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Future Prospective of Friction Stir Welding for Different Industrial Applications

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Abstract:

This paper focuses on Friction Stir Welding (FSW), a fairly recent technique, invented by The Welding Institute (TWI) in 1991, that utilizes a non-consumable rotating welding tool to generate frictional heat and plastic deformation at the welding location; thereby, affecting the formation of a joint while the material is in the solid state. In particular, FSW can be used to join high-strength aerospace aluminum alloys and other high temperature metallic alloys that are hard to weld by conventional fusion welding. FSW is considered to be the most significant development in metal joining in a decade. This work addresses the current state of understanding and development of the FSWprocess. The principles of weld formation, welding parameters, design principles, process speed and application areas of FSW for improved welding are discussed. Since FSW is a leap forward in manufacturing technology, some of the typical industrial applications of FSW in aerospace, shipbuilding and auto industries have also been presented.

Keywords:

FSW, Process parameters, Application areas of FSW.

I. INTRODUCTION:

Friction stir welding, a process invented at TWI, Cambridge, involves the joining of metals without fusion or filler materials; in other terms, it joins materials by using friction heat. This joining technique is energy efficient, environment friendly, and versatile [1]. It is already used in routine, as well as critical applications, for the joining of structural components made of aluminum and its alloys.

Friction Stir Welding (FSW) is a solid-state process, which means that the objects are joined without reaching the melting point [2]. This opens up whole new areas in welding technology. Using FSW, rapid and high quality welds of 2xxx and 7xxx series alloys, traditionally considered un-weldable, now become possible [3]. In FSW, a cylindrical shouldered tool with a profiled pin is rotated and plunged into the joint area between two pieces of sheet or plate material. The parts have to be securely clamped to prevent the joint faces from being forced apart. Frictional heat between the wear resistant welding tool and the work pieces causes the latter to soften without reaching melting point, allowing the tool to traverse along the weldline. The plasticized material, transferred to the trailing edge of the tool pin, is forged through intimate contact with the tool shoulder and pin profile. On cooling, a solid phase bond is created between the work pieces [4].

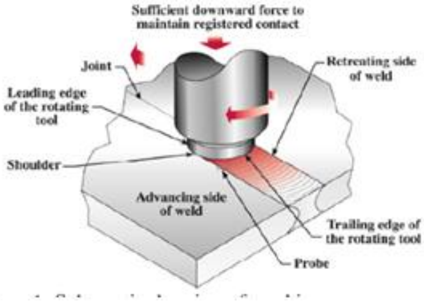

Figure 1: Schematic diagram of working process principle of FSW

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FSW had many advantages over other joining processes for aluminum in numerous applications; so, this process is primarily used on aluminum and most often on large pieces which cannot be easily heat treated post weld to recover temper characteristics. It can be used to join aluminum sheets and plates without filler wire or shielding gas. Material thicknesses ranging from 0.5 to 65 mm can be welded from one side at full penetration, without porosity or internal voids. In terms of materials, the focus has traditionally been on nonferrous alloys, but recent advances have challenged this assumption enabling FSW to be applied to a broad range of materials [5].

II. PROCESS PRINCIPLES:

A. Weldable Alloys:

In terms of high-temperature materials, FSW has been proven successful on numerous of alloys and materials, including high-strength steels, stainless steel and titanium. As what is weldable refers to the material by which the welding tool is made and how the process is applied there are really no limits to what can be achieved.

B. Process Characteristics:

The FSW process involves joint formation below the base material's melting temperature. The heat generated in the joint area is typically about 80-90% of the melting temperature.

Figure 2: Brass, as well as mixed copper / aluminum joints can be friction stir welded.

With arc welding, calculating heat input is critically important when preparing Welding Procedure Specifications (WPS) for the production process. With FSW, the traditional components – current and voltage – are not present as the heat input is purely mechanical and thereby replaced by force, friction, and rotation.

Several studies have been conducted to identify the way heat is generated and transferred to the joint area. A simplified model is described in the following equation:

$Q= \mu\Omega fk$

Where, Heat (Q) is the result of friction (μ)

Tool rotation speed is (ω)

Down force is (F) and a Tool geometry constant is K.

C. Welding Parameter:

In providing proper contact and thereby ensuring a high quality weld, the most important control feature is down force (Z-axis). This guarantees high quality even where tolerance errors in the materials to be joined may arise. It also enables robust control during higher welding speeds, as the down force will ensure the generation of frictional heat to soften the material. When using FSW, the following parameters must be controlled: down force, welding speed, the rotation speed of the welding tool and tilting angle. Only four main parameters need to be mastered, making FSW ideal for mechanized welding.

Table 1: FSW Parameters for Mechanized Welding

Parameter	Effects
Rotation speed	Frictional heat, "stirring", oxide layer breaking and mixing of material
Tilting angle	The appearance of the weld, thinning
Welding speed	Appearance, heat control.
Down force	Frictional heat, maintaining contact Conditions

D. Tools:

Welding tool design is critical in FSW. Optimizing tool geometry to produce more heat or achieve more efficient "stirring" offers two main benefits: improved breaking and mixing of the oxide layer and more efficient heat generation, yielding higher welding speeds and, of course, enhanced quality.

Table 2: Forging temperature range of different alloy groups

Alloy group	Temperature range in °C
Aluminum alloys	440 to 550
Magnesium alloys	250 to 350
Copper alloys	600 to 900
Carbon and low-alloy steels	650 to 800
Titanium alloys	700 to 950

The simplest tool can be machined from an M20 bolt with very little effort. It has proved feasible to weld thin aluminum plates, even with tooling as simple as this, although at very slow welding speeds. However, tool materials should feature relatively high hardness at elevated temperatures, and shouldretain this hardness for an extended period. The combinationof tool material and base material is therefore always crucial to the tool’s operational lifetime. Table 2 illustrates the forging temperature range of different alloy groups.

E. Process Speed:

One of the main “excuses” for not using FSW was the claim that its welding speed was too slow for production, even though the mechanical properties of FSW welds outclass conventional joining processes for aluminum. The typical stated welding speed for 5 mm AA6082 was between 250 mm/min and 400 mm/min. This was typical for a CNC machine, not designed for the high down forces needed in FSW or the high travel speeds. With production machines, welding speeds for the above-mentioned alloy are (and have been for a number of years) almost ten times higher – with 2000 mm/min a typical production speed when joining extruded profiles. In a medium-size welding workshop (between 200 and 400 blue-collar workers), time spent in welding and related functions represents roughly 15% to 20% of total manufacturing time.

This suggests three alternatives for improving productivity:

1. Increase the welding speed of conventional processes (GMAW, GTAW),
2. Introduce a new welding process that offers a speed similar to conventional arc welding but that generates significant cost savings in other aspects of production
3. Introduce FSW, which welds 3-4 times faster than GMAW and generates significant cost savings at a later phase of the production process.

Alternative number 3 is the most attractive, of course. A number of companies have chosen this alternative, for improved economy and increased production capacity. A Norwegian shipyard has reduced production time for a 60-m long catamaran hull from ten to six months, boosting capacity by 40%. This yielded cost savings of 10%, equivalent to 10% of total fabrication costs. These savings derive from three different improvements: 2% to 3% due to improved extruded profile designs and the use of friction stir welded panels, 4% to 5% due to improved streamlined fabrication at the yards and 3% due to new design.

III. APPLICATION AREAS:

A. Aerospace:

1) Space industry:

Friction stir welding was first introduced to a larger, general public at the Schweissen & Schneiden Fair in 1997. It was later purchased by The Boeing Company for research and laboratory use. Besides the laboratory machine, Boeing has been a real pioneer in introducing FSW into industrial manufacturing. In the Delta II and IV programs, FSW has been widely adopted and used for manufacturing rocket-fuel tanks.

Production time for a typical tank has been dramatically reduced and a number of cost savings have been achieved. At about 20% of the cost of riveting, FSW offers surprisingly significant cost gains. Not just at the Boeing Company, but almost anywhere aerospace or civil aviation equipment is being manufactured, FSW production technology is being considered for future designs.

A number of different applications in the commercial and military aircraft industry are under evaluation, including carrier beams, floors and complete fuselages and wings.

2) Civil Aviation:

The main rationale for employing FSW (or welding in general, for that matter) in the manufacture of aerospace components is weight savings, which translate directly into cost savings. Reducing weight enables higher speeds and/or reduced fuel consumption. Friction Stir Welding not only eliminates rivetsand fasteners, but the need for an overlap sheet configuration. The butt-joint configuration also facilitates joint evaluation and quality assurance, because a homogeneous joint with full penetration eliminates crack formation. The fact that FSW offers the means to join previously unweldable Al-Li (e.g. AA2195) alloys has attracted growing interest from the civil aeronautics and aerospace industries. High strength and low weight is always a desirable combination. When allied to a robust welding method, this opens a whole new field of possibilities. Approval by the FAA (Federal Aviation Association), which has certified the friction stir welding process as a joining process for aircraft, signifies a major breakthrough in the field of civil aviation. The Eclipse 500 business class jet is one example where FSW is used in the production of civil aircraft.

3) Aerospace R&D:

Many may believe that the traditional metals for airframe structures are being pushed aside by the recent advances in composites. Major breakthroughs have certainly been achieved in these alternative materials, but important ongoing R&D, in which FSW plays a vital role, continues. Several such R&D programs are funded by the European Commission. The great mechanical properties of FSW have always been thekey justification for adopting the process. Research, driven primarily by the aerospace industry, has shown that post-weld ageing treatments can even improve these properties. In one example, material welded according to T4 status (heat treatment), then aged to T6 status, regained 100% of the parent material’s ultimate tensile strength. The maturity of the technique has led to broader acceptance within companies such as EADS and Boeing, where FSW is now a qualified and certified process. Numerous applications are being considered, for both thin and thick sections of aluminum. Given its elimination of the need for fasteners, the future looks bright for ongoing development of FSW in the aerospace industry. A good manufacturing unit is the basis for research work. There is no use in creating excellent test values in the laboratory if the parameters and conditions cannot be transferred to production. Recognizing this, some of the leading European aerospace research units have purchased production-capable units for their R&D purposes.

B. Shipbuilding:

1) Application Advances:

Imagine a large catamaran that can be constructed from building blocks, just like a toy boat. All the pieces would fit perfectly together, ensuring mastery of dimensional accuracy and simplifying any necessary modifications. FSW represents a first step towards this type of construction approach in shipbuilding. The low heat input during joining assures less residual stress, resulting in precisely welded components that require minimal fit-up work. The resulting savings, both in time and money, are obvious. This offers users of FSW prefabricate a clear competitive advantage, although documented data on actual savings is seldom reported. However, the following gives an idea of how panel producers can benefit from the production of friction stir welded pre-fabricated panels:

- Industrial production featuring a high degree of completion.
- Extended level of repeatability, ensuring uniform level of performance, quality and narrow tolerances.
- The flexible production equipment and capacity permits customized solutions without compromising delivery reliability.

- The completed panel units have been inspected and approved by classification authorities such as DNV, RINA and Lloyd's Register.
- The panels' high degree of straightness ensures easy assembly at the yard, reducing the need for manual welding.
- Less supplementary work for the customer, such as floor leveling and preparation for floor coverings, offering major cost savings.

2) Parts and Components:

One of the most attractive features of friction stir welded products is that they are ready-touse. Normally, time consuming post-weld treatment such as grinding, polishing or straightening is not needed. With proper design, the elements are ready-to-use directly after welding. However, it is important to keep in mind that designs intended for MIG or TIG welding are not necessarily suitable for FSW. A filletjoint geometry, often applied with MIG, may not be suitable for FSW, for which T-joint geometry is much more suitable (Figure 3).

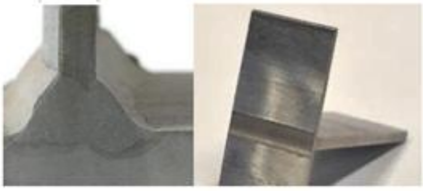

Figure 3: A Traditional fillet joint versus FSW T-joint geometry

When producing large components, like walls or floors, panel straightness is not the only issue to consider: the resulting reflections are also important. A lot of time is spent polishing and "making-up" surfaces that are architecturally visible. In FSW prefabricated panels, the reflections derive merely from the surface appearance of the aluminum plates and profiles in the as-delivered state, not from the reflections caused by welding heat input. One of the earliest examples of a product where FSW was extensively used is shown in Figure 4 – Catamaran made by Fjellstrand AS, using extruded and FS welded profiles, produced by Marine Aluminum AS.

Figure 4: The first vessel in world history made from FS – panels

C. Automotive Industry:

The automotive industry, featuring large manufacturing batches, six sigma requirements and challenging material combinations, from wrought and cast aluminum to magnesium alloys, provides a perfect field for FSW applications. All aluminum components in a car can be friction stir welded: bumper beams, rear spoilers, crash boxes, alloy wheels, air suspension systems, rear axles, drive shafts, intake manifolds, stiffening frames. In larger road transport vehicles, the scope for applications is even wider and easier to adapt – long, straight or curved welds: trailer beams, cabins and doors, spoilers, front walls, closed body or curtains, drop side walls, frames, rear doors and tail lifts, floors, sides, front and rear bumpers, chassis (Figure 5), fuel and air containers, tool boxes, wheels, engine parts, etc.

Figure 5: A car featuring countless application areas of FSW

Also, alloys which are difficult to join using conventional arcwelding processes can often be joined by FSW.

This offers numerous possibilities, as in the construction of military vehicles. Joining components of different thicknesses or dissimilar alloys is a very demanding task when utilizing arc or beam welding processes. With FSW, plates of different thicknesses can be joined securely with a high quality weld overlap joints are also possible with FSW, providing an alternative solution to resistance-spot-welded or seam-welded pieces.

Following is the list of the some of the main benefits of FSW process over convention welding process:

- Reduced weight – Estimated 40% vs. GMAW
- Improved joint efficiency (2x tensile strength of GMAW in 6000 series aluminum)
- Increased fatigue life (2x to 20x GMAW)
- No consumables (no filler wire or shielding gas required)
- Less distortion – Low heat input
- Improved energy efficiency
- Environmentally friendly – No fumes or spatter.

Cast aluminum components can successfully be friction stir welded or processed to improve the quality of the cast structure, or to join inserts in the piston. In Friction Stir Processing there is no “weld joint”, but the tool travels on the material and stirs it and results in fine-grained microstructure, and the porosity typical to castings will vanish. The amount of potential applications in the engine of any motor vehicle alone is incredible, not to mention the cast or forged components used in load-carrying applications. An example of imp roved product quality is shown in Figure 6.

Figure 6: A friction stir processed piston.

More and more aluminum is used in transport vehicles to lower “dead load” and increase payload. The ever increasing awareness of environmental issues has also placed pressure on weight reduction in many road applications.

D. Steel and Other High Temperature Materials:

Steels that are considered un-weldable can be joined with full penetration in a single pass. They are a bit more complicated than aluminum, as the phase transformations can be complex. Different metallurgical properties can be achieved by varying the process. When applied to an HTM alloy, the FSW process. will also require a liquid-cooled tool holder and the addition of a shielding gas (Ar) The weld quality of steels exposed to FSW is much the same as that of aluminum. Both involve a solid-state joining process that produces a fine grain microstructure and, because of the low heat input, the HAZ shows less degradation.

IV. ENVIRONMENTAL ASPECTS:

Friction Stir Welding offers numerous environmental advantages compared to other joining methods which are listed below:

Less Weld-Seam Preparation:

Butt, overlap and blind welds are the main weld applications for the FSW process. To prepare the right bead configuration, work pieces featuring greater wall thicknesses often require a special cutting or milling process.

Fewer Resources:

The FSW Process needs no shielding gas and therefore no gas supply or plant investment such as pressure tanks, pipe fittings and gas regulators, as long as it is applied to low melting temperature materials such as aluminum.

No Consumables:

Eliminating the need for their storage and transport inside the production area, and avoiding the need for their production elsewhere. Also, FSW unit means less investment in the workplace. No need to protect workers/users against UV or IR radiation. The FSW process generates no smoke and, unlike arc welding processes (especially with aluminum), an exhaust system is not necessary.

Energy Saving:

Generally, FSW demands less energy input to the weld than MIG and TIG, but more than laser welding. Total energy input depends on the size of the equipment being used and the thickness of the joint, depending on whether single-pass or multi pass welding is used. FSW is always single pass, offering the greatest energy savings at higher wall thicknesses.

Less Post-Treatment:

With most other welding processes, the weld requires weld and root reinforcement. In the latter case, this means grinding, with a negative impact on the workplace environment, as well as increased energy consumption and additional investment in equipment.

V. CONCLUSION:

Although it is only 26 years since FSW technology was invented at The Welding Institute (Cambridge, UK) in 1991, quite a few successful industrial applications of FSW have been demonstrated. The process has demonstrated its capabilities and been approved as a novel method for joining aluminum and other metals. FSW is opening up totally new areas of welding daily. The welding process improves existing structural properties and leaves the weld “cold.” In some cases, if proper care is taken, weld properties become equal to those of the base material. Anyone currently working with aluminum can use FSW. Although currently not widely used, it is within everyone’s reach and it promises the elimination of smoke and spatter typical of arc welding.

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