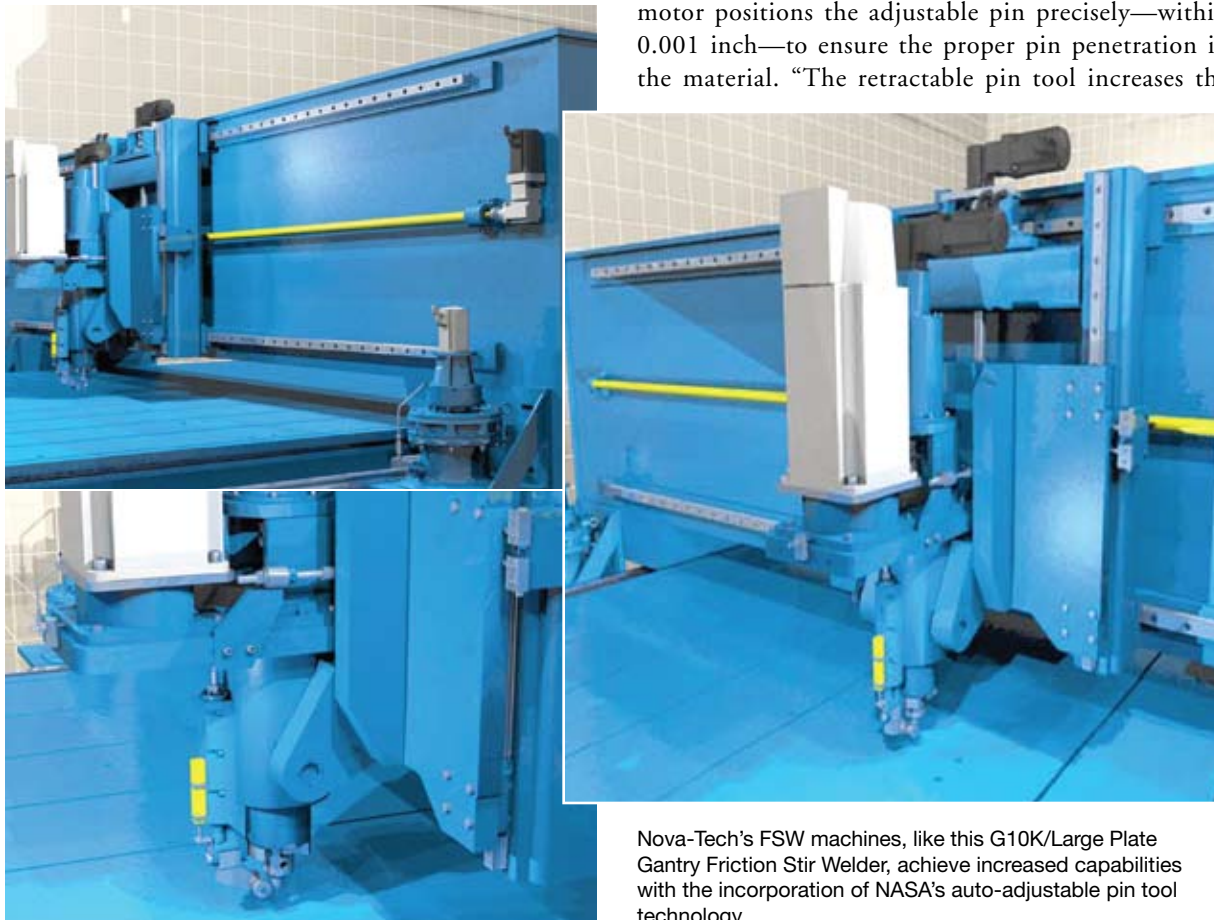
Tech. He explains that the pin provides an integrated solution to the keyhole problem on circumferential welds, and though the technology is not necessary for longitudinal welds, it can still be applied to eliminate the keyhole rather than using run-off tabs (additional lengths of metal that can be trimmed off to eliminate keyholes). Holman also notes that the adjustable pin can sustain uninterrupted full penetration welds on plates of varying thicknesses, without requiring multiple pin tools of varying lengths. A computer-controlled servo motor positions the adjustable pin precisely—within 0.001 inch—to ensure the proper pin penetration in the material. “The retractable pin tool increases the

capabilities of our machines,” Holman says, making them more efficient at creating more precise, stronger FSW welds.

The appeal of Nova-Tech’s adjustable pin-equipped FSW systems has extended across a wide range of industries. Concurrent Technologies Corporation, a nonprofit research and development organization with offices across the country, uses a Nova-Tech five-axis stir welder at its Johnstown, Pennsylvania, location for welding of armor plate for the U.S. Army’s Expeditionary Fighting Vehicle program. Nova-Tech also built a production FSW machine for Noble Drilling Services of Houston, Texas, a leading offshore drilling contractor that uses the machine to weld aluminum riser piping for offshore drilling rigs; the Nova-Tech machine was the first FSW system developed for the oil and gas industry.

Nova-Tech FSW systems are also employed by a number of research institutions exploring ways to improve welding processes for manufacturing. These include the Edison Welding Institute in Columbus, Ohio, and the Missouri University of Science and Technology in Rolla, Missouri. Nova-Tech is additionally a partner of an integrated project team that last year developed and delivered a low-cost FSW system prototype to the U.S. Navy Metalworking Center, which plans to use the machine as an efficient, cost-effective production tool for its Littoral Combat Ship (LCS) program. The LCS program is developing next-generation combat ships for use in littoral, or close to shore, zones.

Just as the demands of space exploration led to the adjustable pin technology Nova-Tech now incorporates in its FSW machines, the company is also contributing back to the space industry. Space Exploration Technologies Corporation (SpaceX), of Hawthorne, California, performs circumferential welds on its rockets using a Nova-Tech FSW system. A private launch company, SpaceX is working in close cooperation with NASA to develop, among other things, a cargo launch system for transporting supplies to the International Space Station. ❖



Nova-Tech’s FSW machines, like this G10K/Large Plate Gantry Friction Stir Welder, achieve increased capabilities with the incorporation of NASA’s auto-adjustable pin tool technology.