A welding method often thought of as a tool for joining large parts is finding new uses
Friction stir welding (FSW) is often considered to work part-and-parcel with huge jobs: ship panels, railroad cars, massive structural applications. But, the uniqueness of the technology – speed, consistent quality, weld strength, costs – is drawing the attention of equipment manufacturers. PTG Industries, for instance, launched a new U.K.-based welding facility to explore the applications for friction welding and the joining of unique and challenging materials.

“Our new sub-contract welding division has proved a considerable success, attracting projects from a number of sectors,” PTG applications manager, Peter Jowett, said in a press release. “With that in mind, we decided the time was right to extend our offering to include research into welding techniques – particularly when involving small-scale components or the joining of exotic and particularly difficult-to-weld alloys.”

Likewise, ESAB, considered the world’s largest welding equipment and accessory supplier, is another major player in the friction welding milieu. ESAB has pursued a variety of options, looking specifically at high-volume production and fabricating settings. In doing so, the company offers Legio FSW machines that feature a modular concept comprised of five basic designs in a series of welding-head sizes. They are available for a range of welding depths for various sheet thicknesses.

The basic Legio machines can be supplemented with different types of fixtures, clamping systems and rotary units to suit the most varied research and fabrication needs. There is also the Rosio FSW robot that enables flexible joining of complex structures, preferably those made of aluminum. The ability to perform welds in an arbitrary direction in a 3-D workspace increases the potential for new FSW applications.
A large panel at a shipbuilding facility is being welded using the friction stir welding method.

In addition to PTG and ESAB, Manufacturing Technology Inc. (MTI) is another player bringing FSW to the mainstream. At IMTS 2016, MTI exhibited a variety of small components produced using FSW.

Adding to the list of companies focusing on friction welded smaller components is Coldwater Machine Co. Unlike ESAB, PTG and others, Coldwater focuses on friction welding methods other than FSW to work smaller parts. Instead, it uses traditional rotary friction welding and refill friction stir spot welding technology. The first of which can join small 3-D parts; the second focuses on sheet metal components. Some of these technologies are being used to join aluminum parts for a high-profile automotive manufacturer as it works to reduce the weight of its vehicles.

"Friction welding technology has been around a long time, and the process has traditionally focused on larger parts that butted against each other," says Mike Spodar, senior welding engineer for Coldwater. "I used to make trailer axles with this process, so it had to be a very rugged and robust process. Our niche at Coldwater is that we specialize in smaller diameters for spin welding applications."

**THE CURIOSITY OF FSW**

Considering FSW was once considered a laboratory curiosity, the technology has come a long way. It was invented by Wayne Thomas at The Welding Institute in the U.K. and patented in 1991 (TWI still holds the FSW patent). The technology might best be known, however, as the technology behind the 170-ft.-tall-by-78-ft.-wide welding tool at the vertical assembly center at NASA’s Michoud Assembly Facility in New Orleans. So, it came as somewhat of a surprise that it is also a good, competitive option for joining smaller components that otherwise might...
be joined with resistance welding, riveting or other fastening options.

Like all friction welding method technologies, FSW requires no filler materials, gases or other consumables and generates no harmful gases, slag or spatter. The solid-state process is not susceptible to solidification-related defects that may hinder other welding processes. It can rapidly produce high-quality, high-strength welds of lightweight materials, including 2000 to 7000 series aluminum, and can weld dissimilar alloys including copper and magnesium, sometimes referred to as “unweldable” materials.

According to an ESAB white paper on FSW, a rotating pin emerging from a cylindrical shoulder is plunged between two pieces of sheet and moved forward along the joint line. The material is heated by friction between the rotating shoulder and the workpiece surface and simultaneously stirred by the pin leaving a solid-phase bond between the two pieces to be joined.

Peter Kjällström, ESAB’s product director for automation and material handling, says that the FSW process takes place in the solid phase below the melting point of the metals to be joined. Thus, all the problems related to the solidification of a fused material are avoided. For instance, comparing FSW to MIG processes, he says that there are several benefits.

• FSW can weld up to 75 mm (3 in.) thickness in one run. “With MIG you need to use a multi-run technique as there has to be a joint preparation (ex V-joint), which is more time consuming to weld and prepare,” he says.

• FSW is a solid-state process, so objects are joined without reaching melting point. This means that the metallurgical structure remains basically the same as the base material even in the weld zone.

• When adding a lot of heat with MIG, plates get distorted, which requires post-work. FSW does not cause distortion.

• It is not possible to weld all aluminum alloys with an open arc process. FSW can manage all types of aluminum alloys.

The Pin Tool
According to ESAB, one limitation of the FSW process is mechanical stability of the pin tool at operating temperature. During FSW, the tool is responsible for not only heating the substrate material to forging temperatures, but also providing the mechanical action of forging. Therefore, the tool material must be capable of sustaining high forging loads and temperatures in contact with the deforming substrate material without either excessive wear or deformation. As a result, the bulk of the FSW applications have involved low forging temperature materials.

According to Kjällström, every alloy/material in different thicknesses requires special parameters with respect to the tool design. The simple pin-shaped, non-profiled tool creates frictional heat and is very useful if enough downforce can be applied.

Unfortunately, the oxide-layer breaking characteristics are not very good, and as material thickness is increased, welding heat at the lower part of the joint may be insufficient.

Figure 1. Some basic tool shapes for friction stir welding.
With parameter adjustment and tool geometry optimization, the oxide layer could be broken more effectively.

Therefore, the need to generate more frictional heat and break the oxide layer more effectively has been a driving force in tool development for lightweight metals. In Figure 1, different pin tools trademarked by TWI are displayed showing differences in shape, size and geometric features to match the needs of specific applications.

The welding forces are for the same thickness, increasing with increased alloying and welding speed. As an example, a 5-mm-thick aluminum 6082 T6 butt joint can be welded at low speed with a certain downforce, but the same welding at 6 m per min. needs eight to 10 times higher downforce. So, the reaction force from the workpiece toward the equipment is changing in the same way. The target is always to get a good balance between welding and fixturing time.

“As FSW requires a fixture, [the process] will be more time consuming when handling smaller components unless you can fit multiple components into the same fixture,” Kjällström says. “[And] small objects can be placed in a fixture where it is possible to weld several pieces at the same time. The target is always to get a good balance between welding and fixturing time.

“On the other hand, large components require larger more costly fixtures,” he continues. “The object has to be positioned and held at the same time. It has to have a strong C frame support the downforces.”

When it comes to varied thickness, information is key. “If the thickness variation is known,” Kjällström says, “a retractable pin tool can be used. It is a tool where the pin can move independently from the shoulder and thereby handle the variations.”

**SPIN AND SPOT**

Coldwater Machine offers equipment for both sheet metal and 3-D friction welding. The 3-D friction spin weld process, known as SpinMeld, focuses on parts less than 2 in. in...
Friction stir welding can weld similar sheet metal material such as the brass panel on the right and the brass and aluminum joined panel on the left.

One diameter, also uses tool depths as a way to solve material thickness differences. This process can join steel, aluminum, cast or sintered metals, magnesium, brass, ceramics with mixed metal connections and dissimilar combinations of these materials. Focusing on smaller parts, SpinMeld requires less force and can join the part at higher speeds, says Spodar. Shafts, valve bodies, pistons, brackets and airbag inflators are just some of the components well-suited for SpinMeld production.

“We are presenting the technology as an alternative to a customer that is using a traditional resistance weld or projection weld,” Spodar says. “In that regard, we typically offer better cycle times and improved strength of the joint. We can turn these parts at up to 23,000 rpm and that leads to low cycle time, very low heat input and less distortion, and we are still producing a good, repeatable weld.”

For instance, if Spodar is welding a 6-mm-dia. aluminum pin, there is
a friction time of 0.1 sec., a speed of 18,000 rpm and a force of about 2,000 lbs. If it is a steel rod measuring 1/2 in. in diameter, it would take approximately 6 sec. at 20,000 rpm and about 3,000 lbs. of force.

“Typically,” he says, “for this application a customer might use a TIG or MIG process. It is going to be a slow process, and it will have a lot of heat input, so there will be distortion issues. Our process is a fairly quick application, and there are no fillers or fumes, and our perpendicularity is going to be almost perfect.”

Coldwater also offers SpinMeld production services for short run and prototype parts. SpinMeld systems rely on rotational friction welding principles and a direct-drive approach where a spinning workpiece, driven at a constant speed by an electric motor, is joined to a stationary one by rotational friction and externally applied force. It’s an extremely fast process that produces frictional heat at a sufficient temperature for the materials to reach a plastic state (non-melting or solid state) at the joint interface. The materials are then forged together by force.

SpinMeld solutions offer numerous benefits, including higher quality joints with high hardness, a small heat-affected zone and no coarse grain formation. The systems are also extremely energy efficient as 95
In this video, Dan Adams, chief technology officer at TWI, showcases various parts produced using the friction stir welding method.

In addition to its ability to join dissimilar and lightweight materials, benefits include high-quality joints with a small heat-affected zone and consistency in weld duplication. It’s also environmentally cleaner and safer with no filler material, spatter, smoke, radiation or shield gases.

Rotational speeds are available from 2,000 rpm to 23,000 rpm and forging forces from 335 lbs. to 12,000 lbs.

In the first phase, the weld head closes. In the second phase, the friction phase, the pin and sleeve are placed on the surface of the upper sheet and rotate to generate sufficient frictional heat for plunging. In the third phase, the sleeve advances into the material and the pin retracts, pulling softened material from the metal sheets into the tool. During the fourth phase, the sleeve retracts and the pin advances flush with the sleeve, pushing displaced material back into the hole and forging the finished weld. Finally, in the fifth phase, the weld head opens and the weld process is complete.

In a material stack-up application in which there are three sheets of 3-mm 6000 series material and one sheet of 1.5-mm 5000 series material, the process would take less than 6 sec.

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