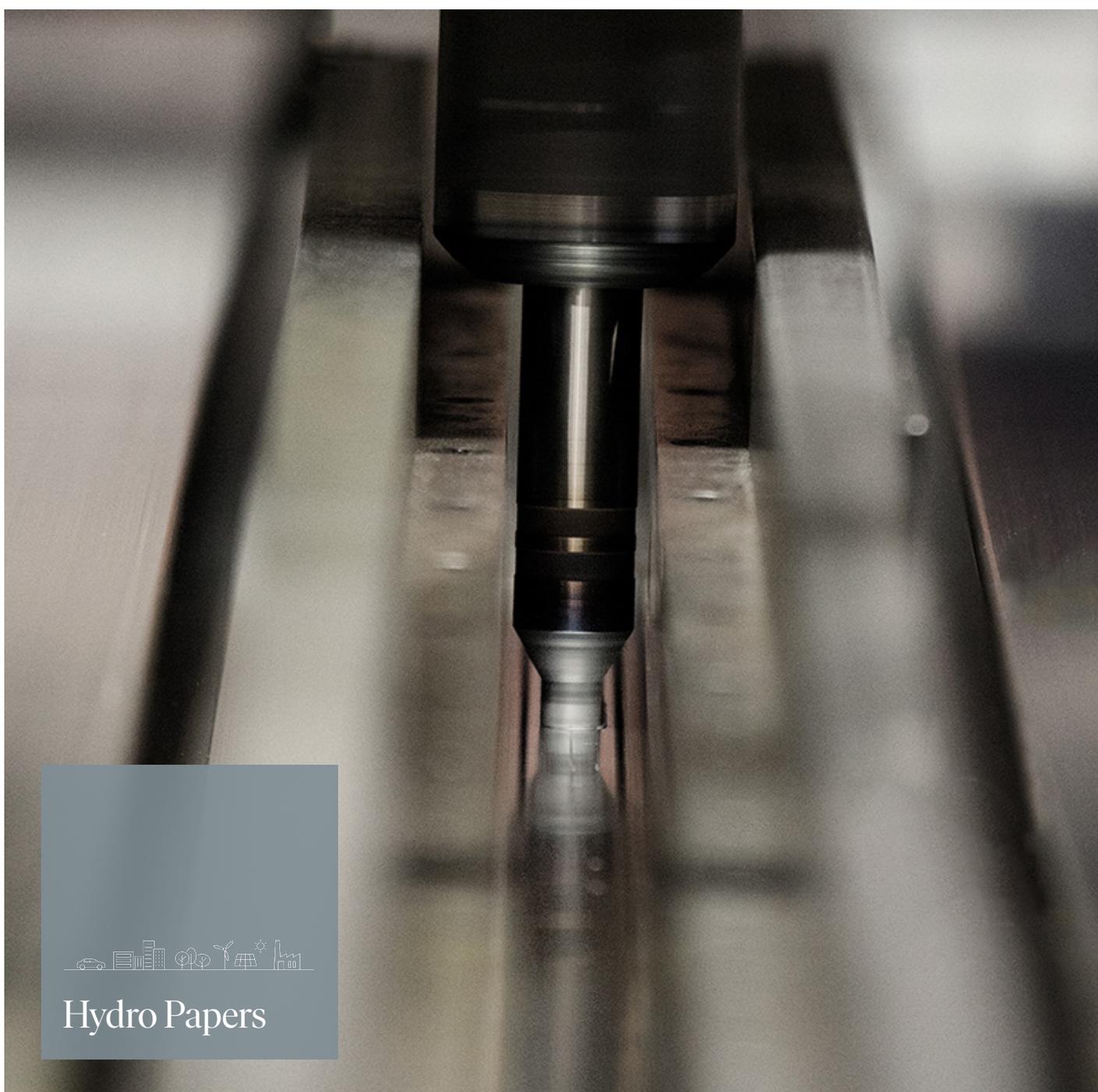




Friction stir welding (FSW)



Hydro Papers

Friction stir welding

About the process and equipment, some user applications, the benefits and the comparison with fusion welding.

Abstract

In this white paper, you will get an overview of the friction stir welding (FSW) technology and the equipment needed. You will also learn about its benefits and how it compares to traditional fusion welding like for example MIG.

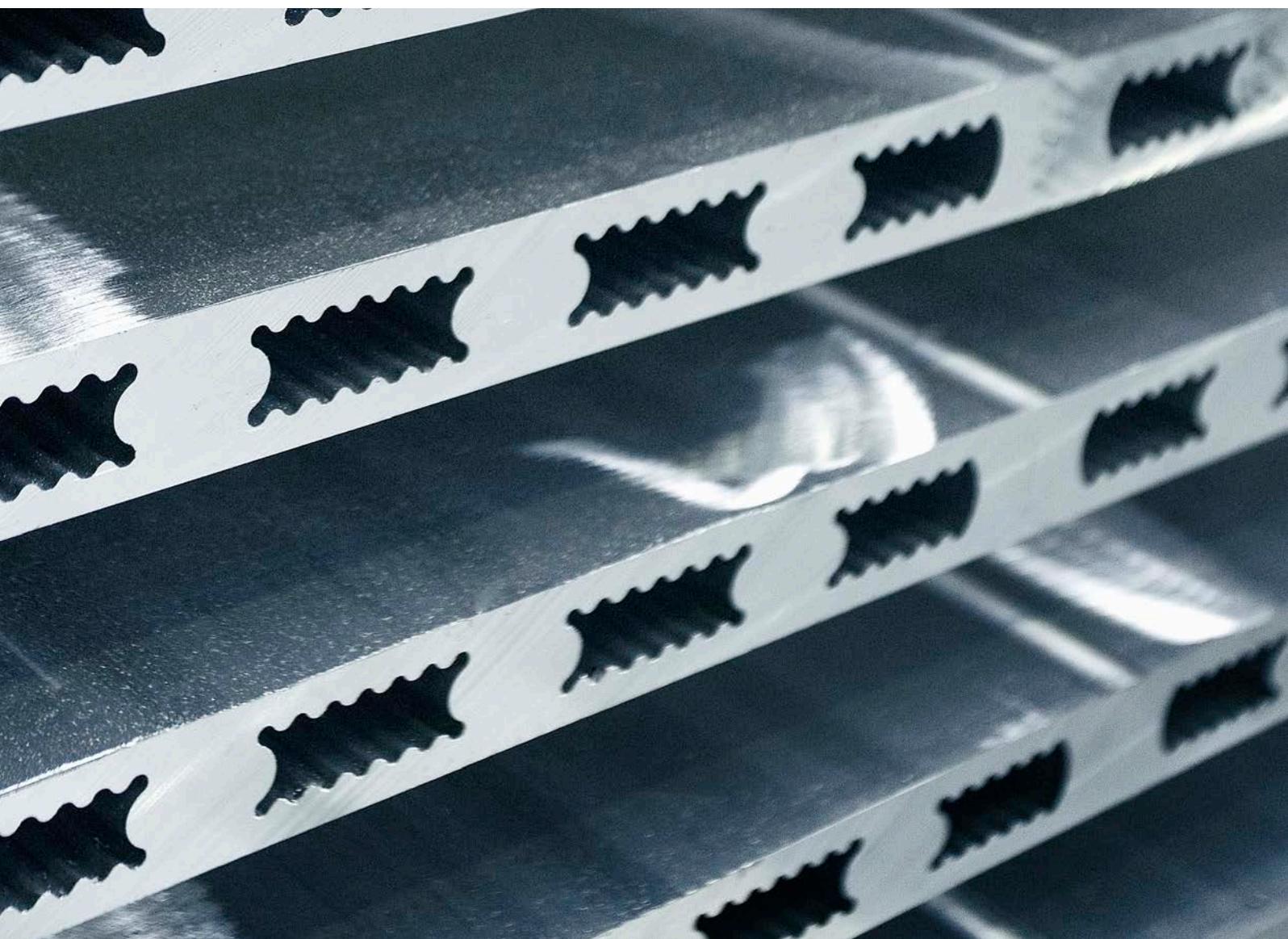
You will be introduced to some typical applications where FSW offers many benefits compared to traditional methods and has been able to solve some key challenges, these applications have been struggling with.

Hydro manufactures aluminium plate, sheet and customized extrusions based products. Hydro can also assist in the design and production of customized extruded solutions. These aluminium solutions are used in many different industries like for example rail, shipbuilding, automotive and power electronics cooling.



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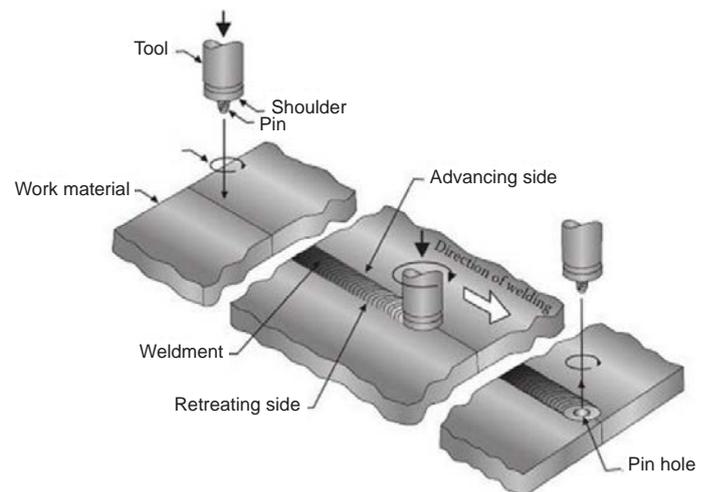
Introduction

Friction stir welding of aluminium is a proven technology. The Welding Institute (TWI) in Cambridge, UK, invented the method. After having turned laboratory results into full-scale production capabilities, Hydro introduced FSW as part of its serial production in 1996.

The process

Friction stir welding is a solid-state process. A rotating tool plunges into the metal, initiating frictional heating and severe plastic deformation. The softened material is readily mixed by the tool, and a homogeneous joint is formed as the tool moves forward along the joint line. Neither filler material, preheating nor shielding gas are necessary for the welding process.

The FSW method is standardized according to ISO 25239.



Picture 1 - schematics of the FSW process

Equipment

As the FSW process is a solid-state process, the forces involved in moving the tool through the materials to be joined are considerable. To control the process correctly and deliver the highest quality and certified products, the FSW equipment should be sturdy. This necessitates strong backing, fixation (tolerances, handling) and a rigid machine.

For smaller products, the equipment may vary from a manually controlled sturdy CNC machine to an automated robot line.



Picture 2 - FSW robot cell

For larger products, for example panels for the marine or rail industry, automated large table production lines with double-sided welding heads are used.

Because the welding process is easy to repeat, it consistently delivers high-quality welds. Only a few variables need monitoring: tool type, feeding rates, rotational speed and position. Attention should also be paid to the tool wear and clamping of the components to be joined.



Picture 3 - FSW tool and quality inspection camera



Picture 4 - long length FSW panel production line

User applications

Train coaches

Straight and curved double skin FSW panels are used for the production of train coaches. These panels, the length of a coach, are used for the sides, the floor and the roof. The structure does not necessitate any additional frame, is self-bearing and very stiff. The straightness, length and good surface quality make FSW very suitable for this application.



Picture 5 - FSW double skin train coach panel

Ship structures

For the construction of decks, bulkheads and superstructures, large quantities of flat panels are used. Use of pre-fabricated FSW panels will save MIG welding cost and almost eliminate the necessity of filler material to create flat surfaces. The total production lead time can be reduced considerably, as MIG welding is only needed to connect the panels.



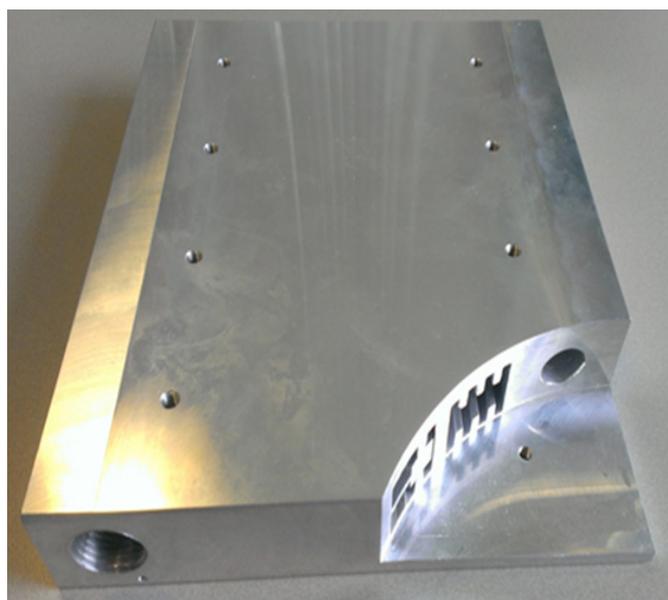
Picture 6 - FSW single skin deck panels



Liquid coolers

By taking advantage of the extrusion process, fluid channels are incorporated into the profile eliminating the need for costly downstream operations. The profiles are then cut to the length needed for the cooler, the end-channels milled and sealed using end-cover plates that are Friction Stir Welded in place. The result is a high performance cooling system with 100% leak-proof joints, maintaining the parent metal's conductivity. This process is very suitable for high-volume series production as it can be easily automated.

It can be seen in the above user cases, that FSW can help solve challenges related to flatness, straightness, cost- and production time reduction of larger panels as well as increased cooling- and leak performance of liquid coolers.



Picture 7 - FSW extrusion based liquid cooler

Comparison to traditional fusion welding

The FSW process differs from traditional fusion welding in the following aspects:

- It uses no filler material. Combining a filler with the parent material results in a weld with a solidification microstructure that differs from that of the parent material.
- It needs no protecting medium. For quality control of conventional fusion processes, exposure of the molten metal puddle to ambient atmosphere must be avoided. Consequently, TIG and MIG processes use shielding gas.
- There is no risk for solidification cracking, porosity, and shrinkage – contrary to fusion welding.

Weld performance

The tensile strength performance of friction stir welded aluminium alloys is superior to fusion welding, with joint efficiencies measuring 83 percent or higher. Data also shows that the performance of friction stir welds in aluminium alloys is superior to that of fusion processes in terms of fatigue. In addition, FSW results display a high degree of repeatability, with low scatter in the data.

Strength

Experience and extensive testing show that a FSW joint is usually stronger than a fusion weld.

The table below shows the standardized joint efficiency factor T for arc-welded butt joints as specified in SS EN ISO 15614-4.

Standardized T-values for FSW joints are provided according to ISO 25239-4. The values for Hydro joints are based on a number of measurements that far exceeds the minimum required quantity, and should be regarded as our standard values.

Weld factor for the ultimate tensile strength of butt welds, Al-Mg-Si alloys

Condition of parent metal material before welding	Aging after welding	$T = \frac{R_m (w)}{R_m (pm)}$		
		Arc ¹	FSW ²	FSW ³
T4	Natural aging	0.7	0.7	0.9
T4	Artificial aging	0.7	0.7 ⁴	≥ 0.9
T5-T6	Natural ageing	0.6	0.6	≥ 0.7
T5-T6	Artificial ageing	0.7	0.7 ⁴	≥ 0.8

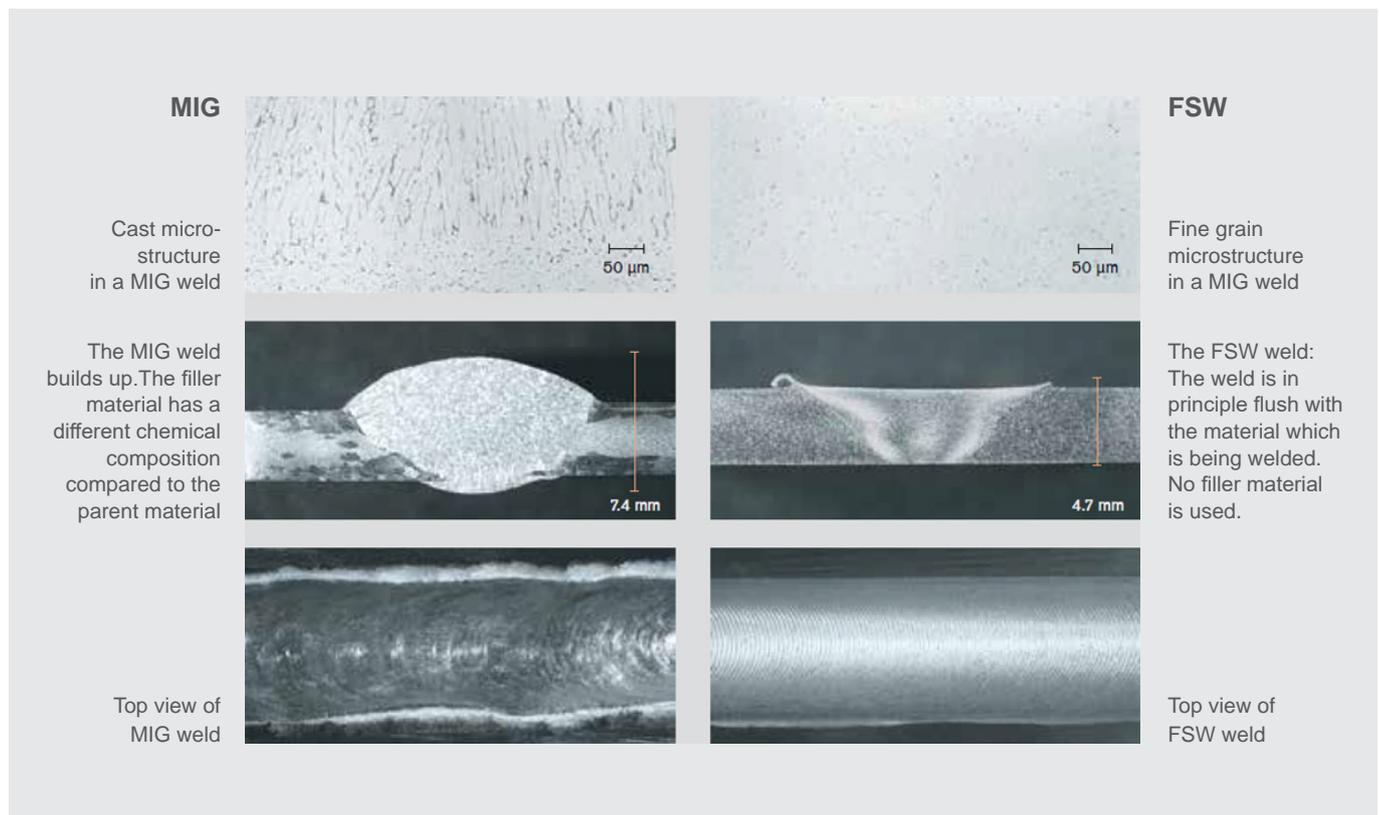
1. e.g. MIG or TIG.
2. FSW values according to ISO 25239-4
3. typical values for Hydro welds
4. higher properties can be achieved if a full post-weld heat treatment is applied

The tensile strength ($R_m (w)$) of the welded specimen shall satisfy the following requirements:

$R_m (w) = R_m (pm) \times T$, where $R_m (pm)$ is the specified minimum tensile strength of the parent material and T is the joints efficiency factor.

Weld structure

Apart from a performance difference, there are also visual differences between FSW and fusion welds. Below the characteristic visual differences are shown from 3 different perspectives: micro structure, cross-section and top-view.



Corrosion resistance of friction stir welds

The corrosion resistance performance of FSW welds in common 5xxx and 6xxx aluminium alloys is comparable to the parent material and often exceeds that of fusion welds. This is related to a finer microstructure, absence of porosity and no addition of other materials (filler). Tests of FS welded 6082 revealed that, after 1,000 hours of SWAAT

testing, neither yield nor ultimate strength are affected. Through the correct control of the FSW parameters, this performance can even be improved. Variation of welding speed and tool rotation can have a positive impact on the corrosion resistance in the weld.

Typical benefits of aluminium

Aluminium is a light weight material, with its high strength-to-weight ratio usually offering 30–50% weight reduction compared to common carbon steels.

Aluminium offers design flexibility due to its malleability and the possibility to integrate different kinds of functionalities into extruded solutions.

Aluminium is corrosion resistant with virtually no maintenance needed and can be recycled over and over again without any loss of quality.

Benefits of friction stir welding aluminium

During the FSW process, no additional heat nor filler material are added resulting in relatively low temperatures, little distortion with tight tolerances and a fine grain structure in the weld zone with improved weld strength. Due to the stability of the process, the welds are void-free and leak-proof and virtually flush with the parent material.

Typical markets using FSW

FSW is frequently used in series production in the following markets:

- Railways – floors, body sides, roofs (long, flat, straight panels)
- Shipbuilding – decks, floors, bulkheads, bulwarks, longitudinal walls, side sheets, shell plating, fish freezer plates (long, flat, straight panels)
- Automotive – body components, rear seat frames, suspension parts, trim parts (mass production, high weld strength, FS spot welds)
- Aerospace – rocket fuel tanks, carrier beams, floors, complete fuselages and wings (long, flat, straight components with high weld strength)
- Power electronics – liquid coolers, large air coolers (leakage free, high weld strength, automated production)
- Offshore – living quarters, stair towers, boarding gangways (long, flat, straight components with high weld strength)

Hydro delivers FSW products in high volumes to most of the above industries. Hydro can manufacture aluminium panels of up to 3.5 meters in width by 18 meters in length. These panels are made of extruded profiles joined by means of FSW. They are produced per customer specifications regarding shape, length and width. Hydro has been approved by leading classification associations for railway and marine applications.

For the smaller components and cooling solutions, Hydro has extensive FSW production capabilities incl. complicated CNC fabrication and robotized high volume production lines with integrated leakage testing.

Conclusion

Compared to traditional fusion welding, FSW provides increased strength, improved sealing with void-free and leak-proof joints, welds flush with the parent material and tight tolerances due to reduced heat distortion.

FSW combined with the extrusion process offers the potential to reduce the production cost. It can replace many passes of MIG welding, completely eliminates the usually necessary MIG weld preparations and can make use of extrusions with functionalities already incorporated into the profiles instead of having to weld them on afterwards.

In many different industries, FSW can be a game changing technology for solving challenges with flatness and straightness, weld strength and leakage-performance as well as production cost reduction.

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Industries that matter

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Our purpose is to create more viable societies by developing natural resources
into products and solutions in innovative and efficient ways.