The FSW technology

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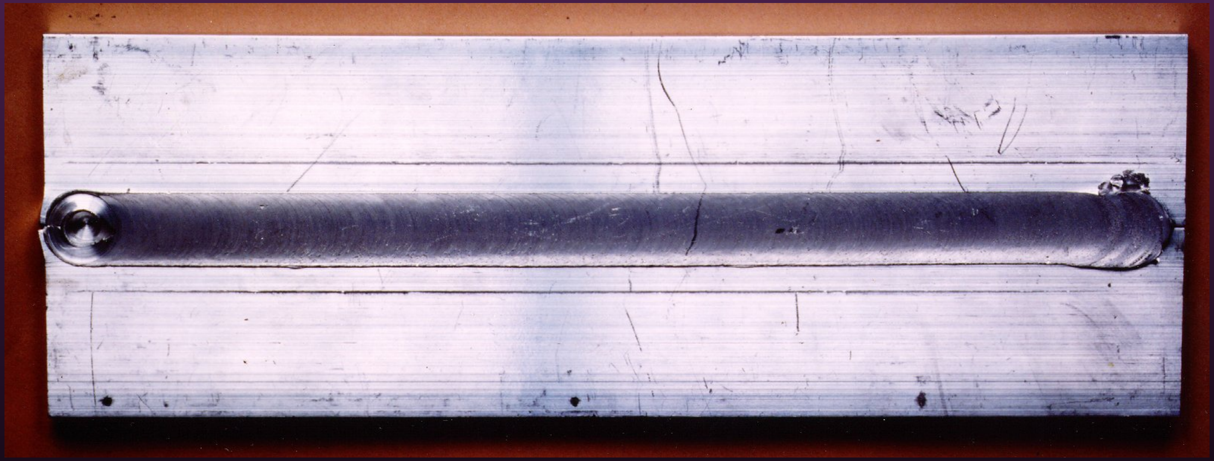


University of Trieste

Light alloys welding troubles

- Metallurgical

$$4Al + 3O_2 \rightarrow 2Al_2O_3 + \text{energy}$$

$$\rho_{Alumina} \cong 4 > \rho_{Aluminum} \cong 2.7$$

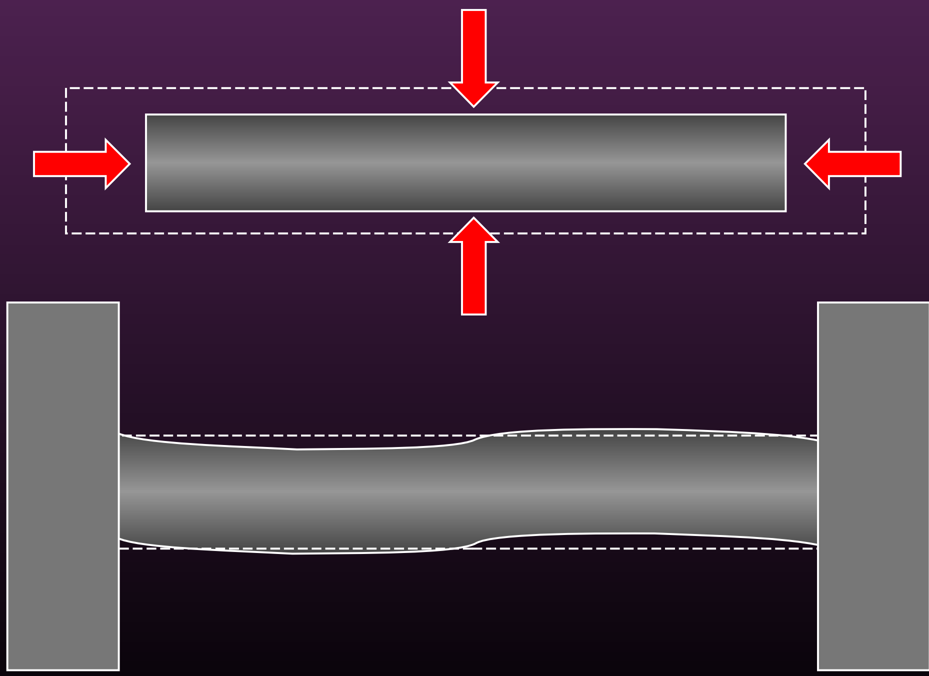
Poor joint strength due to porosity, inclusions and sticking

- Inert gas shielding (GMAW, GTAW, PAW)
- Ion blasting
- Rework

Light alloys welding troubles

- Mechanical

High coefficient of thermal expansion (up to twice that of steel)



Shrinkage and distortions

- Clamping
- Rework

FSW: brief history

In 1991, Wayne Thomas, an engineer working for TWI (UK) came up with the idea of Friction Stir Welding.

This was a **revolutionary new process** which could produce welds in aluminum alloys that were **solid phase**, with minimal distortion and with excellent properties.

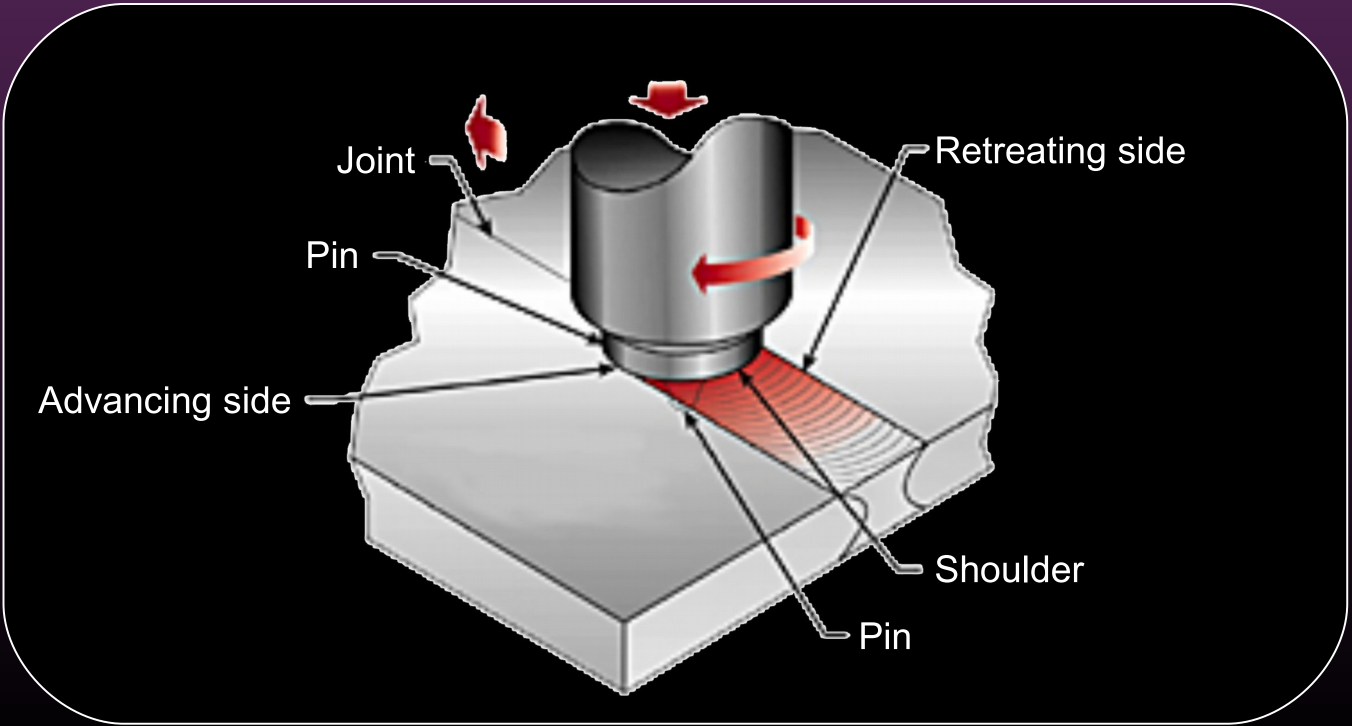
TWI patented the process in Europe, USA, Japan and Australia (about 800 related patents known).

The only problem was that no-one knew, in 1991, whether this invention could be applied effectively in industry – many other inventions coming through at the same time did not enjoy the same success.

Twelve years on, Friction Stir Welding **has completely changed the design and manufacturing approach for many products** including rockets, airframes, trains, ships and automotive components.

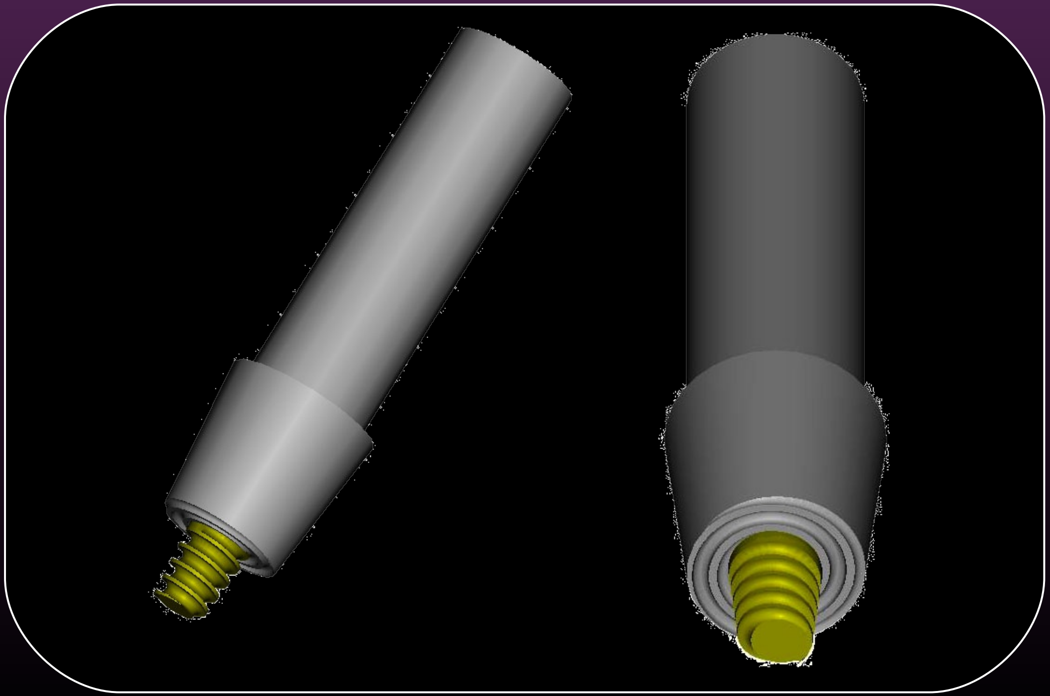
FSW: what is that?

The FSW process occurs at a temperature **below the melting point of the work piece material (max.: 0.8 T_m)**: this fact leads to **several advantages** over fusion welding.



FSW: how it works?

- Welding sequence
- 3D welding



FSW: some advantages

- ✓ Non-consumable tool.
- ✓ One tool can typically be used for up to 1000m of weld length in 6000 series Al alloys.
- ✓ No filler wire.
- ✓ No gas shielding for welding aluminum.
- ✓ No welder certification required.
- ✓ Some tolerance to imperfect weld preparations - thin oxide layers can be accepted.
- ✓ No grinding, brushing or pickling required in mass production.
- ✓ FSW produces desirable microstructures in the weld and heat-affected zones.
- ✓ FSW is environmentally "friendly" (no fumes, noise, or sparks).
- ✓ FSW produces less distortion than fusion welding techniques.
- ✓ It can be used in all positions (Hor., Vert., Overhead)

FSW: drawbacks

- **Welding speeds are moderately slower than those of some fusion welding processes (up to 750mm/min for welding 5mm thick 6000 series Al alloy on commercially available machines)**
- **Workpieces must be rigidly clamped**
- **Backing bar required**
- **Keyhole at the end of each weld**

BUT:

2003: NASA presents its pin retractable FSW tool, which **overcomes keyhole problem**!

2003: MAZDA announces its self-reacting pin, which **doesn't requires back bar**!

FSW applications

Space applications

Ships building

FSW aerospace applications

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 tested. The process could also be used to increase the size of commercially available sheets by welding them before forming.

- ✓ 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

FSW railway applications

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

- High speed trains
- Rolling stock of railways, underground carriages, trams
- Railway tankers and goods wagons
- Container bodies

FSW land transportation applications

- Engine and chassis cradles
- Wheel rims
- Attachments to hydroformed tubes
- Space frames, e.g. welding extruded tubes to cast nodes
- Truck bodies
- Tail lifts for lorries
- Mobile cranes
- Armour plate vehicles
- Fuel tankers
- Caravans
- Buses and airfield transportation vehicles
- Motorcycle and bicycle frames
- Articulated lifts and personnel bridges
- Skips
- Repair of aluminum cars
- Magnesium and magnesium/aluminum joints

FSW construction applications

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

FSW other applications

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

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 Al or Cu coils in rolling mills
- ✓ Furniture

FSW solution example

The AAAV (Advanced Amphibious Assault Vehicel) is an armored personnel carrier under development for the U.S. Marine Corps. General Dynamics Land Systems, the AAAV's prime contractor, selected 2519-T87 as the main structural alloy.

Problem: GMAW butt joints do not pass the ballistic shock tests.

Solution 1: AAAV design avoids simple butt welds $\Rightarrow$ greater complexity and higher manufacturing costs.

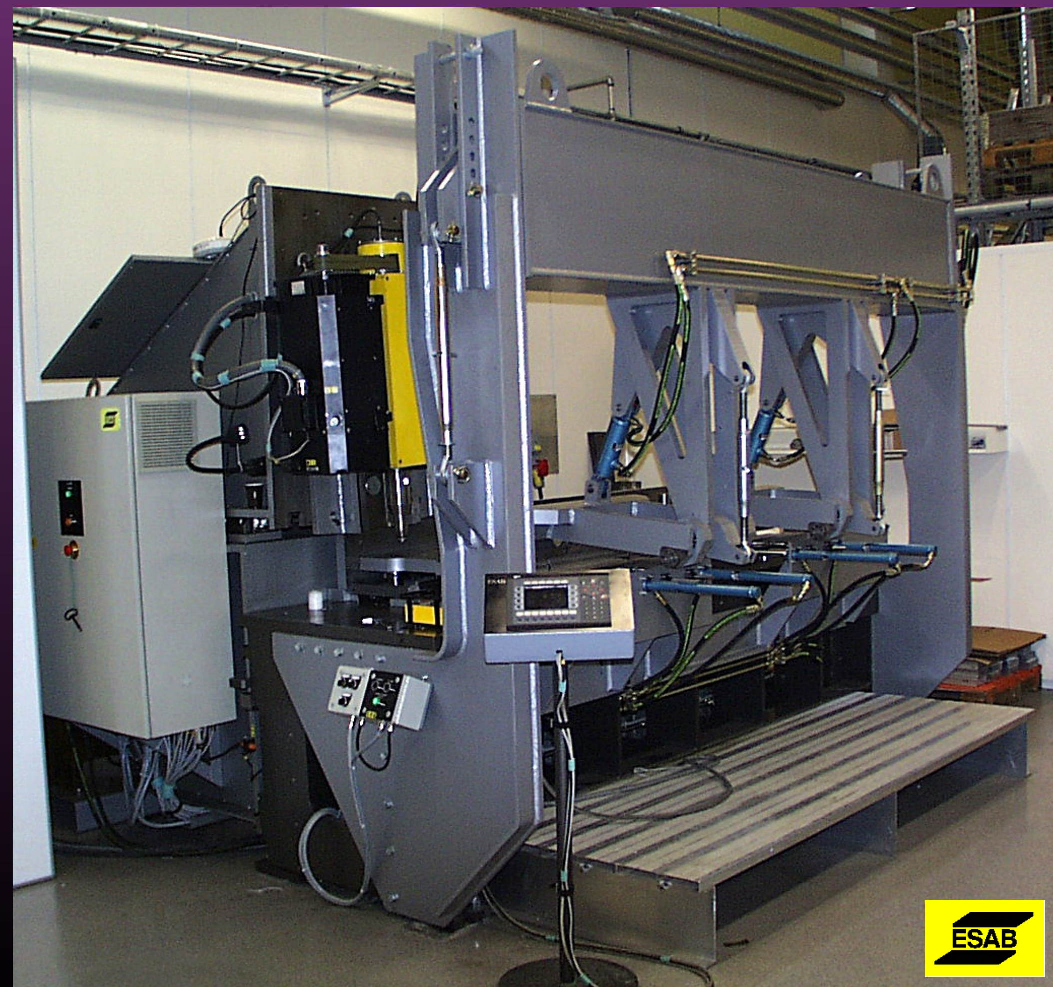
Solution 2 (better): One-pass FSW joints in both flat-butt and 90-degree corner configurations.

The joints of the one-inch thick bottom plate to the two-inch thick sidewall, made at a speed of four inches/minute, show a 124 MPa increase in tensile strength and 300% increase in ductility over GMAW joints.

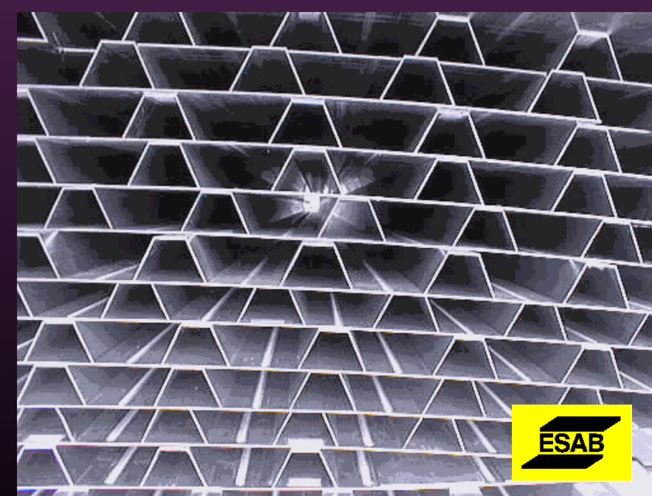
FSW equipments examples

ESAB SuperStir™ basic:

- Small workpieces
- FSW 1A for 1.2 -15 mm
- Weld length 2 m
- Hydraulic clamping



FSW equipments examples



ESAB **SuperStir**™ at Marine Aluminium Norway

FSW equipements examples

This **ESAB SuperStir™** is designed mainly for manufacturing of **panels for ships and railway wagons**, but also for other parts.

Some features:

✓ The welding operation is fully automatic and all parameters can be easyly adjusted thru a user frendly interface.

✓ Aluminium alloys from **1.6 - 15 mm** are weldable in one run.

✓ The plant is complete with in-feeding and out-feeding facilities.

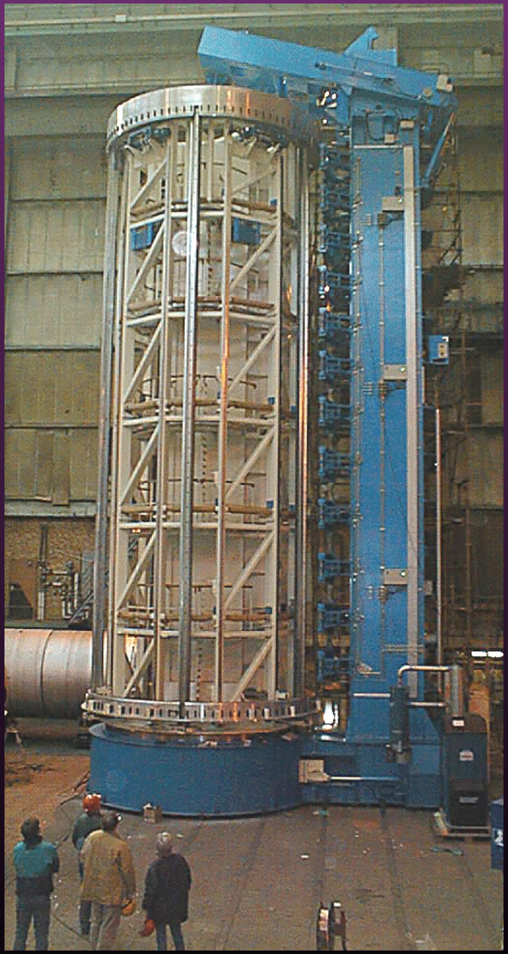
✓ Maximum panel dimension is **16 x 6 meters**

✓ The plant has produced, in the first run, 200 000 m of welds without one fault of any kind.

FSW equipements examples

Aerospace Industry (Pressure vessels)

FSW equipements examples



- Two of these machines have been delivered to The Boeing Company in the 1998 and 1999
- The equipment is designed to weld fuel tanks
- The plant is equipped with one milling head and one welding head travelling on the vertical main beam.
- The parts to be welded are loaded on an indexing fixture and the edges are milled, welding is carried out and the final length is milled.
- Tanks of 5 m diameter and max 12 m length can be welded

Aerospace Industry (Pressure vessels)

FSW capabilities

Weldable materials (demonstrated):

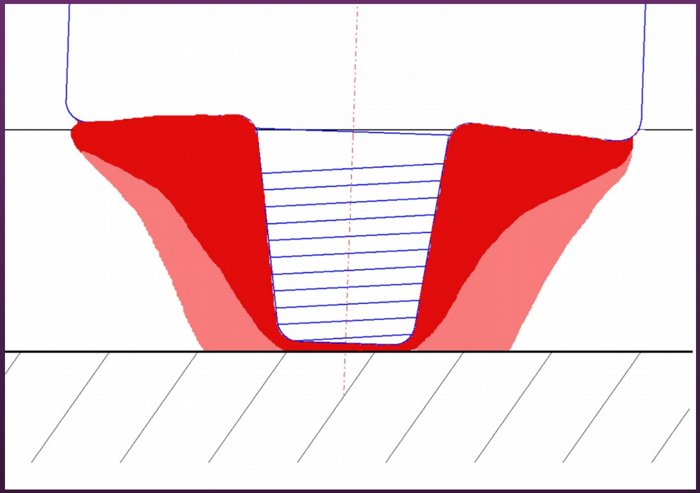
- ✓ Aluminum alloys (2000, 5000, 6000, 7000, 8000 series)
- ✓ Copper and its alloys
- ✓ Lead
- ✓ Titanium and its alloys
- ✓ Magnesium alloy, Magnesium to aluminum
- ✓ MMCs based on aluminum (metal matrix composites)
- ✓ Plastics
- ✓ Mild steel

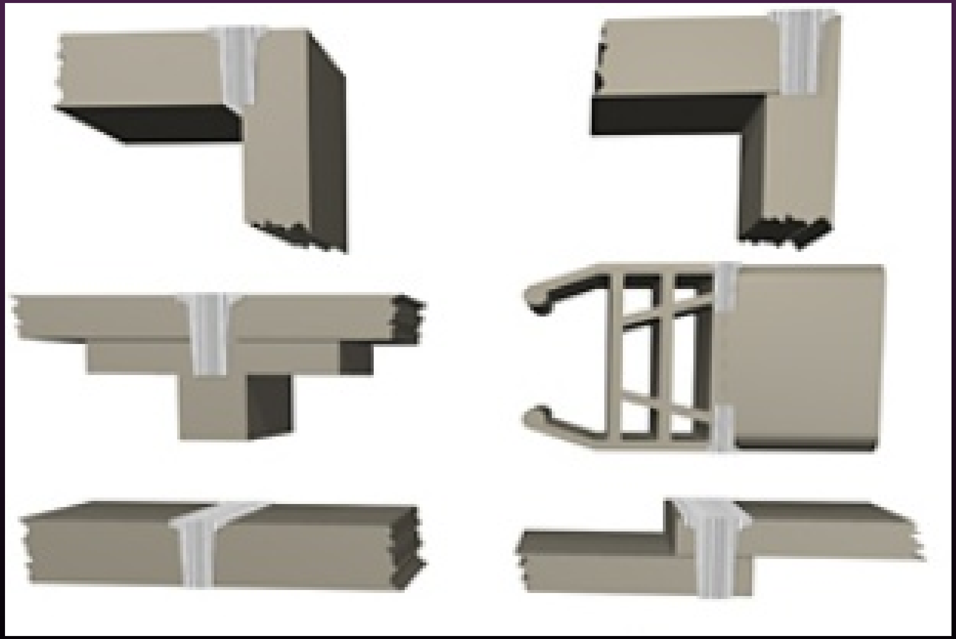
Thickness range:

Single pass butt joints have been made in thickness ranging from **1.2mm to 50mm without the need for a weld preparation**.

Thickness of **up to 100mm can be welded using two passes**, one from each side.

FSW capabilities





FSW capabilities

FSW capabilities

Falcon 9, SpaceX – rocket booster tank

FSW capabilities

Ford GT - centre tunnel

FSW capabilities

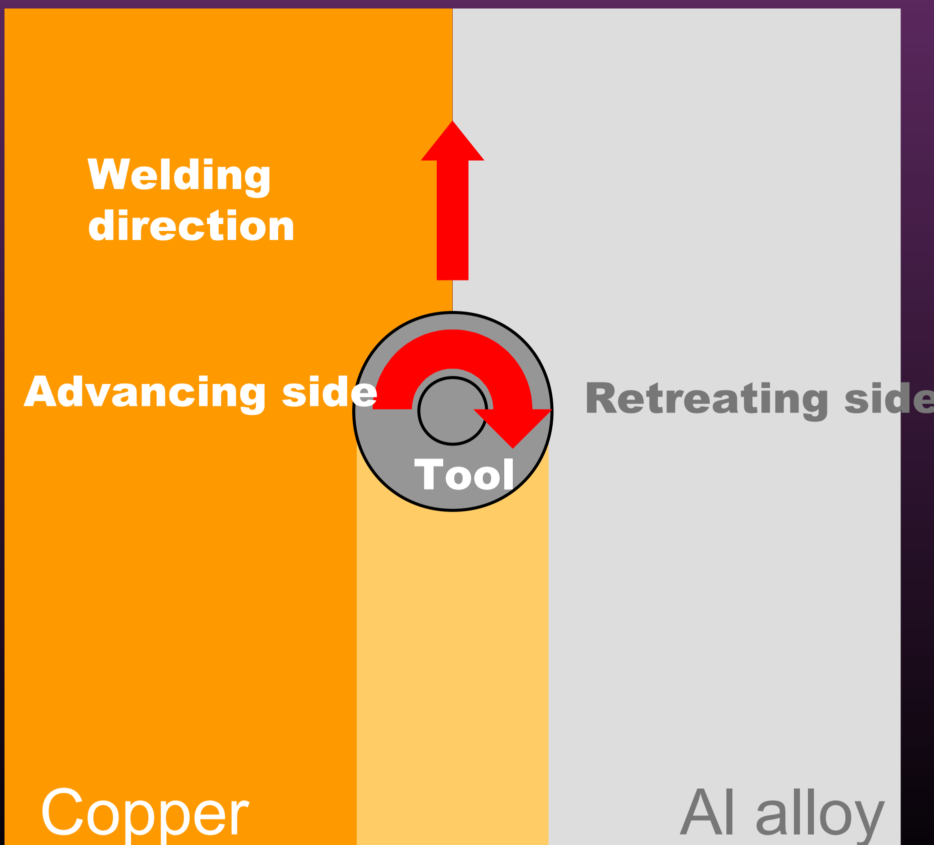
Hitachi A-Train Class 395 - body

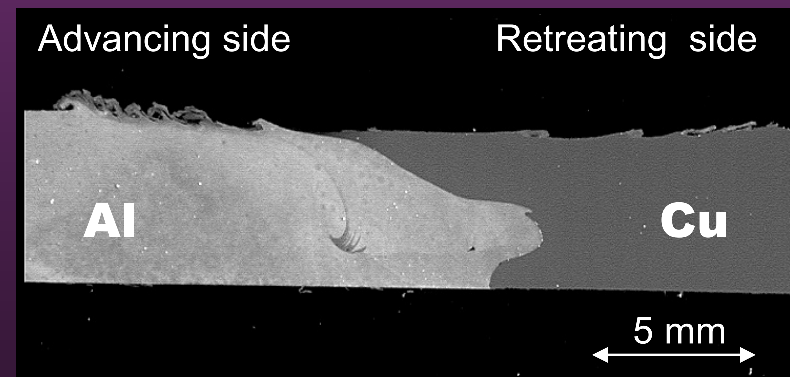
FSW capabilities

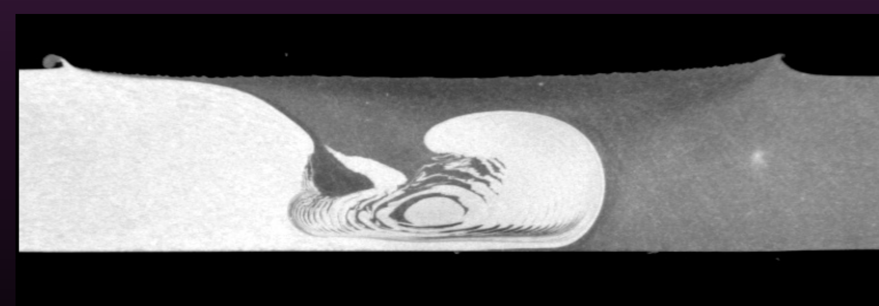
Nuclear waste
canister
body to lid weld

FSW capabilities

Welding of dissimilar materials has been demonstrated:







AA6082 / AA5083

FSW joints microstructure

FSW tool produces a weld with a finer microstructure than the parent material.

The weld metal strength can be, in the as welded condition, in excess of that in the thermo-mechanically affected zone.

In the case of annealed materials in the O condition, tensile tests usually fail in the parent material well away from the weld and heat affected zone.

Preliminary results on fatigue tests on friction stir welds (5083-O and 2014-T6) are quite exceptional in that they show little scatter and are far better than those of fusion welding processes such as GTA and MIG.

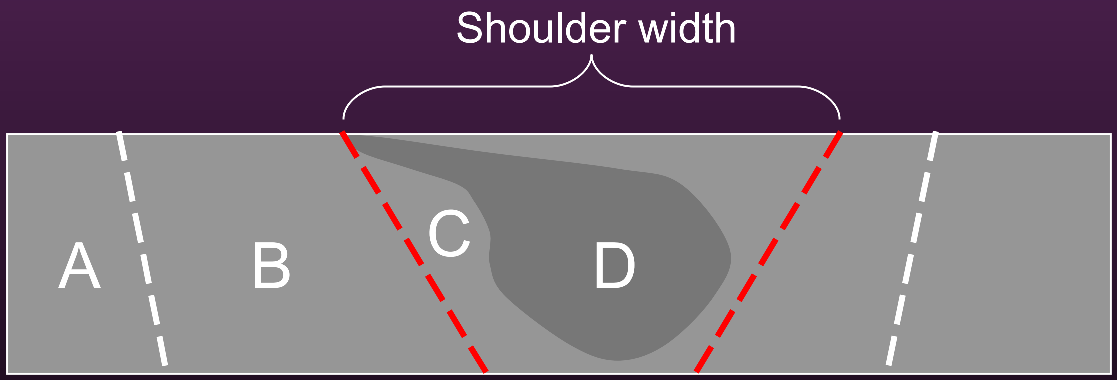
FSW joints microstructure

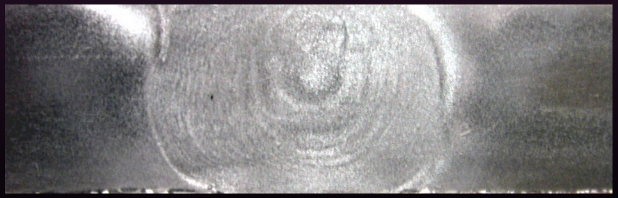
A: Unaffected parent material

B: Heat affected zone

C+D: Thermomechanically affected zone

D: Recrystallized nugget in Al



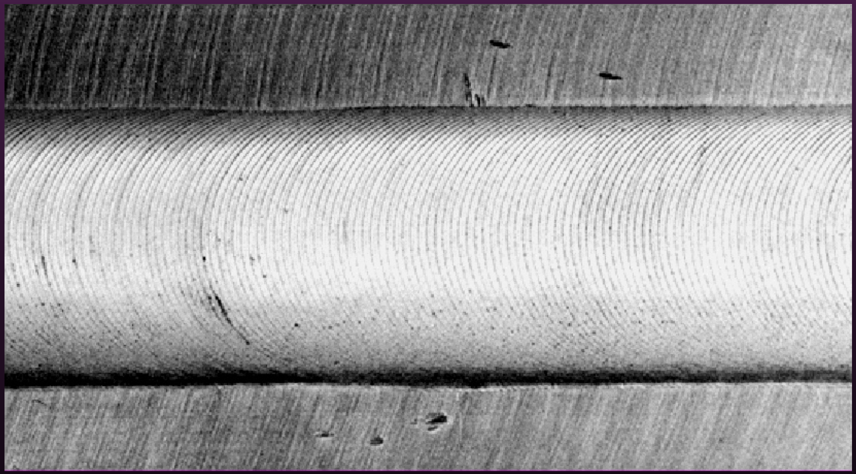


6082-T6 alloy
Welded at UniTs

FSW joints look

FSW joints appearence is pleasant and the parts don't require usually any rework.

Top surface



Bottom surface