



Friction Stir Welding European Qualifications

Operator



Co-funded by the
Erasmus+ Programme
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1. FSW Fundamentals

1.1 – Introduction to FSW

1.1 – Introduction to FSW

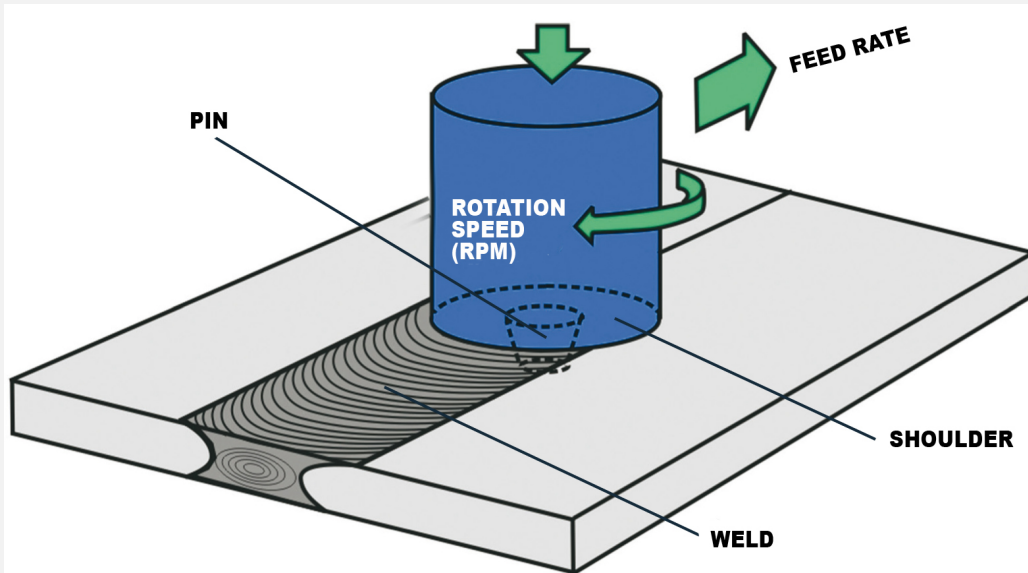
Friction Stir Welding (FSW)

- A material joining process where two or more metal workpieces are joined by the friction heating and mixing of material in the plastic state caused by a non-consumable rotating tool that traverses along the weld.

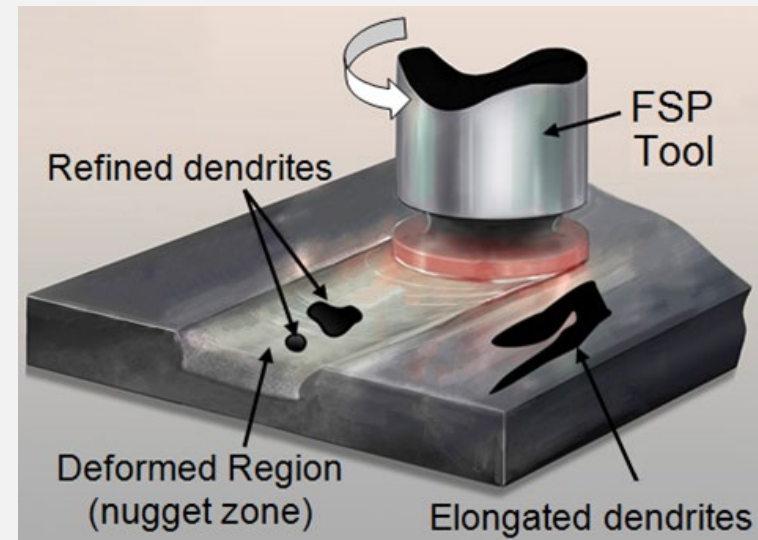
Friction Stir Processing (FSP)

- Is a variation on the FSW operation.
- The FSW process locally changes the microstructure and properties of the weld region
- Friction stir processing applies the FSW process to whole pieces of material. The tool is inserted and traversed back and forth changing the properties of the material.

1.1 – Introduction to FSW

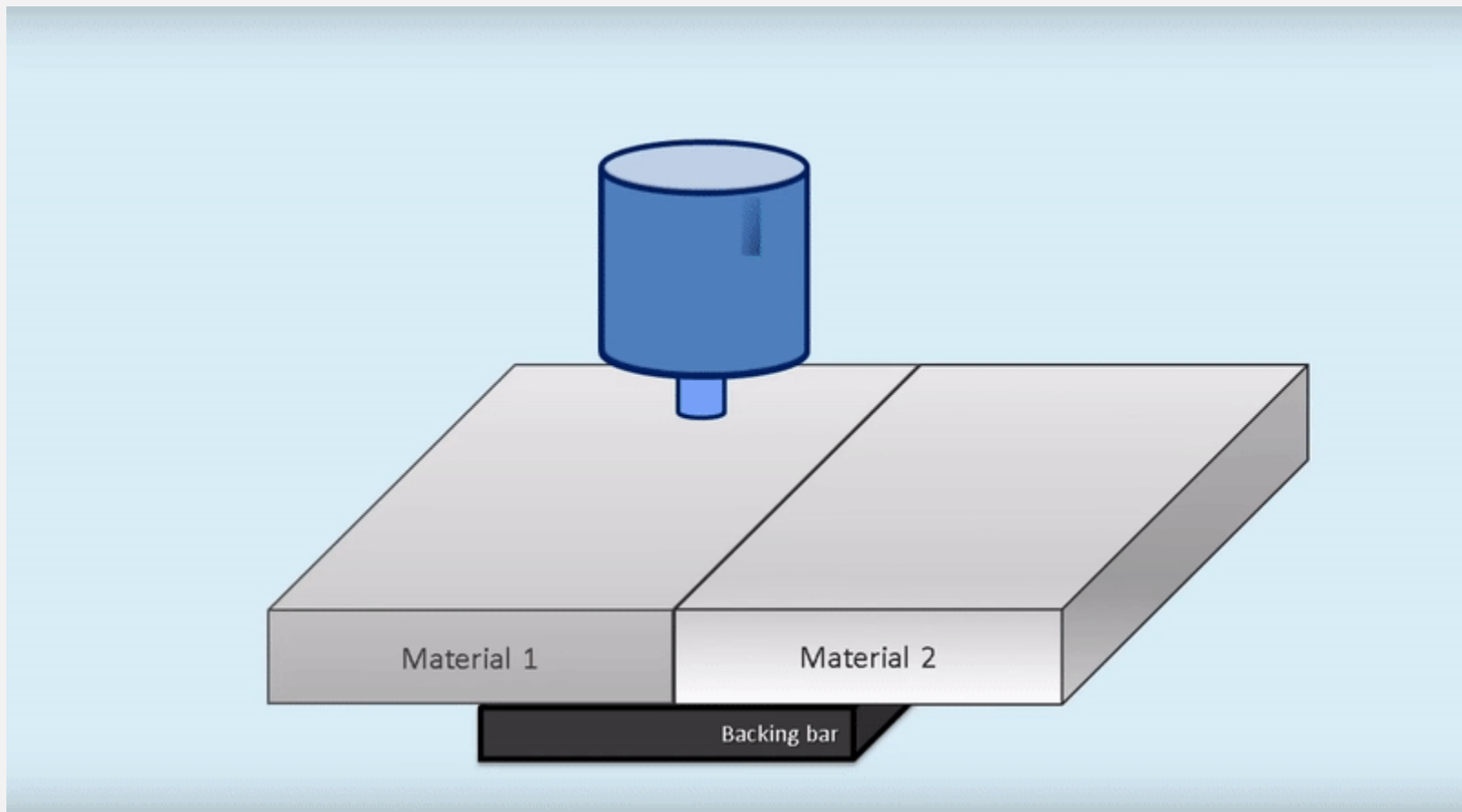


Friction Stir Welding (FSW)



Friction Stir Processing (FSP)

1.1 – Introduction to FSW



1.1 – Introduction to FSW

Metallurgical benefits:

- Solid phase joining process
- Small distortion
- High dimensional stability and repeatability
- No loss of alloying elements
- Excellent mechanical properties in joint
- Fine recrystallized structure
- Non-occurrence of solidification cracking

1.1 – Introduction to FSW

Environmental benefits:

- No shielding gas required
- Requires minimum surface preparation
- Eliminates grinding wastes
- Eliminates solvent cleaners and degreasers
- Savings in consumable materials
- Absence of harmful emissions

1.1 – Introduction to FSW

Energy benefits:

- Reduced energy consumption compared to laser welding
- Minimized weight of joint lead to decreased fuel consumption in automotive, ship and aircraft applications
- Reduction in weight results from improved material use

1.1 – Introduction to FSW

Disadvantages of FSW process:

- A great amount of tool wear takes place during the plunging stage,
- Single pass welding speeds in some alloys are slower than for some arc welding techniques
- Equipment used for FSW is massive and expensive, because of high welding forces
- High melting temperature materials, such as steel and stainless steel are known to have welding tool limitations
- Absence of a filler wire means that the process cannot easily be used for making fillet welds
- Presence of an exit hole after conventional FSW process

1.1 – Introduction to FSW

FSW can be used in following industries:

- Shipbuilding and Off-shore
- Automotive
- Railways
- Aerospace
- Fabrication
- Others (electrical, oil and gas, nuclear industry, construction)

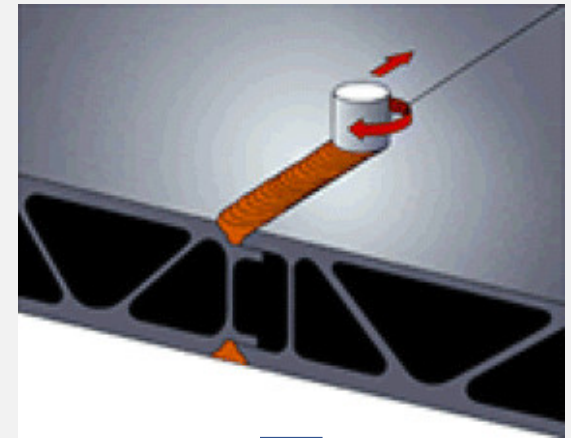
1.1 – Introduction to FSW

The Friction Stir Welding Process for the **Railway** can be mainly utilized for aluminum panels for railway rolling stock

1.1 – Introduction to FSW



Railway – fully automatic extruded profile panels welding



Extruded profile welding

1.1 – Introduction to FSW

The Friction Stir Welding Process for the **Automotive** can be utilized for:

- Closures
- Tanks
- Suspensions
- Pistons
- Wheel rims
- Trailers

1.1 – Introduction to FSW

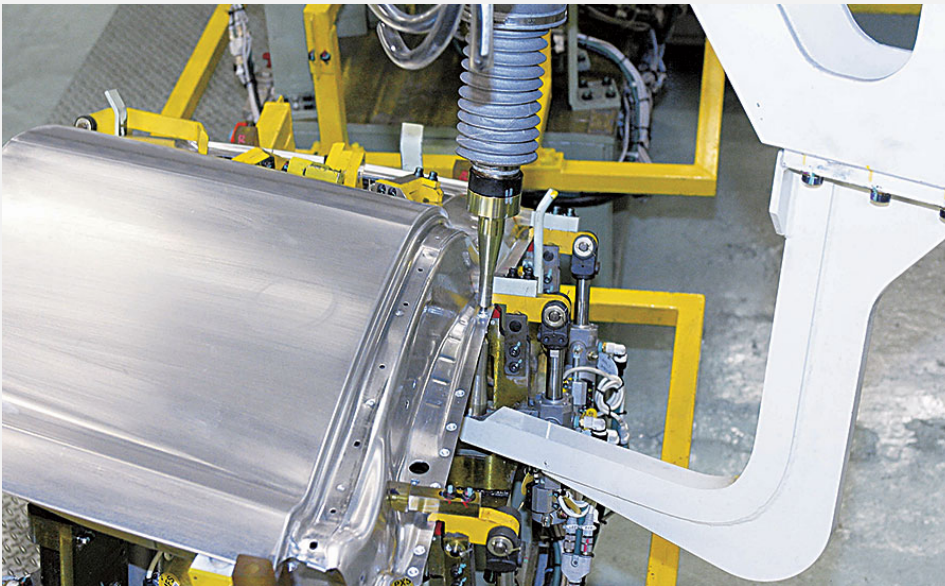


Automotive - manufacturing of wheel rims.



Robotic FSW of car body panel

1.1 – Introduction to FSW

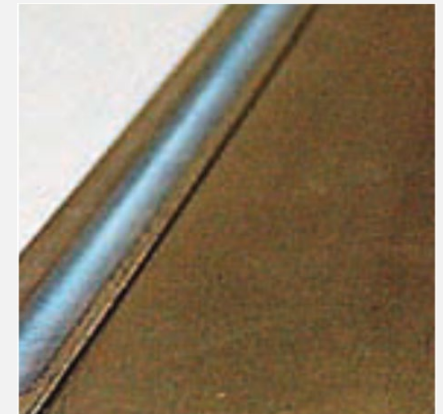
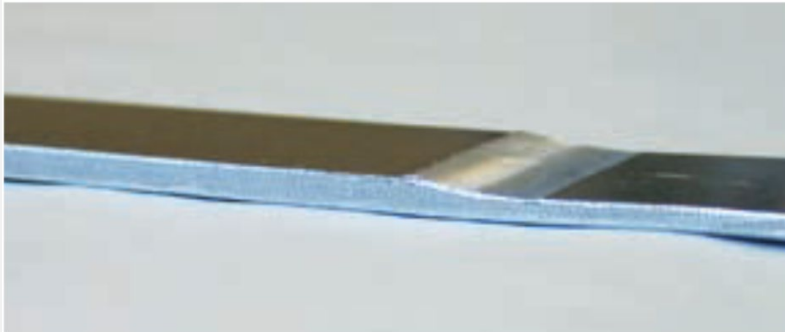


Friction stir spot welding



Dissimilar metals joining

1.1 – Introduction to FSW



Possible automotive applications for friction stir welding: mixed joint between two thickness, folded seal weld and overlap joint.

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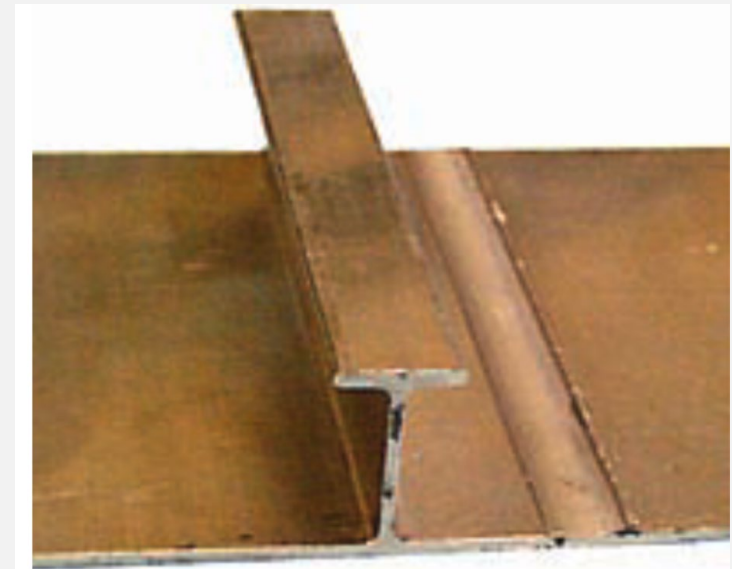
The Friction Stir Welding Process for the **Shipbuilding** can be utilized for:

- Aluminum panels for deep freezing of fish on fishing boats
- Joining extrusions to create panels for decks and bulkheads
- Honeycomb panels
- Sea water resistant panels

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Shipbuilding – large panel FSW



Panel welded with FSW

1.1 – Introduction to FSW

The Friction Stir Welding Process for the **Architecture and Construction Industry** can be utilized for:

- Flooring
- Decks
- Walkways
- Gangways
- Walls
- Awnings
- Weather Shields
- Suspended Systems
- Brackets

1.1 – Introduction to FSW



Construction – canopy manufactured with FSW



Gangway and weather shield

1.1 – Introduction to FSW

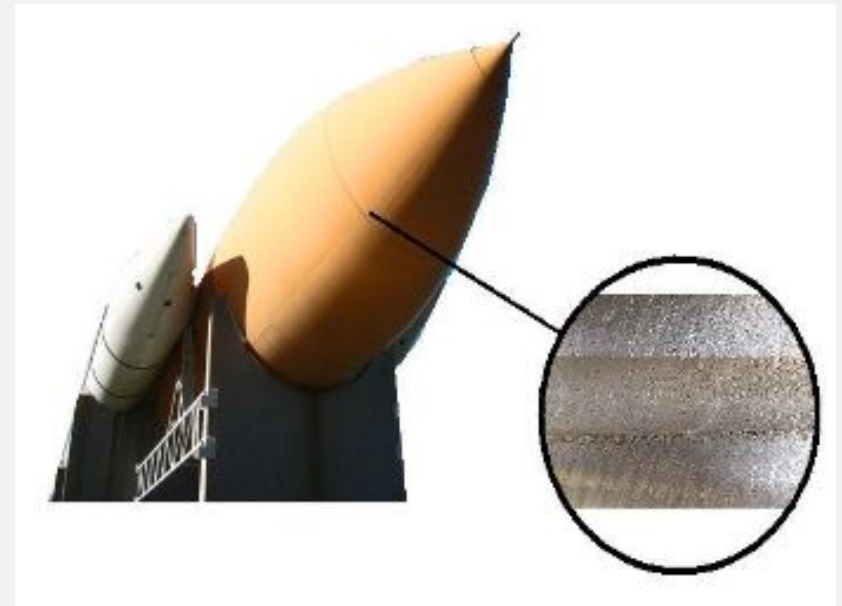
The Friction Stir Welding Process for the **Aerospace** can be utilized for:

- Fuel tanks for spacecrafts
- Toe nails of cargo ramp
- Aluminum panels
- Sandwich assemblies
- Landing gear doors
- Aircraft fuselages
- Wings

1.1 – Introduction to FSW



Aerospace industry - aircraft paneling



Rocket fuel tank

1.1 – Introduction to FSW

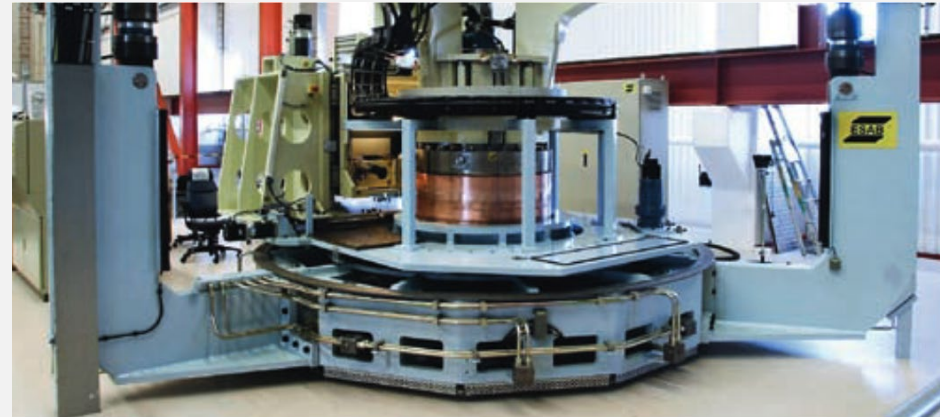
The Friction Stir Welding Process can be also utilized for:

- Motor and loudspeaker housings
- Heat sinks
- Heating, ventilating and air conditioning unit
- Vacuum vessels
- Drying trays – food industry
- Copper canisters for nuclear waste

1.1 – Introduction to FSW

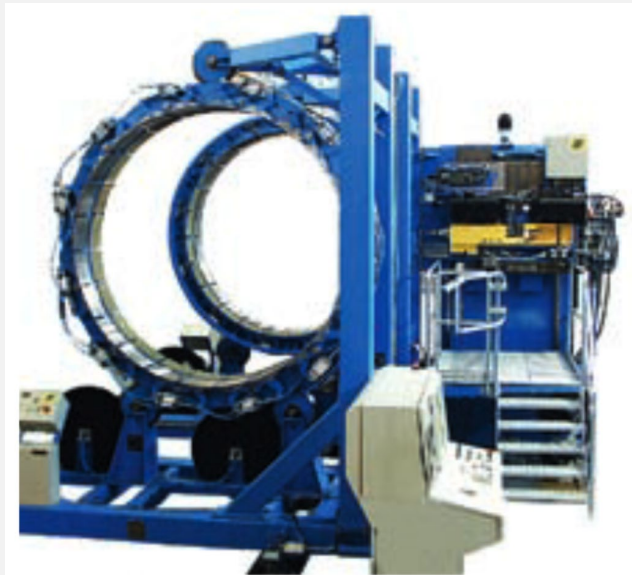


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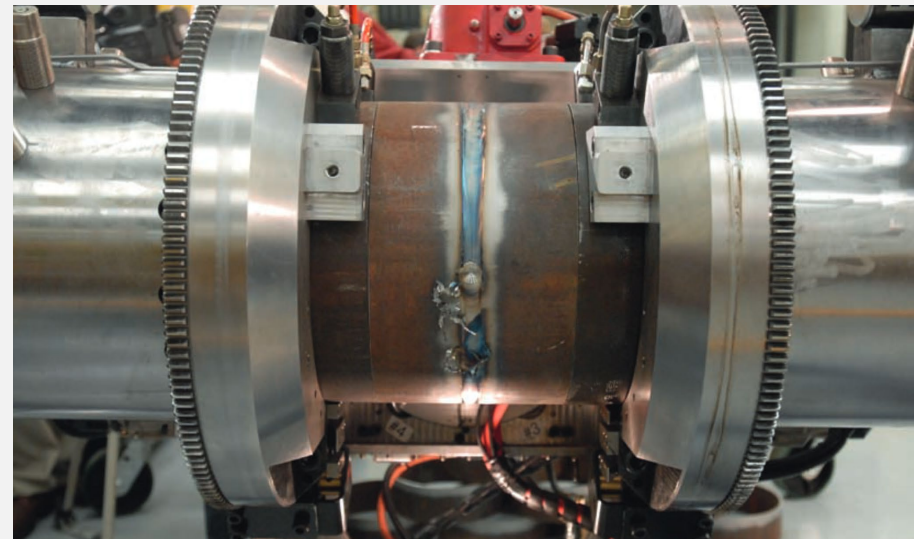


Nuclear industry – Copper canister with cast iron insert for nuclear fuel welded with FSW

1.1 – Introduction to FSW



Circumferential welding machine

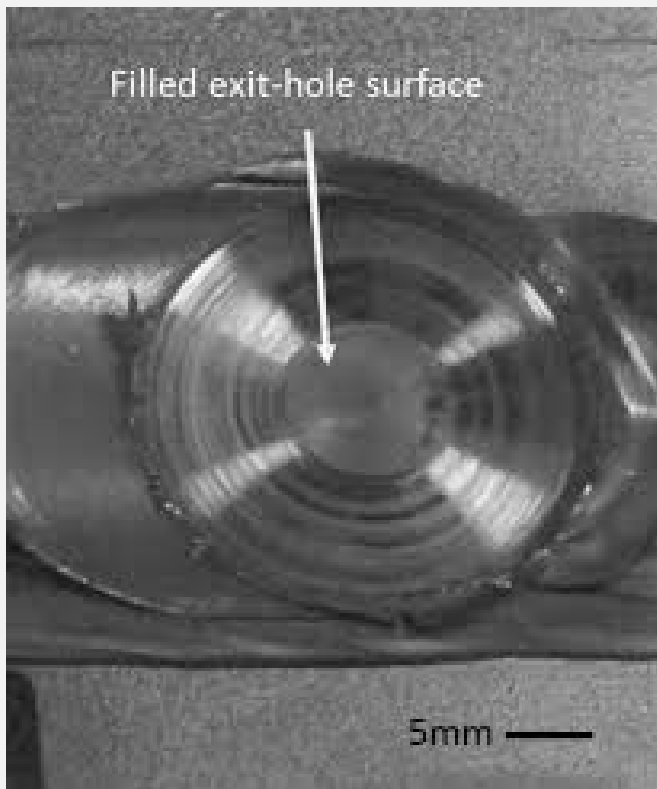


Orbital friction stir welding of steel pipe

1.1 – Introduction to FSW



1.1 – Introduction to FSW



Filled exit-hole surface

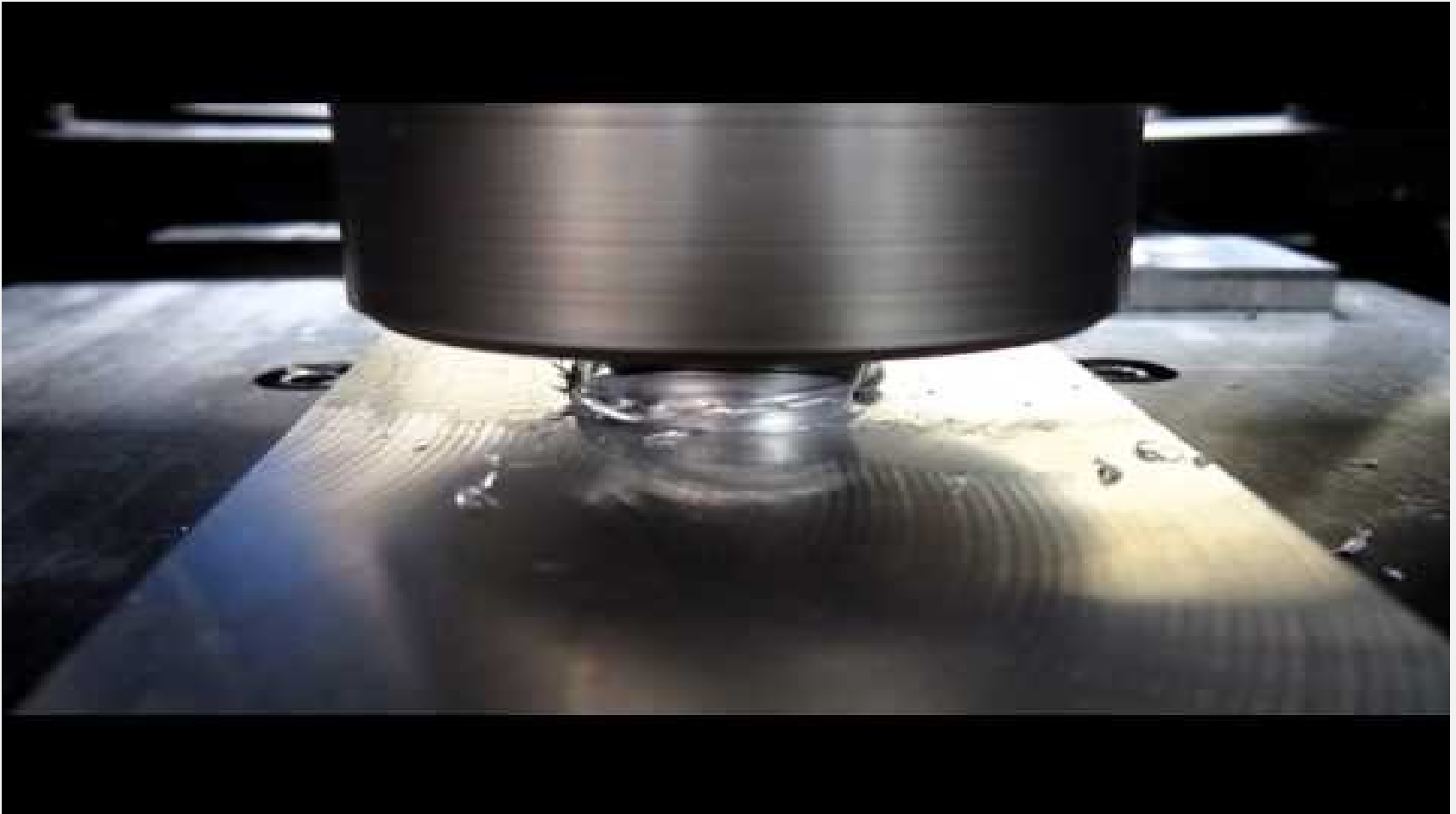


Tandem FSW exit holes

1.1 – Introduction to FSW



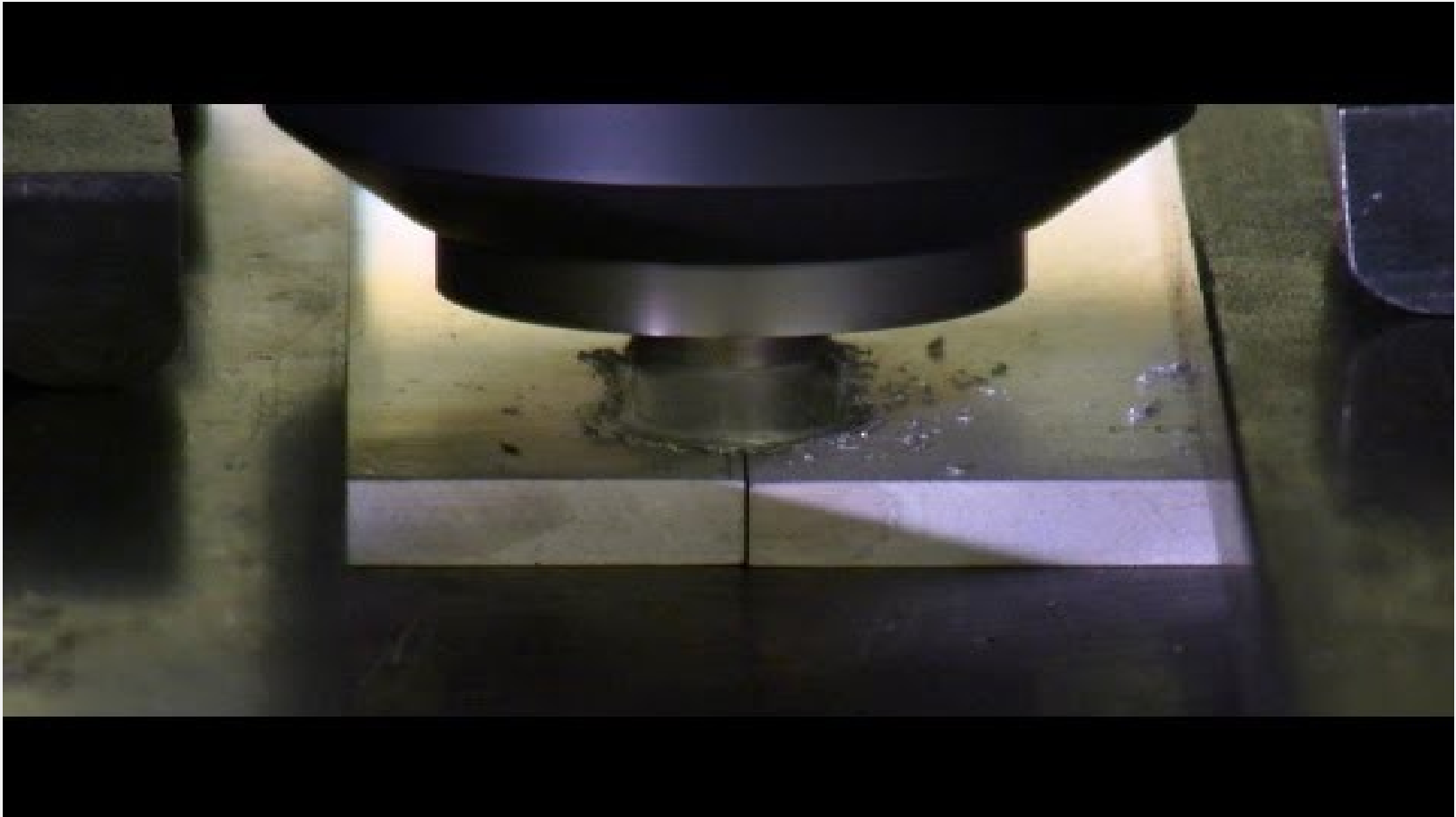
1.1 – Introduction to FSW



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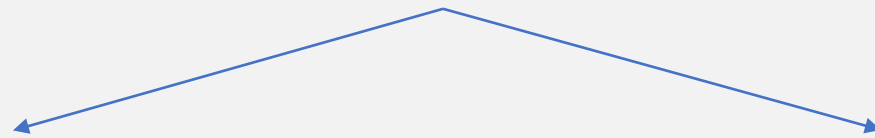


1.1 – Introduction to FSW



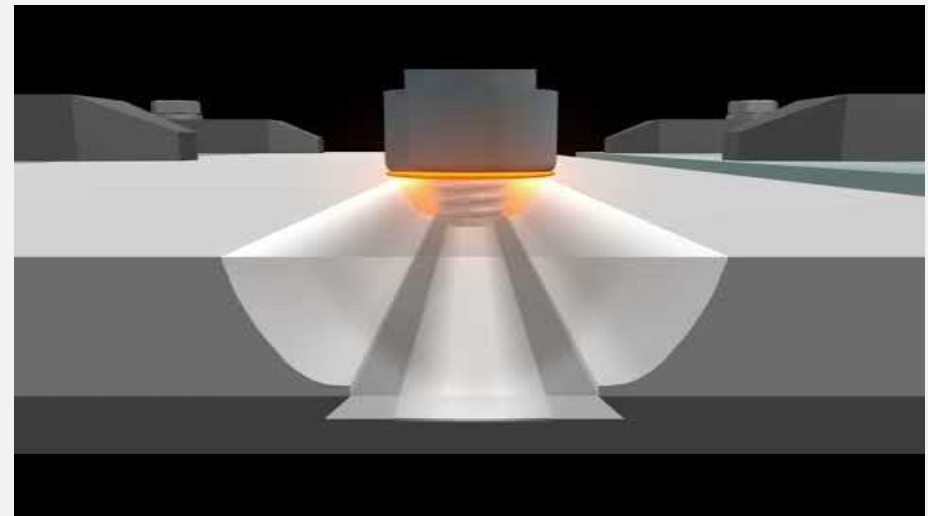
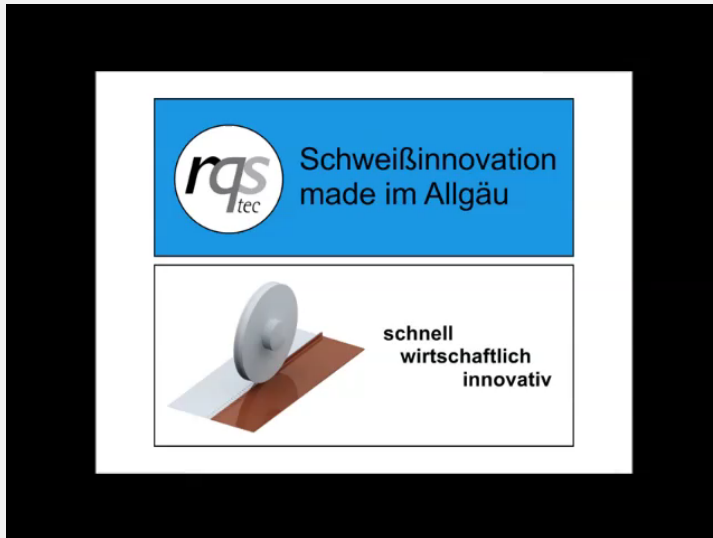
1.1 – Introduction to FSW

Developed on the base of friction stir welding



Friction Crush Welding (ger. Reibquetschschweißen)

Friction Stir Dovetailing



1. FSW Fundamentals

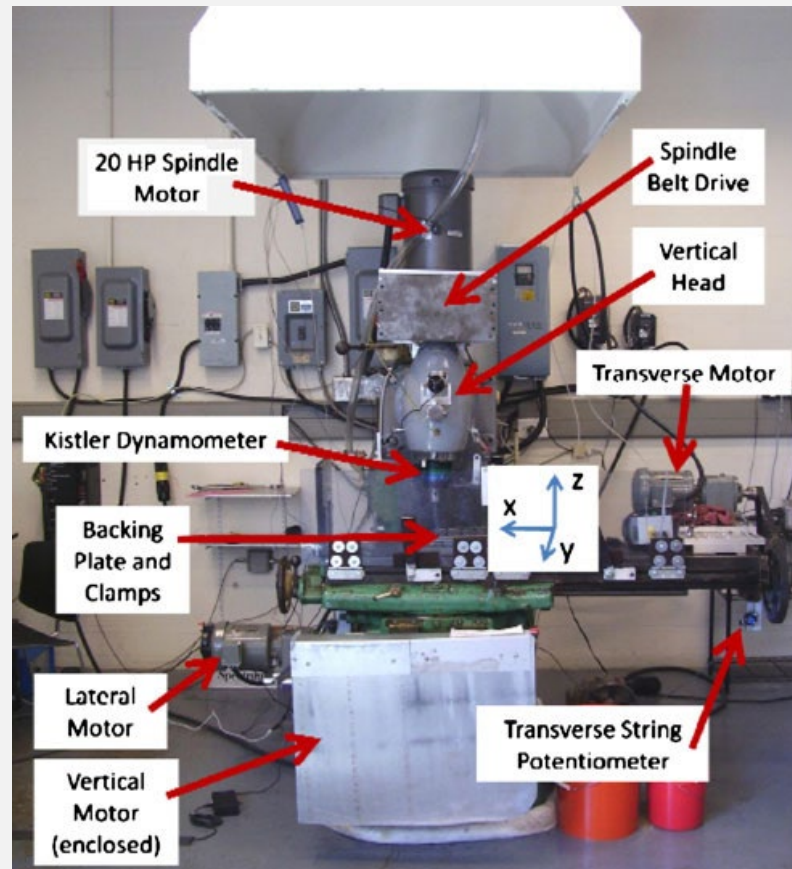
1.2 - Welding equipment

1.2 – Welding equipment

Basic system components include:

- Spindle
- Motors
- Motor drive mechanism
- FSW tool

1.2 – Welding equipment



Example of FSW system configuration

1.2 – Welding equipment

Additional features, that can be incorporated into a machine, include:

- CNC control
- Production monitoring
- Weld temperature monitoring
- Joint tracking
- Gas shielding
- Machine Fixturing
- Data Acquisition System
- Height Sensing

1.2 – Welding equipment

Conventional machine tools

- Low initial cost
- Flexibility can be improved by the introduction of additional motors (additional DOF)
- Stiffness of the machine – need to be strengthened
- Force control solutions are needed to prevent equipment damage, ensure human safety and to achieve good weld quality

Adapted milling machine for FSW



1.2 – Welding equipment

Robotic FSW machines

- High repeatability and flexibility
- Relative low cost
- 3D paths welding
- Process automation
- Low accuracy that worsens when they are subjected to high loads
- Relatively low stiffness and moderate load capability

Articulated arm robots



1.2 – Welding equipment

Robotic FSW machines

- Support higher loads
- Significantly higher stiffness than articulated arm robot
- 3D paths welding
- Process automation
- Their cost can be notably higher and their volume is significantly lesser than the articulated arm robot

Parallel-kinematic robot

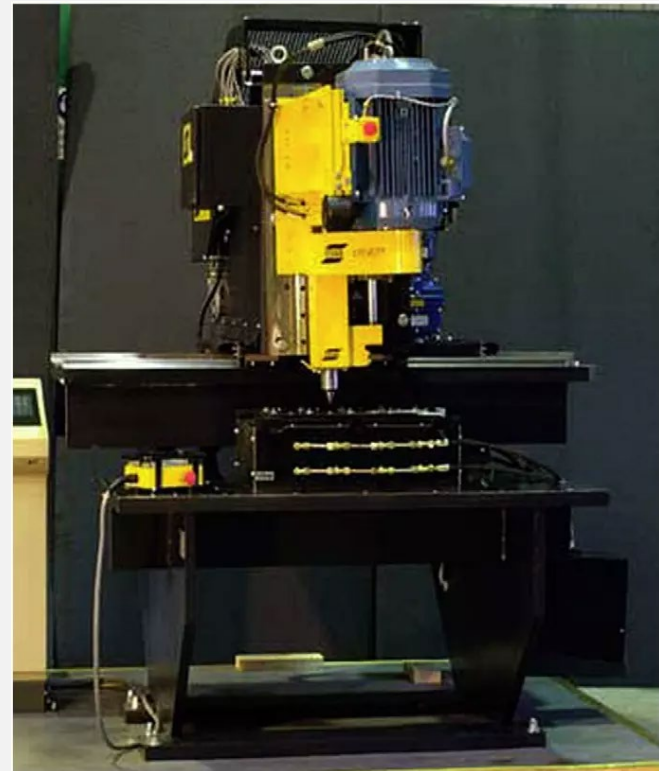


1.2 – Welding equipment

Dedicated FSW machines

- High load capability, stiffness, accuracy and availability
- Possible different configurations thus presenting levels of flexibility
- The dedicated FSW machines are most robust and structurally stiff machines (welding of high temperature materials)
- Rather expensive and their cost increase with increase in flexibility

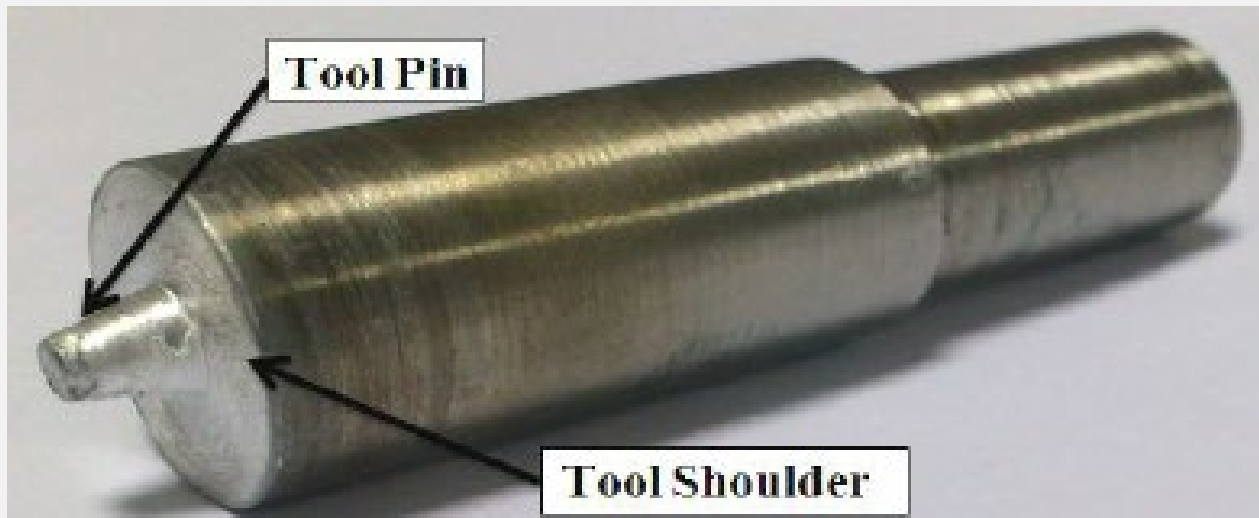
Dedicated FSW machine



1.2 – Welding equipment

	Milling machine	FSW machine	Parallel robot	Articulated robot
Flexibility	Low	Low/Medium	High	High
Cost	Medium	High	High	Low
Stiffness	High	High	High	Low
Work volume	Medium	Medium	Low	High
Setup time	Low	High	Medium	Medium
Number of programming options	Low	Medium	High	High
Capability to produce complex welds	Low	Medium	High	High
Control type	Motion	Motion/force	Motion	Motion

1.2 – Welding equipment



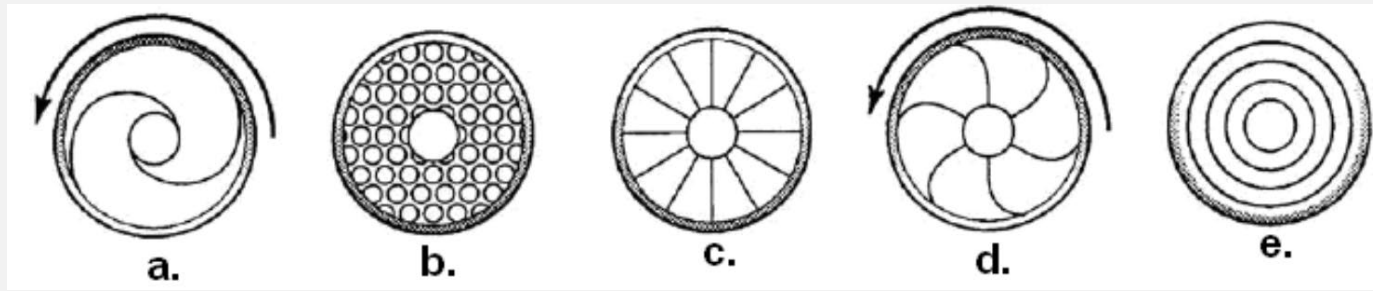
Example of tool geometry

1.2 – Welding equipment



Different types of pin geometries

1.2 – Welding equipment



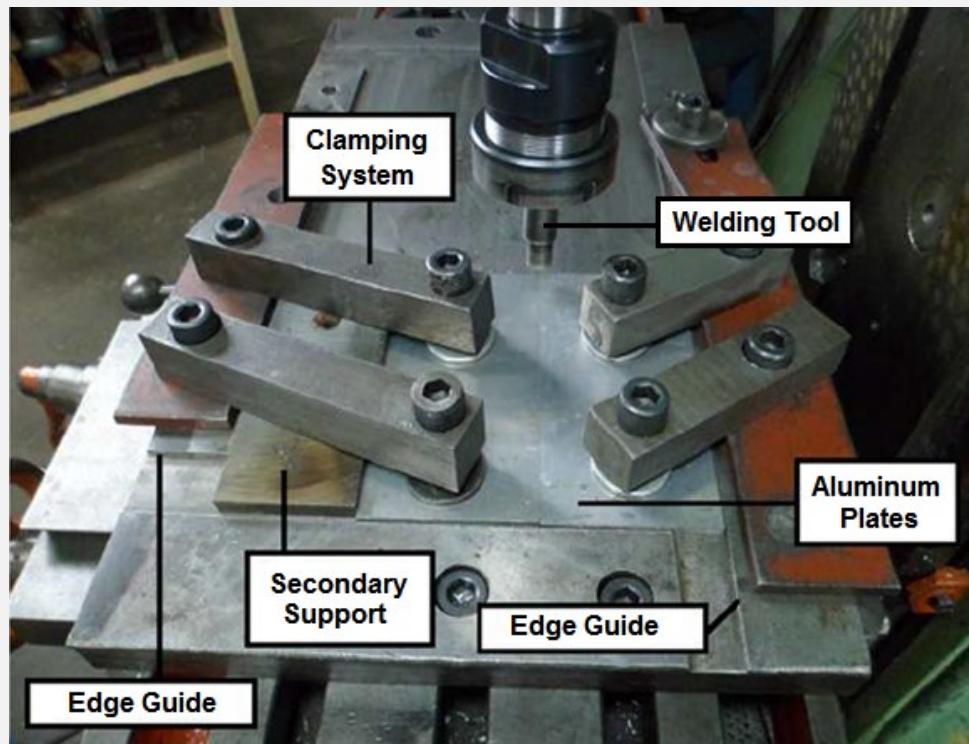
Different shoulder features (top) and example of convex and scrolled shoulder (bottom)

1.2 – Welding equipment

Possible clamping systems include:

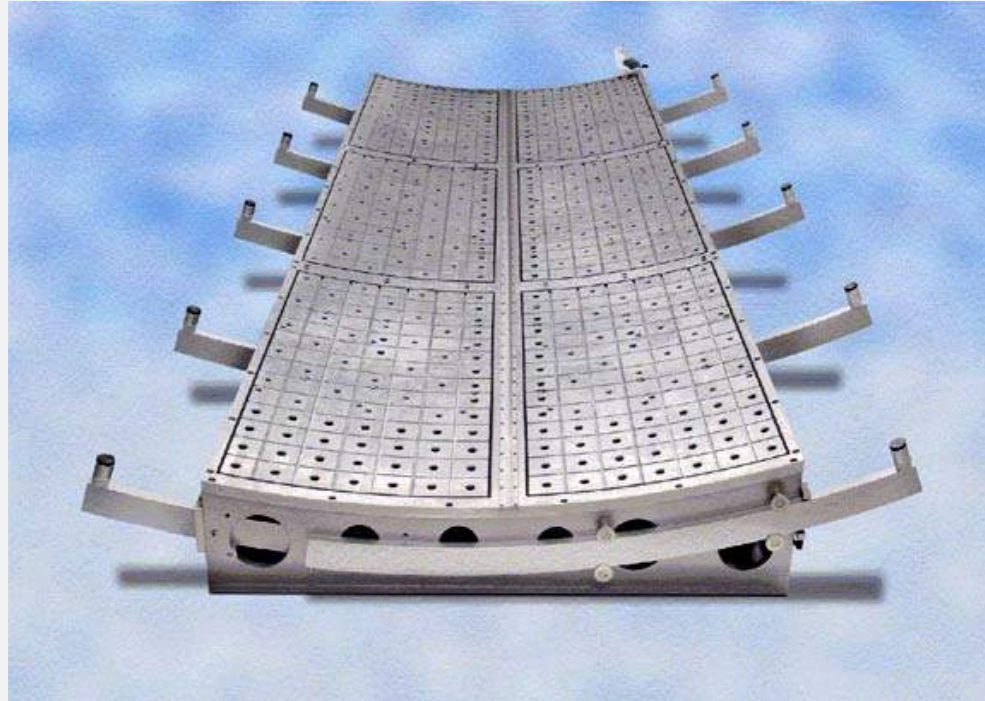
- Clamping claws
- Hydraulic and pneumatic systems
- Vacuum clamping systems

1.2 – Welding equipment



Clamping system

1.2 – Welding equipment



Vacuum clamping system

1.2 – Welding equipment

Cooling enhanced FSW

- Water
- Liquid CO₂
- Liquid nitrogen

- Steel, titanium, stainless steel and higher-temperature alloys are friction stir welded with coolant-cooled tools

Heating

- Electrically assisted FSW
- Laser assisted FSW
- Arc assisted FSW
- Ultrasonic energy assisted FSW

- The heating can minimize tool wear (especially the plunge) and increase the tool travel speed

1.2 – Welding equipment

The key components of FSW machine include:

- Welding head and its motor
- Guide rails and its components
- Hydraulic units

Maintenance plans, inspections and complete documentation should ensure long term and trouble-free operation

1. FSW Fundamentals

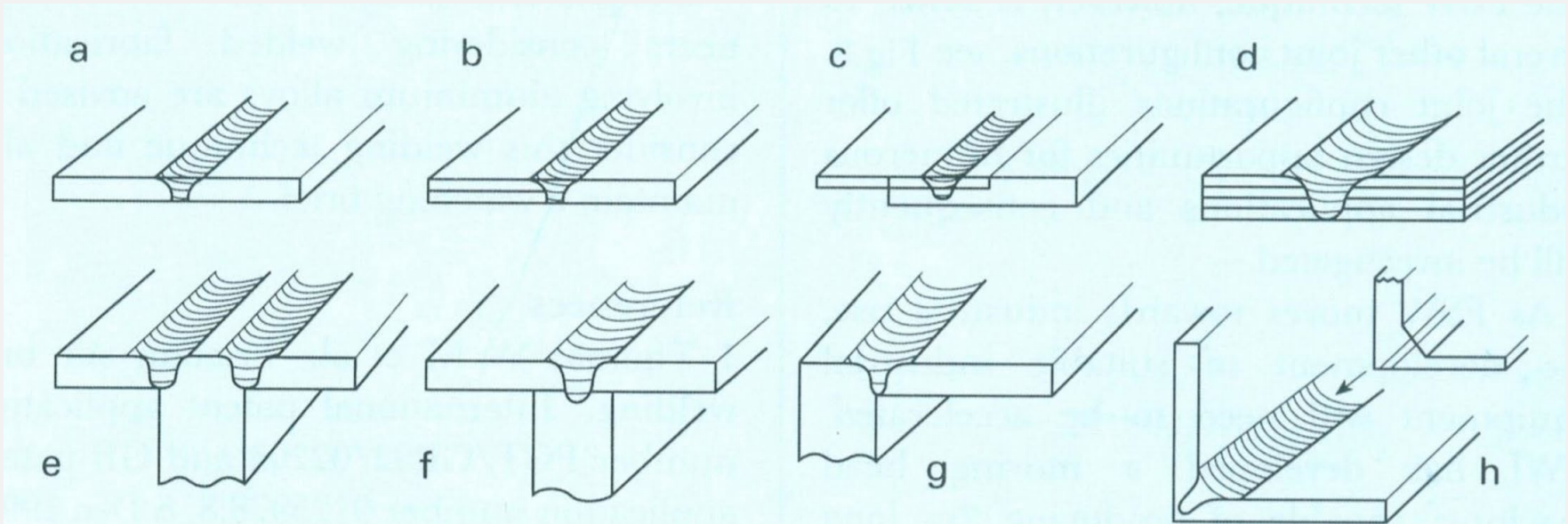
1.3 - Welding processes

1.3 – Welding processes

Design implications of FSW:

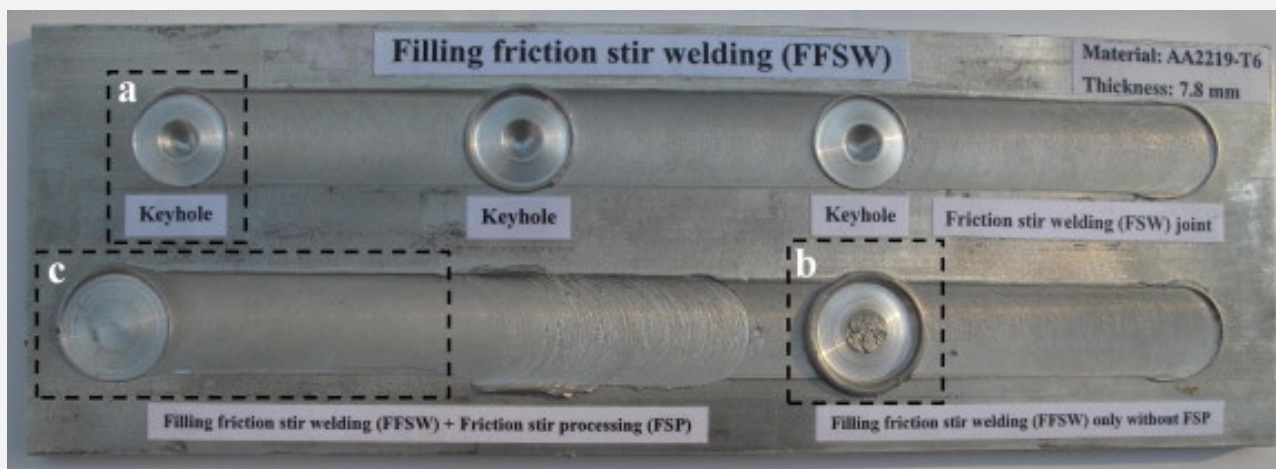
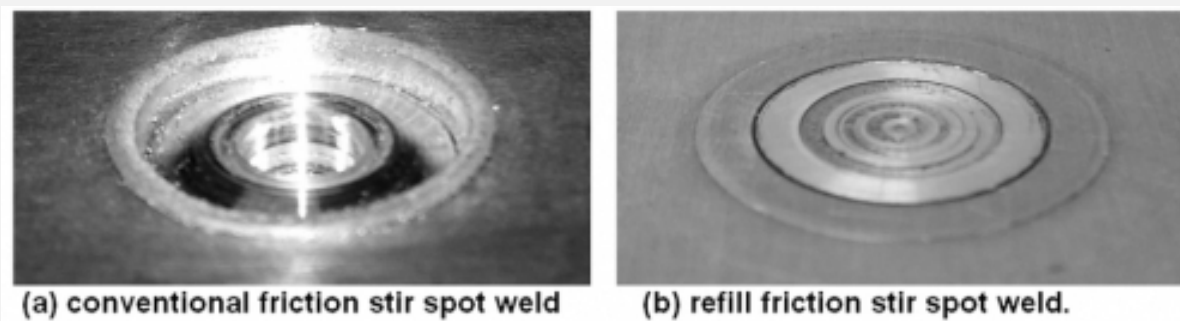
- Mechanical limitations
- Fixture limitations
- Joint design limitations
- Keyhole limitations
- Workpiece and base material thickness limitations
- Material

1.3 – Welding processes



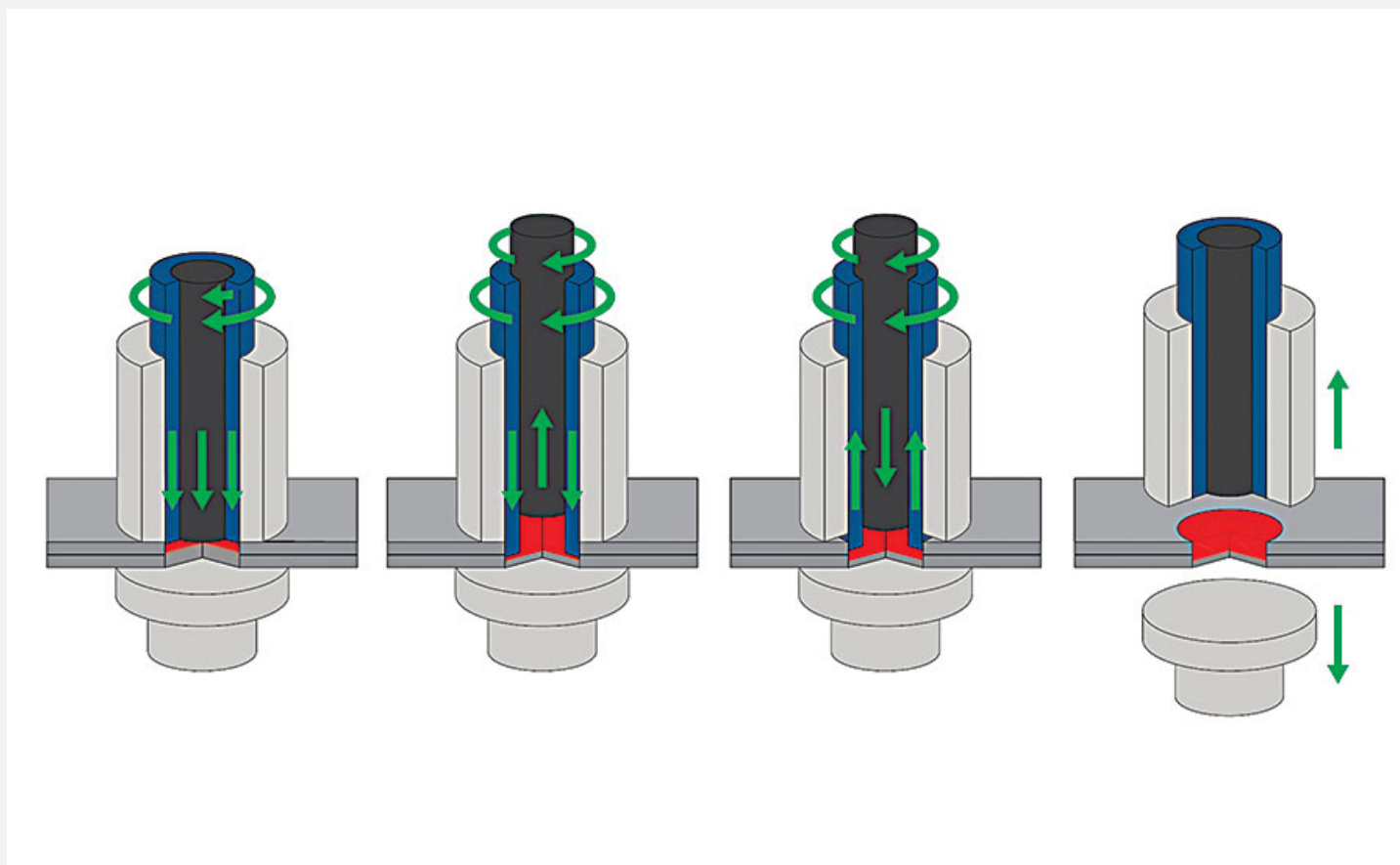
Possible joint configurations: square butt ; (b) and (c) lap joint; (d) multiple lap joint; (e) T butt joint (f) T lap joint (g) edge butt (h) fillet joint

1.3 – Welding processes



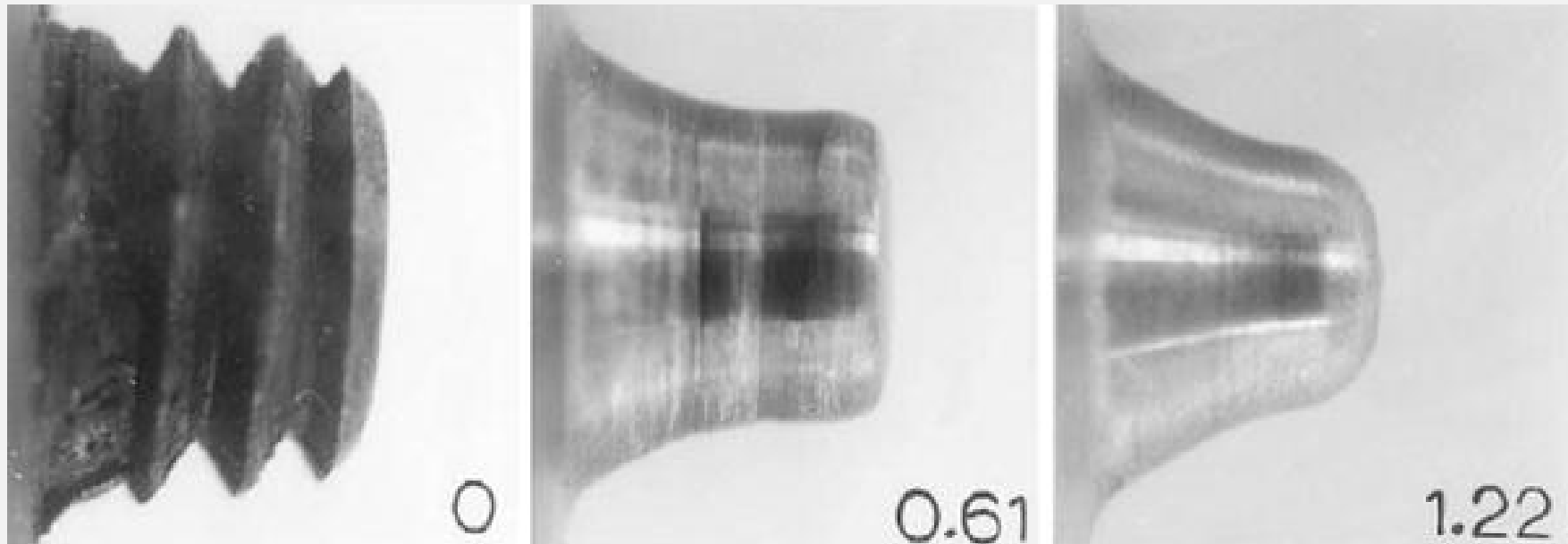
Filling of keyhole

1.3 – Welding processes



Refill FSW process

1.3 – Welding processes



Tool wear

1. FSW Fundamentals

1.4 - Parent Materials

1.4 – Parent Materials

- FSW can be used in joining materials like aluminium, copper, magnesium, steel, thermoplastics and titanium.
- It is also possible to perform dissimilar material welding.
- Welding of high melting point materials is more difficult, because the welding tool material is working in harsh operating conditions.

1.4 – Parent Materials

- Stiffness and force handling are major factors for the FSW machine, which limits the thickness of workpiece. Material thickness should be in range from 0.8 mm to 65 mm.

Alloy	Thickness, mm	Tool material
Aluminium alloys	<12	Tool steel, WC-Co
	<26	MP159
Magnesium alloys	<6	Tool steel, WC
Copper and copper alloys	<50	Nickel alloys, PCBN, tungsten alloys
	<11	Tool steel
Titanium alloys	<6	Tungsten alloys
Stainless steels	<6	PCBN, tungsten alloys
Low-alloy steel	<10	WC, PCBN
Nickel alloys	<6	PCBN

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