FRICTION STIR WELDING - PROGRESS IN R&D AND NEW APPLICATIONS

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In spite of its very recent introduction into industry, Friction Stir Welding is already frequently used in production. This article presents some recent results from the continuous research work that is in progress on the process, a new machine series that is going to be introduced and an extremely fascinating new application in the welding of thick copper.

Metallurgical considerations in Friction Stir Welding

Friction Stir Welding is a comparatively new welding process introduced by TWI in the UK in 1991. The very first applications in production were in the 6000 series aluminium alloys at SAPA in Sweden and Hydro Marine Aluminium (shipbuilding) in Norway, followed by the automotive industry in Australia, Sweden and Norway, also using the 6000 series.

High-strength aluminium alloys in the 7000 series grades started the evolution in the aerospace industry. The FSW process is still finding new applications in aluminium alloys. Other materials such as copper and magnesium alloys are ready to be introduced in production. Steel and the joining of dissimilar materials such as copper and aluminium are shortly expected to leave the laboratories, while titanium and stainless steel are waiting for tests of tool materials to withstand the heat.

The process

FSW is a solid state welding process in which the weld is completed without creating molten metal. A rotating tool specially designed for its purpose generates heat and deformation of a superplastic nature close to the tool, which moves along the joint interface (Figure 1). The tool usually has a large-diameter shoulder and a smaller threaded pin. The rotating tool creates a thin plasticised zone around the pin and material is transported from the front to the rear by a solid-state keyhole effect. The process is thus characterised by high strain rates and super-plasticity near the rotating tool.

The thermal cycle created by the spindle action at different speeds is a controlling factor for the microstructures found in the stirred zone and the heat affected zone. A temperature gradient is superimposed on the super-plastic deformation between the top surface and root of the weld. When the energy input is increased by higher rotation speed, the hardness across the nugget zone is more equal and the grain size increases. At very high tool rotation speeds, the nugget properties start to deteriorate due to the precipitation around the coarse grains. It is obvious that there is an optimum speed constellation of rotating

The FSW plant at DanStir, Denmark

speed and the forward feed for a given material and thickness.

Developments started with welds from one side, where the distance between the tool end and the root has an important effect on the welding result. Subsequent applications include two-sided welding with two heads and a bobbin tool on solid material and with two heads on hollow extrusions. With these systems, the tolerances in material thickness are easier to cope with and they create new opportunities in production technology. Curved surface welding is also on the way.

Quality assessment

The best way to determine the weld qualities of FSW is to compare the properties obtained in FSW with those produced by other welding methods. The very local deformation at low heat inputs in solid state FSW makes this welding method superior to other welding methods such as MIG and MAG welding. Structures with rigorous performance requirements, such as rockets and aircraft, and applications in which high quality is required by codes are other areas for FSW. In the as-welded condition, FSW has demonstrated properties superior to those produced by other welding methods. The welding speed and the high quality obtained without any pre- or after-work on the welds will result in the steady extension of applications. Most design and welding codes currently accept FSW due to the high quality that has been demonstrated worldwide.

Increased welding speed in the 6000 series aluminium alloys

ESAB and other companies and research institutes have done a great deal of research on the 6000 series of aluminium alloys. These alloys are the most commonly used in railway wagons, ship panels and the automotive industry and they are now also starting to attract the interest of aircraft manufacturers. Normal welding speeds in production are 0.8-2.0 m/min. for 5 mm thick workpieces. As 6082 material is often used in the T6 condition (heat treated to produce higher mechanical properties), one task for R&D is to reduce the decline in hardness in order to retain as much as possible of the T6 treatment effect. One solution is to weld quickly. It is not often that a high welding speed means higher quality, but in this case it does.

In the ESAB laboratories in Laxå, a great deal of test welding has been performed with the aim of increasing the welding speed. A year ago, 3 m/min. was reached, but recent tests with refined procedures have shown that 6 m/min. in 5 mm 6082 material is possible and that this very high speed is definitely not the ultimate limit. These very promising results will further increase the number of profitable applications for Friction Stir Welding.

Research centres using ESAB SuperStir®

- The FSW process was invented and developed by TWI in the UK. TWI is still leading the way to new applications and materials. With its new FSW - plant, it is well equipped for future interesting tasks.
- The aerospace industry demonstrated great interest in the new process at a very early stage. The Boeing Company at Huntington Beach, Ca, USA developed the process for aerospace applications, together with TWI, and it is continuously working in its laboratories on new tasks for aerospace, aircraft and other applications (Figure 2).
- Boeing in St. Louis is conducting a great deal of research for the aircraft industry to produce new Friction Stir Welded parts. Among other things, a new hollow profile floor section has been produced together with SAPA in Sweden.
- Following Boeing's success, other aerospace and aircraft research institutes have invested in advanced machines for research work and test welding. EADS in France, together with Institute Soudure, Alenia Spacio in Italy and EADS in Germany, are examples of these institutes. Other companies have chosen to conduct their tests at ESAB, TWI or other research centres.
- For the automotive and other segments, Tower Automotive in the USA has a well-equipped FSW centre for research, test welding and test production.

- DanStir in Denmark is one of several companies focusing on test welding, the production of test series and low series production with FSW. DanStir, however, has a large, flexible FSW plant well suited to different tasks (photo page 11).
- The research and development of production data is continuously being conducted by the producers of aluminium structures, such as Hydro Marine Aluminium in Norway and SAPA in Sweden.

Figure 1. FSW process in a butt joint against backing bar

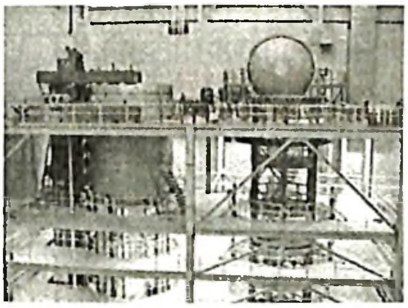

Figure 2. Take-over test of the FSW plant supplied by ESAB AB, Welding Automation to Boeing's space rocket plant

- At its plant in Laxå, ESAB has two FSW machines for research work, demonstrations and test welding for customers (Figure 3). Its engineering division is well equipped to comply with customers' requirements for production solutions, including the design, manufacture, commissioning and service of FSW machines and complete production plants worldwide.

New modularised machine series

In order for manufacturers to invest in the FSW welding technique in a cost-effective manner, ESAB is now launching a new modularised machine series called LEGIO™, new members of the ESAB Super Stir™ programme. With the new machines, material with a thickness of between 1.4 and 100 mm can be welded. The spindle power ranges from 1.5 kW to 100 kW. The machine series consists of two main types, the S series for straight welds and the U series for straight welds in the X or Y directions, as well as in optional patterns such as circles, squares and so on. Each series has two main designs, one floor mounted with vertical surfaces for mounting large fixtures, circumferential welding units or a lower head assembly for double-sided welding and one type with a table for mounting small fixtures.

The FSW 3 UT (Universal type with table, 11 kW spindle, max. capacity 10 mm in the 6000 series) will be introduced at the Essen Alu Fair in Germany in 2002 (Figure 4).

Welding thick copper material with FSW

Developments in the Friction Stir Welding (FSW) of copper will take a further step forward, as the Swedish Nuclear Fuel and Waste Management Co. (SKB) is investing in a full-scale FSW plant at its canister laboratory in Oskarshamn, Sweden. The background to SKB's interest in welding thick copper sections is the Swedish decision to deposit high-level nuclear waste in copper canisters at a depth of 500 metres in the bedrock. The sealing of the copper canisters needs to be of a very high quality, as it must remain intact during the 100,000-year service life of the repository.

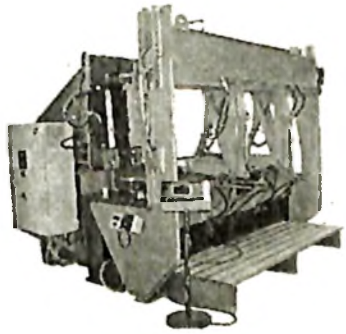

Figure 3. At the test centre at ESAB Laxå, FSW process development and investigation of different customer applications are made

Figure 4. FSW 3 UT - one example of the new modularised machine series from ESAB AB, Welding Automation

SKB has studied different welding methods in co-operation with TWI in the UK. Full-scale electron beam welding tests have been performed. In 1998-1999, a test rig was built at TWI for the Friction Stir Welding of mock-up canisters. A fixture holds the canister and rotates it during welding (Figure 5). The lid is pressed down with four hydraulic cylinders. The welding speed reaches 150 mm per minute. At the beginning, the trials were exclusively limited to welding segments, but, after fine-tuning the process, a full circumferential weld could be completed in November 2000. The FSW process has functioned well and SKB now feels confident about taking the next step in the development and has decided to install a full-scale FSW machine at its canister laboratory in order to investigate the feasibility of the process for the production of canisters (Figure 6). SKB has assigned the task of designing, manufacturing, testing and commissioning the machine to ESAB AB, Welding Automation, Laxå. Test welding in Oskarshamn is scheduled to start early in 2003. SKB can then begin the work of optimising the welding parameters. This has not been possible with the test rig at TWI.

When welding a circular seam with FSW, a hole is left in the material when the FSW tool is retracted. This hole can be filled afterwards or simultaneously when the tool is retracted. A more simple and reliable method is to finish the weld in solid material outside the joint (Figure 7). In the latter case, SKB is planning to finish the weld at the top of the lid. However, the hole may create difficulties for the non-destructive testing after welding. Remaining R&D work will also focus heavily on the design of the lid and the testing methods. The testing methods that are developed by SKB in co-operation with Uppsala University at the SKB canister laboratory are digital radiography, ultrasonic and inductive testing. Another important part of the development of the welding and testing techniques is to determine the criteria for the size and form of the weld defects that can be accepted.

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