

TALAT Lecture 4410

Friction Stir Welding

13 pages, 6 figures

Basic Level

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Objectives:

This chapter is a brief presentation of the technique of Friction Stir Welding

To provide basic information about:

- the principles
- the advantages / disadvantages of FSW as joining technique
- areas of application

Prerequisites:

The lecture is recommended for those situations, where a brief information about Friction Stir Welding is needed. For further information please contact TWI or consult the TWI Website at the following address :

http://www.twi.co.uk/j32k/unprotected/band_1/fswintro.html

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4410 Friction Stir Welding

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Introduction

Tungsten inert Gas (TIG), Metal Inert Gas (MIG) and plasma keyhole arc welding are proven and well established techniques for joining the 5xxx and 6xxx series aluminium alloys that are generally used for fabricating structures in rail road and marine transport and for bridges, off-shore oil-platform and buildings. Nevertheless, the production of sound welds when using these techniques requires special care in terms of joint edge preparation, the removal of surface oxide immediately prior to welding, the application of weld pool shielding gas, the selection of the correct filler wire, plus the implementation of the process control and operation parameters. Moreover, long welds in extrusions and plates when made using these techniques are prone to producing substantial work piece distortion, often necessitating mechanical re-alignment of large structures to return them to their original pre-weld shape.

Friction stir welding (FSW) is a relatively new technique which has been systematically developed for joining aluminium alloys. It is proving to be far more forgiving to use than arc welding techniques and can consistently produce long welds, especially between extrusions, of high quality and with very low distortion. Consistent with the more conventional methods of friction welding, which have been practised since the early 1950s, the weld is made in the solid phase, that is no melting. Since its invention, the process has received world-wide attention and today companies in Scandinavia, Japan and the USA are using the technology in production, particularly for joining aluminium alloys. This introduction to FSW describes: the development background, the principle of operation, weld properties in different aluminium alloys, advantages and disadvantages, future developments and finally areas of application.

1. Background

Friction Stir Welding (invented, patented and developed at TWI) is a derivative of conventional friction welding (see TALAT lecture 4400), which enables the advantages of solid-phase welding to be applied to the fabrication of long butt and lap joints, with very little post weld distortion. Furthermore, it is simple to operate, and a very cost effective form of machine tool technology.

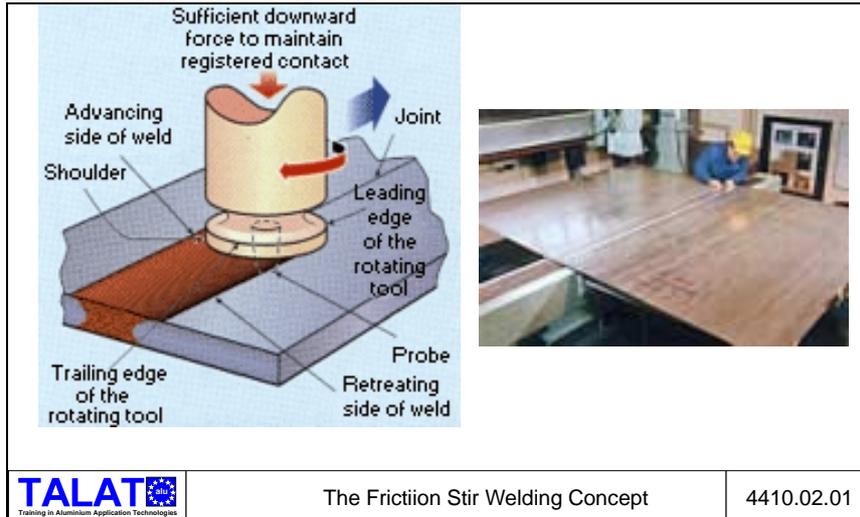
The joining of aluminium alloys, especially those which are difficult to weld, has been the initial target for developing and judging the performance of FSW. Work to date has concentrated on single pass welds in material thickness from 1.6 mm to 10 mm but it has been shown that thickness up to 50 mm can be joined with one pass and up to 75 mm with 2 passes, one for each side (see [Figure 4410.01.01](#)).



Special lap joint tools have been developed for thicknesses of 1.2 mm to 6.4 mm. The rapid development and the industrial use of FSW by other industries, have been achieved through a Group sponsored project (GSP) conducted at TWI for an international group of TWI member companies. Systematic welding trials have covered various 2xxx (Al-Cu), 5xxx (Al-Mg), 6xxx (Al-Mg-Si), 7xxx (Al-Zn) and 8xxx (Al-Li) series alloys and in each case a high level of weld quality and process repeatability has been observed. With the permission of the GSP sponsors, the exceptionally good metallurgical and mechanical weld properties achieved in some of these alloys are listed.

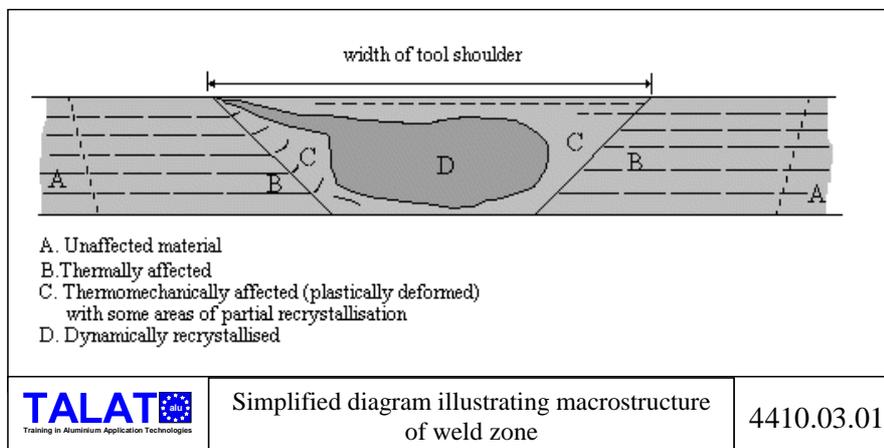
2. Principle of operation

The operating principle of friction stir welding is shown in [Figure 4410.02.01](#). A rotating tool with a central probe is pressed into the joint and traversed along the weld line. Frictional heat, generated mostly under the tool's shoulder, softens the material. The shoulder also acts to contain the softened material which is forced to the back of the tool, in the process becoming consolidated to form a solid phase weld. Providing the components are adequately restrained, a high quality solid phase weld is formed following considerable hot working of the material at the joint.



3. FSW properties in Aluminium Alloys

The transverse, through thickness, cross section of a butt weld, shown in [Figure 4410.03.01](#), illustrates a typical solid-phase friction stir weld formation. The weld comprises a continuous consolidated nugget of forged material with a much refined grain size. At optimised welding conditions (which have proved to have a generous tolerance to variation) welds can be achieved which are completely void- and crack-free.



The solid-phase weld formation produced by FSW provides three important metallurgical advantages when compared to fusion welds in aluminium alloys; first, joining in the solid-phase eliminates cracking; second, there is no loss of alloying elements through weld metal evaporation and the alloy composition is preserved; and finally, the crushing, stirring and forging action of the welding tool produces a weld metal with a finer grain structure than that of parent metal. In the case of heat treated materials, this enables the weld metal strength in the as-welded condition, to be in excess of that of the overaged material in the heat affected zone (HAZ). With respect to materials in the O condition, tensile failures can occur in the parent material, well away

from the weld and HAZ region. Tensile test data for welds made in the case of alloy 5083 are given in Table I.

Table I. Tensile test data for welds made in 6.4 mm thick alloy 5083 – O condition (average of 3 samples taken over 400 mm weld length)

Test Machine calibrated to Grade 1.0 requirements of BS EN 10002-2: 1992									
Tensile Tests	Sample	Dimensions			0.2% proof		Max Stress		El %
Identity/ Position		Size mm	CSA mm ²	GL mm	Load kN	Stress N/mm ²	Load kN	Stress N/mm ²	
Cross-Weld tensile	1-3 (average)	19.97 x5.89	117.7	62	16.58	141	35.21	298	23
Parent plate tensile	4	19.76 x6.02	118.9	62	17.64	148	35.53	298	23

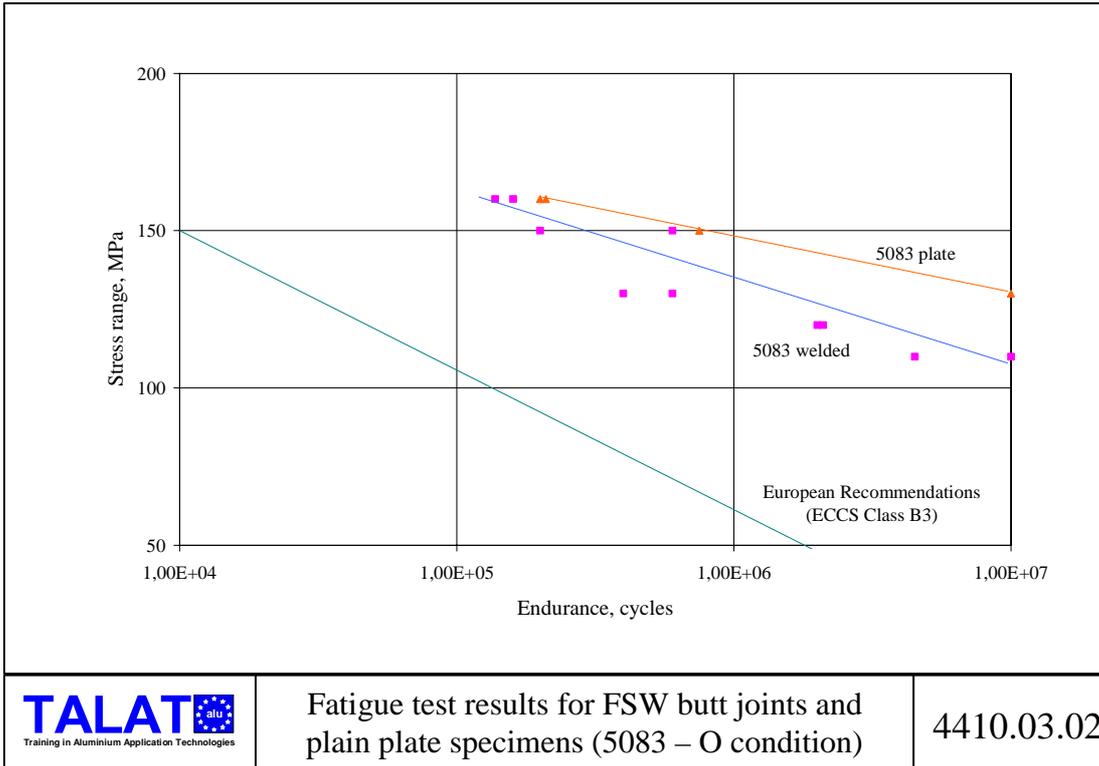
Comment: Cross-weld tensile sample 1-3 fractured in the parent metal

The friction stir weld metal and HAZ in solution heat treated and artificially aged aluminium alloys (e.g. 2xxx and 6xxx series) can be returned to a strength close to the fully heat treated parent metal, by using a post weld ageing heat treatment. Research in Norway has reported achieving 90 % of the T5 strength in 6060 alloy.

Bend tests with the weld root in tension are more searching in terms of weld metal quality than tensile tests. Friction stir welds in alloys 5083 and 6082 can easily withstand 180° bend tests without failure (the bend radii used were 2t and 3t, respectively; t - metal thickness).

The fatigue properties of FSW joints are quite exceptional in that they have little scatter and are close to the parent plate when tested using a stress ratio of 0:1. **Figure 4410.03.02** shows the results of tests conducted on 6.4 mm thick alloy 5083 - O condition. These results are far better than those that have been obtained to date by TIG and MIG processes and also surpass plasma-keyhole welding.

Despite the fact that the fatigue tested FSW joints were single pass from one side, these results substantially exceed BS 8118 Class 35 and the European Design Recommendation ECCS B3 for fusion welded joints.



4. FSW Advantages

4.1. Production cost savings

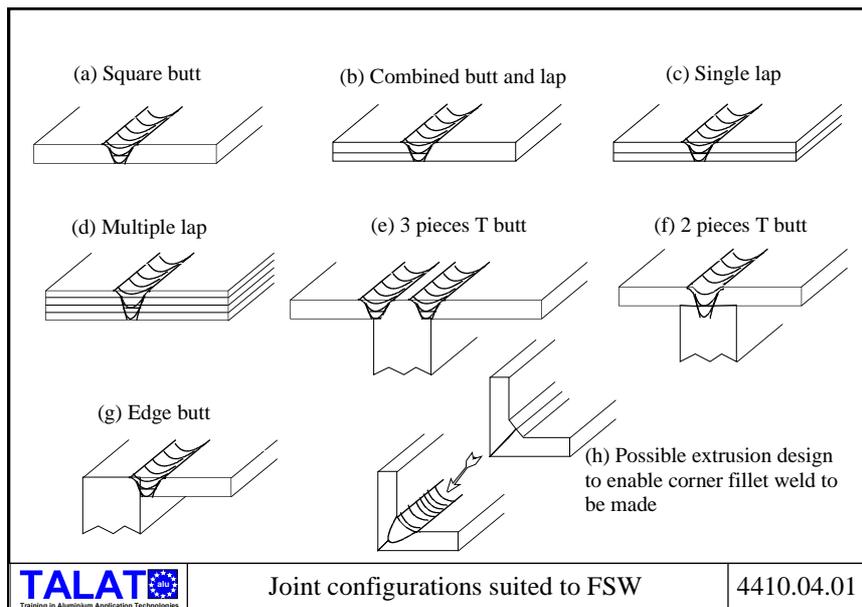
The welding operation is simple, energy efficient and eliminates the need for costly consumables :

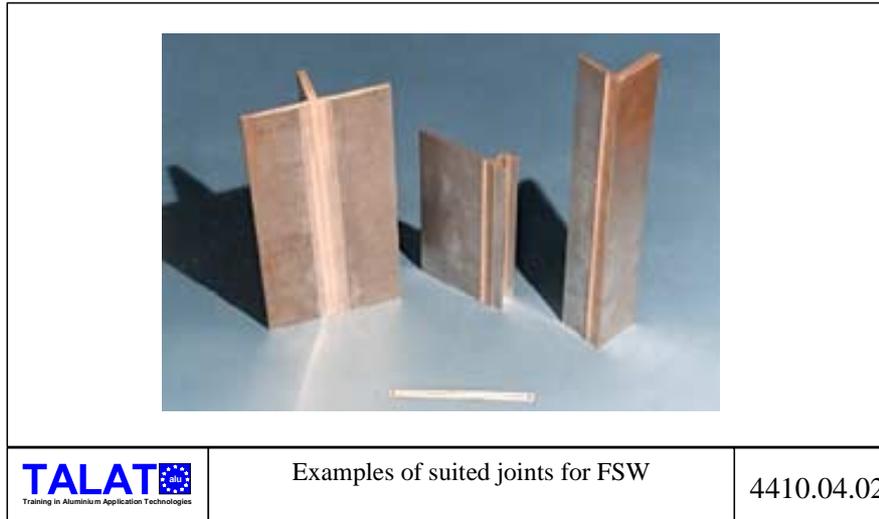
- ◆ The simple push button electro-mechanical machine tool equipment is energy efficient - a single pass 12.5mm deep weld can be made in 6xxx alloy with a gross power of 3kW - requires very little maintenance and, apart from welding tools and electric power, relies on no other consumables.
- ◆ The welding process does not require filler wires and weld pool shielding gas.
- ◆ Special joint edge profiling is unnecessary.
- ◆ Oxide removal immediately prior to welding is unnecessary.
- ◆ The technique is ideally suited to automation.
- ◆ If necessary the welding operation can take place in all positions from down hand to overhead.

4.2. Weld qualities that provide opportunities for improved and new product designs

The low distortion repeatable quality solid-phase welds can improve existing products and lead to a number of new product designs previously not possible. For example, in the case of aluminium alloys:-

- ◆ Welds can be made in alloys which cannot be fusion welded because of crack sensitivities.
- ◆ High joint strengths can be achieved in heat treatable alloys.
- ◆ No porosity.
- ◆ The solid-phase weld formation enables the retention of metallurgical properties in alloys, such as metal matrix composite materials, or those produced by rapid solidification processing techniques, where fusion welding can give rise to unfavourable metallurgical reactions.
- ◆ Dissimilar material conditions can be joined, i.e. castings to extrusions, castings to wrought products, etc.
- ◆ Many component shapes, such as long, large cross section, one-off, box sections and spars, which normally would not be practical, or cost effective, to extrude or cast, can now be fabricated by FSW. Moreover, the process is suited to several different joint configurations, see [Figure 4410.04.01](#). and [Figure 4410.04.02](#)
- ◆ Extruded lightweight panels, which are difficult to extrude in large sizes, or fusion weld together without distortion, can be friction stir butt welded together to form larger structures, such as the internal car decking and compartments for ships.
- ◆ Difficult to make hollow castings, such as manifolds, can be produced more easily by FSW together two simple solid castings, or possible extrusions.





4.3. Product quality insurance

The process is completely mechanical and therefore the welding operation and weld energy input are accurately controlled:

- ◆ Weld quality is determined by the stir welding tool profile and pre-set mechanical machine actions and consequently simple in-process monitoring can be used to terminate the welding operation if the machine actions were to deviate from the selected machine settings.
- ◆ Since the welding operation is mechanical the monitored output of the individual machine settings can be digitised and stored if necessary to provide a case history of each weld.
- ◆ The faying faces do not have to be close fitting prior to welding (although close fitting is desirable). Gaps can be tolerated, e.g. 0.2mm for 1.6mm sheet and 1.25mm for 12.7mm plate.

4.4. Safety

The welding operation only requires normal cutting machine (milling type) tool guards and above all is environmentally friendly. The process is clean and does not produce any major safety hazards, such as welding fume or radiation.

5. FSW Disadvantages

The single pass welding speeds in some sheet alloys are slower than for some mechanised arc welding techniques (although to date experimental single pass welds 40mm deep have been made by FSW):

- ◆ The parts must be rigidly clamped against a backing bar, to prevent weld metal breakout, if full penetration welds are required (it may be possible to overcome this problem in the future if a bobbin tool concept under investigation can be perfected).
- ◆ At the end of each weld run a hole is left where the tool pin is withdrawn.
- ◆ Run-on/run-off plates are necessary where continuous welds are required from one edge of a plate to the other
- ◆ Due to workpiece clamping and access requirements, applications where portable equipment could be used, may be limited.

6. Future FSW Development and access to data

Friction stir welding has a lot to offer for fabrication structures made from aluminium alloys. To this end, much process data exists within the international GSP development programme, which can be accessed by contacting TWI, who are currently offering GSP projects in: friction stir welding of aluminium extrusions for the transportation industries; mechanical properties of FSW welds; and, in addition, projects on FSW of titanium and steel.

7. Applications

7.1 Shipbuilding and marine industries

The shipbuilding and marine industries are two of the first industry sectors which have adopted the process for commercial applications. The process is suitable for the following applications:

- Panels for decks, sides, bulkheads and floors
- Aluminium extrusions
- Boat sections
- Hulls and superstructures
- Helicopter landing platforms
- Offshore accommodation
- Marine structures
- Masts and booms, e.g. for sailing boats
- Refrigeration plant

7.2 Aerospace industry

At present the aerospace industry is welding prototype parts by friction stir welding. Opportunities exist to weld skins to spars, ribs, and stringers for use in military and civilian aircraft. This offers significant advantages compared to riveting and machining from solid, such as reduced manufacturing costs and weight savings. Longitudinal butt welds and circumferential lap welds of Al alloy fuel tanks for space vehicles have been friction stir welded and successfully launched in commercial flights. The process could also be used to increase the size of commercially available sheets by welding them before forming. The friction stir welding process can therefore be considered for:

- Wings, fuselages, empennages
- Cryogenic fuel tanks for space vehicles
- Aviation fuel tanks
- External throw away tanks for military aircraft
- Military and scientific rockets
- Repair of faulty MIG welds

7.3 Railway industry

The commercial production of high speed trains made from aluminium extrusions which may be joined by friction stir welding has been published. Applications include:

- High speed trains
- Rolling stock of railways, underground carriages, trams These are already in service in Japan.
- Railway tankers and goods wagons
- Container bodies

7.4 Land transportation

The friction stir welding process is currently being experimentally assessed by several automotive companies and suppliers to this industrial sector for its commercial application. A joint EWI/TWI Group Sponsored Project is investigating representative joint designs for automotive lightweight structures. Potential applications are:

- Engine and chassis cradles
- Wheel rims
- Attachments to hydroformed tubes
- Tailored blanks, e.g. welding of different sheet thicknesses
- Space frames, e.g. welding extruded tubes to cast nodes
- Truck bodies
- Tail lifts for lorries
- Mobile cranes
- Armour plate vehicles

- Fuel tankers
- Caravans
- Busses and airfield transportation vehicles
- Motorcycle and bicycle frames
- Articulated lifts and personnel bridges
- Skips
- Repair of aluminium cars
- Magnesium and magnesium/aluminium joints

7.5 Construction industry

The use of portable FSW equipment is possible for:

- Aluminium bridges
- Facade panels made from aluminium, copper or titanium
- Window frames
- Aluminium pipelines
- Aluminium reactors for power plants and the chemical industry
- Heat exchangers and air conditioners
- Pipe fabrication

7.6 Electrical industry

The electrical industry shows increasing interest in the application of friction stir welding for:

- Electric motor housings
- Busbars
- Electrical connectors
- Encapsulation of electronics

7.7 Other industry sectors

Friction stir welding can also be considered for:

- Refrigeration panels
- Cooking equipment and kitchens
- White goods
- Gas tanks and gas cylinders
- Connecting of aluminium or copper coils in rolling mills
- Furniture

8. References

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9. Acknowledgements

TWI would like to thank the Industrial Sponsors of Group Sponsored Project 5651, "Development of the New Friction Stir Technique for Welding Aluminium", for giving permission to publish some of the information in this lecture.

10. List of Figures

Figure No.	Figure Title (Overhead)
4410.01.01	Example of FSW with 2 passes
4410.02.01	The friction stir welding concept
4410.03.01	Simplified diagram of macrostructure of weld zone
4410.03.02	Fatigue test results on FSW butt joints and plain plate specimens (5083 – O condition)
4410.04.01	Joint configurations suited to FSW
4410.04.02	Examples of suited joints for FSW