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Friction Stir Welding-A Review

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Abstract- *Friction stir welding(FSW), a new solid state joining process combining deformation heating and mechanical work to obtain high quality, defect-free joints. Friction stir welding is well suited for joining aluminium alloys in a large range of plate thickness and has particular advantage over fusion welding when joining of highly alloyed aluminium is considered, high quality joints may even be made in discontinuously reinforced aluminium alloys. Because of the many demonstrated advantage of FSW over fusion welding techniques, the commercialization of friction stir welding is proceeding at a rapid pace. Current production application includes both large and small scale products.*

Keywords: *Friction Stir Welding, Process Parameters, Mechanical Properties*

I. INTRODUCTION

In many industrial applications steels are readily replaced by nonferrous alloys, in most cases by aluminum alloys. Some of these materials combine mechanical strength comparable with structural steels and low weight, allowing for a significant reduction of weight. While production of components of aluminum alloys is not very complex, joining of these materials can sometimes cause serious problems. Lack of structural transformations in solid state, excellent thermal and electrical conductivity which cause problems in fusion and resistance welding of aluminum alloys. That led to the development of Friction Stir Welding a solid state joining technique in which the joined material is plasticized by heat generated by friction between the surface of the plates and the contact surface of a special tool, composed of two main parts: shoulder and pin. Shoulder is responsible for the generation of heat and for containing the plasticized material in the weld zone, while pin mixes the material of the components to be welded, thus creating a joint. This allows for producing defect-free welds characterized by good mechanical properties.

II. Working Principle

Traditionally, friction welding is carried out by moving one component relative to the other along a common interface, while applying a compressive force across the joint. The friction heating generated at the interface softens both components, and when they become plasticized the interface material is extruded out of the edges of the joint so that clean material from each component is left along the original interface. The relative motion is then stopped, and a higher final compressive force may be applied before the joint is allowed to cool. The key to friction welding is that no molten material is generated, the weld being formed in the solid state

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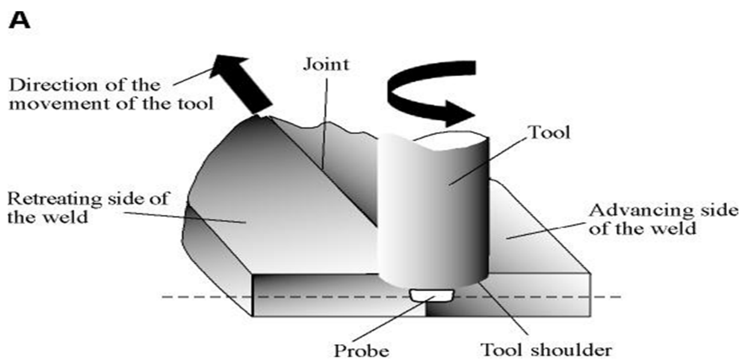
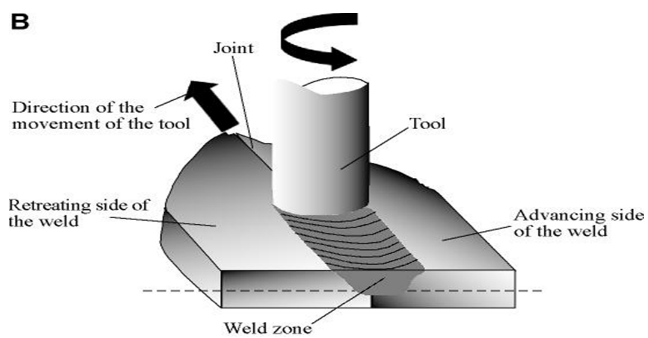
A. Friction Stir Welding



a) Two discrete metal work pieces butted together, along with the tool (with a probe).



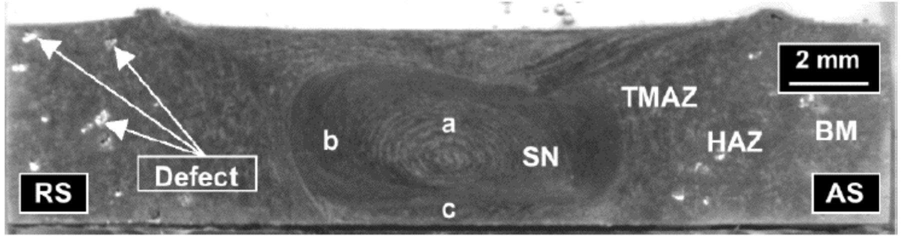
b)The progress of the tool through the joint, also showing the weld zone and the region affected by the tool shoulder

Working principle of FSW Tool is pushed into the materials to be welded and is brought into contact with the two parts to be joined. The rotation of tool heats up and plasticizes the materials in contact with tool. Movement of tool forces the plasticized material to back of the tool whilst applying a substantial forging force to consolidate the weld metal.

B. FSW of Aluminium

- The most popular aluminum alloy contains about 8 wt% of silicon.
- It therefore solidifies to primary aluminum-rich dendrites and a eutectic mixture of aluminum solid-solution and almost pure silicon.
- The latter occurs as coarse silicon particles which tend to be brittle.
- The cast alloy usually has some porosity.
- Friction stir welding has the advantage that it breaks up the coarse silicon particles and heals any pores by the mechanical processing, as illustrated below.

Friction Stir Welding



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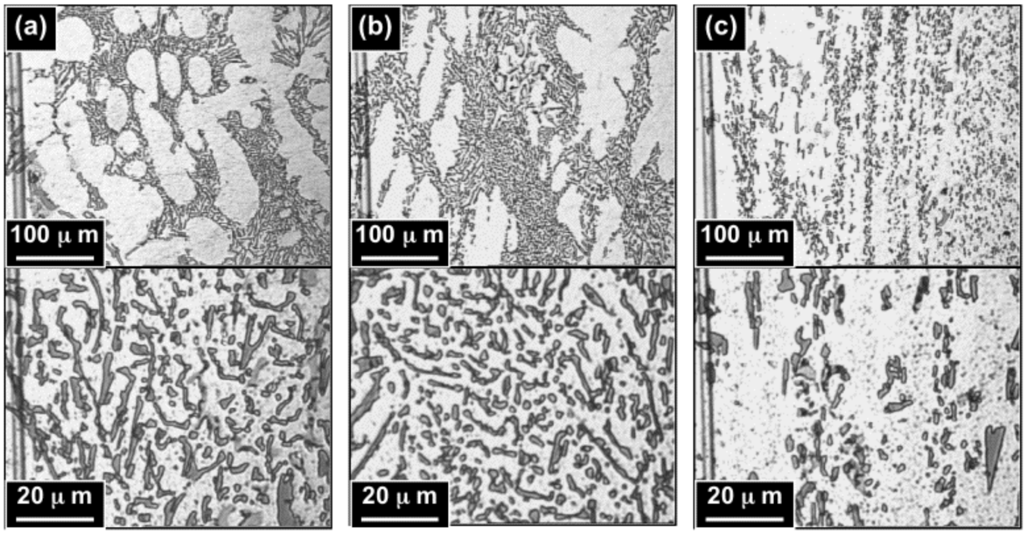
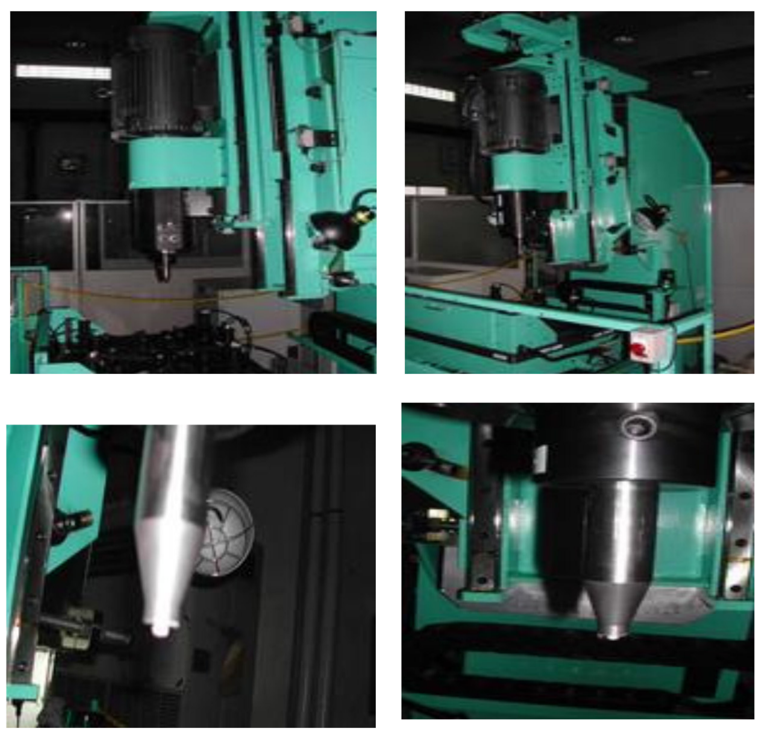
A section through a friction stir weld made in an Al-Si casting alloy. There are pores indicated in the base metal (BM). HAZ represents the heat affected zone, TMAZ the thermo mechanically affected zone.



Optical micrographs showing the microstructure in (a) the base metal; (b) heat-affected zone; (c) the microstructure

III. Machine

The six photographs below show a typical friction stir welding (FSW) machine. This one is at the Joining and Welding Research Institute



III. Tool

Each tool has a shoulder whose rotation against the substrate generates most of the heat required for welding. The pin on the tool is plunged into the substrate and helps stir the metal in the solid state. High speed steel is used for welding aluminium

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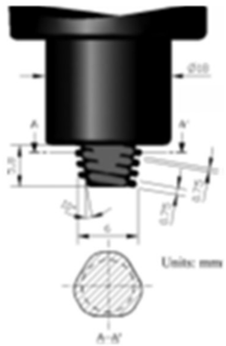

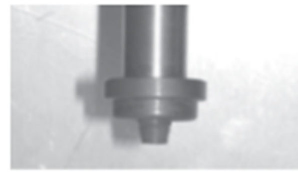

IV. Parameters

A. Flow of Material

Material motion occurs by two processes: Material on the advancing front side of a weld enters into a zone that rotates and advances with the pin. This material was very highly deformed and sloughs off behind the pin to form arc-shaped features when viewed from above (i.e. down the tool axis). It was noted that the copper entered the rotational zone around the pin, where it was broken up into fragments. These fragments were only found in the arc shaped features of material behind the tool. The lighter material came from the retreating front side of the pin and was dragged around to the rear of the tool and filled in the gaps between the arcs of advancing side material. This material did not rotate around the pin and the lower level of deformation resulted in a larger grain size.

B. Generation and Flow of Heat

For any welding process it is, in general, desirable to increase the travel speed and minimize the heat input as this will increase productivity and possibly reduce the impact of welding on the mechanical properties of the weld. At the same time it is necessary to ensure that the temperature around the tool is sufficiently high to permit adequate material flow and prevent flaws or tool fracture.

The welding cycle can be split into several stages:

Dwell: - The material is preheated by a stationary, rotating tool in order to achieve a sufficient temperature ahead of the tool to allow the traverse. This period may also include the plunge of the tool into the work piece.
Transient heating: - When the tool begins to move there will be a transient period where the heat production and temperature around the tool will alter in a complex manner until an essentially steady-state is reached.
Pseudo steady-state: - Although fluctuations in heat generation will occur the thermal field around the tool remains effectively constant, at least on the macroscopic scale.
Post steady-state: - Near the end of the weld heat may 'reflect' from the end of the plate leading to additional heating around the tool.

C. Welding Forces

During welding a number of forces will act on the tool:A downwards force is necessary to maintain the position of the tool at or below the material surface. Some friction-stir welding machines operate under load control but in many cases the vertical position of the tool are preset and so the load will vary during welding.

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The traverse force acts parallel to the tool motion and is positive in the traverse direction. Since this force arises as a result of the resistance of the material to the motion of the tool it might be expected that this force will decrease as the temperature of the material around the tool is increased.

The lateral force may act perpendicular to the tool traverse direction and is defined here as positive towards the advancing side of the weld.

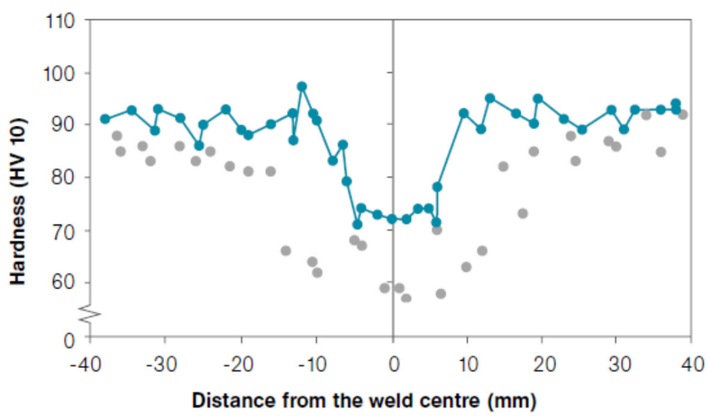
In order to prevent tool fracture and to minimize excessive wear and tear on the tool and associated machinery, the welding cycle should be modified so that the forces acting on the tool are as low as possible and abrupt changes are avoided.

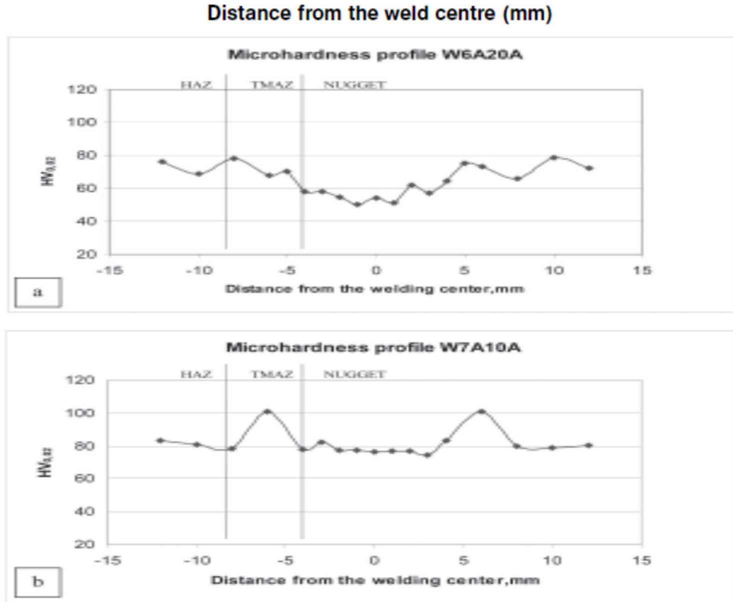
D. Tool Design

The design of the tool is a critical factor as a good tool can improve both the quality of the weld and the maximum possible welding speed. It is desirable that the tool material is sufficiently strong, tough and hard wearing, at the welding temperature. Further it should have a good oxidation resistance and a low thermal conductivity to minimize heat loss and thermal damage to the machinery further up the drive train. Hot-worked tool steel such as AISI H13 has proven perfectly acceptable for welding aluminium alloys within thickness ranges of 0.5 – 50 mm but more advanced tool materials are necessary for more demanding applications such as highly abrasive metal matrix composites or higher melting point materials such as steel or titanium.

6. Mechanical Properties

A. Hardness Profile





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The graph above shows the variation in the Vickers hardness at a cross-section of an FSW joint welded at a speed of 1400 mm/min, and an MIG weld.

Comments: In both welds, the hardness in the heat affected zone (HAZ) decreases, although clearly more in the MIG weld. The hardness is lowest (just below 60 HV) around the centre of the MIG weld. The reason is that fusion welding involves higher working temperatures, the addition of a 'foreign' filler metal, and a less favorable structure in the weld.

In TIG welding, more heat is supplied than in MIG welding, and the HAZ is therefore somewhat wider. No significant difference was observed in the HAZ for the two different welding speed using FSW.

In order to investigate softening or hardening effects induced by the FSW process on the aluminium matrix alloys, micro-hardness measurements, with a very low load (HV0.02), were made from the base material to the nugget zone, on cross-sections of the welded plates. The results are shown in the plots of Fig.12 (a) for the W6A20A, and Fig.12(b) for the W7A10A. The micro-hardness profile of the W6A20A shows a decrease of the inter particles matrix micro-hardness from about 80 HV0.02 in the base material up to about 50 HV0.02 at the middle line of the FSW zone. This micro-hardness decrease in the aluminium alloy matrix, even with a reduction in its grain size, was also observed in FSW unreinforced AA6061 and should be probably related to coarsening or partial dissolution of the intermetallic compounds, induced by the frictional heating and severe plastic deformation. The micro-hardness profile for the W7A10A, in Fig.12(b), shows a minimum value of about 77 HV0.02 at the middle line of the nugget zone, a maximum value of about 100 HV0.02 in the thermo-mechanical affected (TMAZ) zone, a second minimum of about 75 HV0.02 in the heat affected zone (HAZ); then, the inter particles matrix micro-hardness increased up to about 84 HV0.02 in the base material. This trend can be also related to the microstructural changes induced by the friction stir welding process on the aluminium alloy matrix. In particular, the observed maximum in the TMAZ is probably due to the concurrent effects of strain-hardening and re-precipitation of the transition phases; the lower micro-hardness in the nugget should be related to coarsening and/or dissolution of the precipitates and, finally, the minimum of micro-hardness in the HAZ may be caused by coarsening of the precipitates induced by the frictional heating. The different inter particles micro-hardness profiles in the two FSW composites is therefore due both to the different aluminium matrix grain size, induced by dynamic re-crystallization in the nugget, and to the different aging response of the matrix alloys during and after welding.

B. Fatigue Strength

The above figure shows the results of the fatigue tests on MIG welds, TIG welds and FSW joints.

Comments: The FSW joint yields the best values throughout. In the study, TIG welds gave much better results than MIG welds.

For failure at 500 000 cycles, the stress ranges were:

- Approx. 60 MPa for MIG
- Approx. 70 MPa for TIG
- Approx. 90 MPa for FSW at 700 and 1400 mm/min (slightly higher at 1400 mm/min).

7. Advantages

Diverse materials: Welds a wide range of alloys, including previously un-weld-able (and possibly composite materials)
Durable joints: Provides twice the fatigue resistance of fusion welds.
Versatile welds: Welds in all positions and creates straight or complex-shape welds
Retained material properties: Minimizes material distortion
Safe operation: Does not create hazards such as welding fumes, radiation, high voltage, liquid metals, or arcing
No keyholes: Pin is retracted automatically at end of weld
Tapered-thickness weld joints: Pin maintains full penetration

8. Limitations of Friction Stir Welding

- Work pieces must be rigidly clamped
- Backing bar required (except for self reacting and directly opposed tools)
- Key holes at the end of each weld
- Cannot make joints that require metal deposition
- Less flexible than manual and arc processes

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9. Applications

- The original application for friction stir welding was the welding of long lengths of material in the aerospace, shipbuilding and railway industries.
- Examples include large fuel tanks and other containers for space launch vehicles, cargo decks for high-speed ferries, and roofs for railway carriages.

10. Conclusion

FSW is the best process to welding Aluminum for long lengths with an excellent quality. Considerable effort is being made to weld higher temperature materials such as titanium and steels by using FSW. Take the process beyond its current use of mainly simple butt and lap joint configurations and make it a much more flexible fabrication process.

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