Effect of Welding Parameters and Tool Pin Profiles on the Microstructural and Mechanical Properties of Friction Stir Welded Joint: A Review

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Abstract— In the present world, the use of magnesium is done because of its high strength, light weight, better chemical properties and better recyclability. Here, research work has been carried out on magnesium alloy AS41A which has good creep resistance, high strength, better castability and heat resistance. In this research work, the review of the process Friction Stir Welding has been done. Few of the important considerations to be understood here are the temperature distribution and metal flow properties during the stirring process, process parameters and the tool pin profiles. Also, it has been studied and reviewed that threaded conical tool pin profile and hexagonal tool pin profile are the optimum tool pin profiles. Also, the rotational speed of 350 rotations per minute and 100 mm/minute are found to be optimum from the literature. The load applied is found to be 7.3-9.8 kN. Thus, the review of the literature done here will help in selecting the optimum tool pin profile and welding parameters to design the best weld in present research work.

Key words: FSW, Welding Parameters, TWI

I. Introduction

Friction Stir Welding (FSW) was invented by Wayne Thomas at The Welding Institute (TWI) Ltd in 1991. It would overcome the problems associated with traditional fusion welding techniques such as shrinkage, solidification cracking and porosity. FSW is a solid state process which produces welds of high quality in materials which are difficult to weld and is quickly becoming the process of choice for manufacturing light weight transport structures such as boats, trains and aero planes. Friction stir welding (FSW) is a joining process which produces no fumes; uses no filler material; is environmentally friendly and can join several metal alloys such as aluminum, copper, magnesium, zinc, steels, and titanium. FSW sometimes produces a weld that is stronger than the base material. FSW is a solid-state joining process, where metal is not melted. It uses a cylindrical shouldered tool with a profiled pin rotated and slowly plunged into the weld joint between two metal pieces of sheet or plate that are to be welded together . The parts must be clamped onto a backing bar in a manner that prevents the abutting joint faces from being forced apart or in any other way moved out of position. Frictional heat is generated between the tool and material which causes the work pieces to soften without reaching the melting point, and then mechanically intermixes the two pieces of metal at the place of the joint, then softened metal due to the elevated temperature is joined using mechanical pressure, applied by the tool. As melting does not occur and joining takes place below the melting temperature of the material, a high-quality weld is created.[1-5]

As stated by Marta Lipinska (et. all) [7], the mechanical properties of the FSW joints are also higher than compared to other joining techniques. For instance, a decrease in Yield Strength between an Al–Mg–Sc alloy base material and joint is 20% in plates joined by FSW, and 50% between Base Material and Tungsten Inert Gas Welding joint. Also detailed hardness examination revealed lower values in the Metal Inert Gas Welded specimens.

II. Principle of Operation

As stated by Nuno Mendes (et. all) [4], the traditional FSW process consists of the insertion of a rotational tool, formed by a pin and a shoulder, into the abutting surfaces of pieces to be welded and translated along the weld joint, as illustrated in Fig. 1.1. During the process, the pin located inside the weld joint generates heat through both friction and plastic deformation which softens the material and enables plastic flow, causing the mixture of materials. At the same time, the shoulder placed on the surface of the seam heats and drags material from the front to the back side of the tool, preventing leakage of material out of the welding joint and forming a smooth surface.

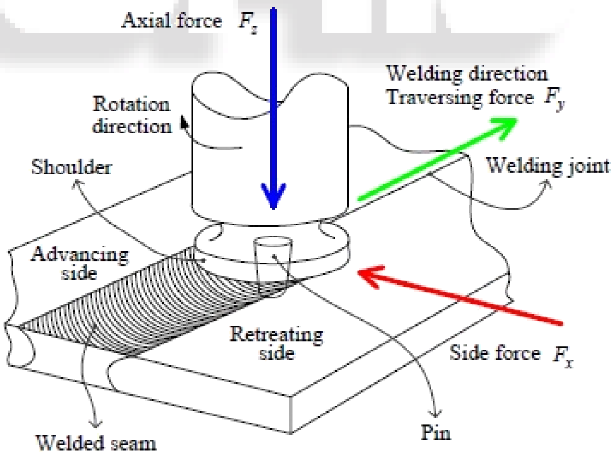

Fig. 1.1: FSW Principle[4]

During the welding process the FSW tool can be tilted backward (travel angle) and sideways (work angle), as shown in the Figure 1.2. While travel angles other than zero are mainly applied when a rotational shoulder tool is used, work angles other than zero are applied in dissimilar-thickness butt weld applications. This process is applied mainly to butt, lap and T-butt weld joints but other joint geometries can be welded.

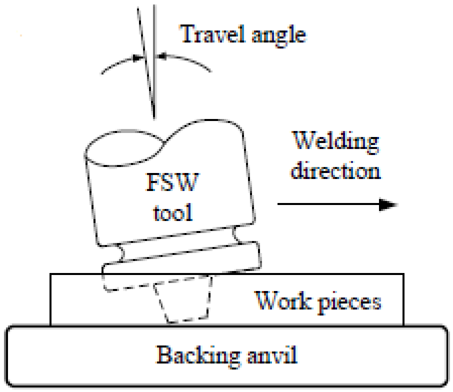

Fig. 1.2(a): Travel Tilt Angle Used In FSW[4]

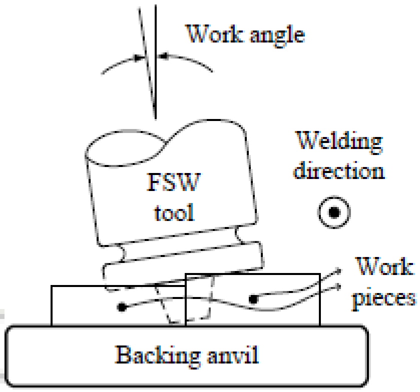

Fig. 1.2(B): Work Tilt Angle Used In FSW[4]

A. Load Applied

The load applied in order to hold the plates in the rigid position to continue the process of FSW is different for different materials. As Nuno Mendes (et. all) [4] stated that the load applied for the magnesium AZ31B and AZ61A is 3-5 kN. Also, Lina Yu (et. all) [17] stated that load applied for the material AS41A is 7.35-9.8 kN.

III. TEMPERATURE DISTRIBUTION AND METAL FLOW IN STIRING PROCESS

As stated by Rajiv S. Mishra (et. all) [18], the physical process of Friction Stir Welding can be understood by the experimental analysis. It is considered that the hotter welds are associated with the higher rotational speed and lower translational speed while the relatively cooler welds are associated with the lower rotational speed and higher translational speed. It is observed that the temperature distribution is asymmetric and the temperature is higher on the retreating side. This was correlated with tensile test failures which were occurring predominantly on the retreating side of the weld in the heat affected zone. The overheating of the welds at higher rotational speeds is avoided by the use of non-rotating shoulders. Also, the majority of heat generation occurred at the shoulder workpiece interface and very minute (2% to 20%) heat input was observed at the tool pin. It was also observed that maximum temperature was recorded at the top surface and at the core centre while the temperature was decreasing from top to bottom and from centre to periphery.

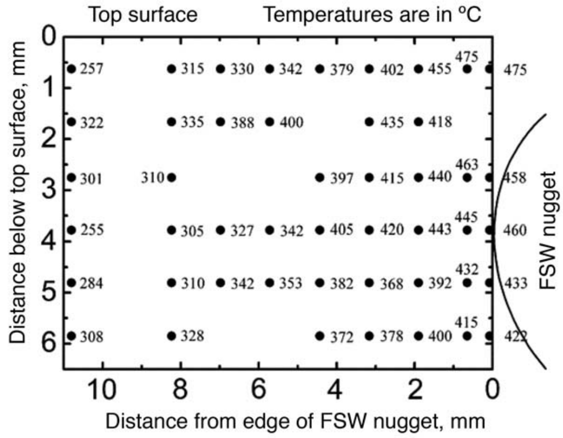

Fig. 2.1: Temperature Distribution Observed[18]

When the temperature of the weld metal reduces below a critical temperature, then slip conditions occur. It is observed that when slip conditions occur, then no onion rings pattern appears. The onion ring patterns are just to interpret the thermomechanical processes, although it has no concern with the quality of the weld.

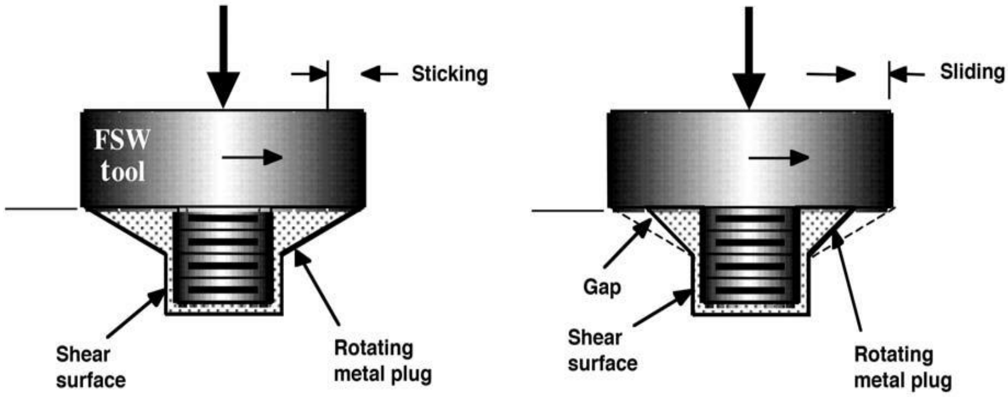

Fig. 2.2: Alternating (Stick Slip) Boundary Conditions At The Interface[18]

Using the different tracers for detecting the metal flow during the experiments, two models have been prepared which describe the metal flow according to the tool pin geometry and the process parameters. Those models are Nunes Kinematic Model and Arbegast Metal Working Model.

In Nunes Kinematic Model, three incompressible flow fields of the friction stir weld combine to form two flow currents. These three flow fields are rigid body rotation, uniform translation, and ring vortex. The respective flow currents resulted are observed on the advancing and the retreating side. It has straight through flow and maelstrom(whirlpool) flow. Also, interleaving of the two flow paths occur and stick-slip phenomenon is considered to be the reason for interleaving between the two flow paths.

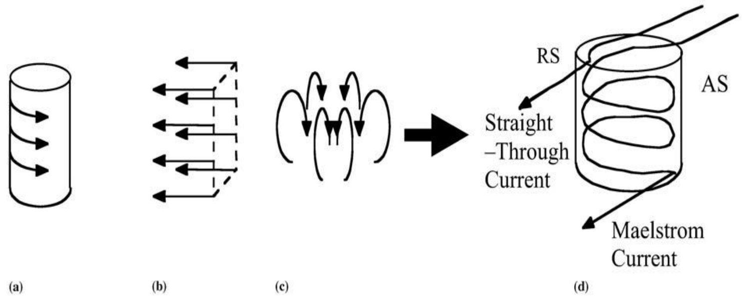

Fig. 2.3: Deconvolution Of Fsw Process Of Three Flow Fields Into Two Flow Currents (a) Rigid body motion (b) Uniform translation (c) Ring vortex (d) Two flow currents: Advancing side and Retreating side[18]

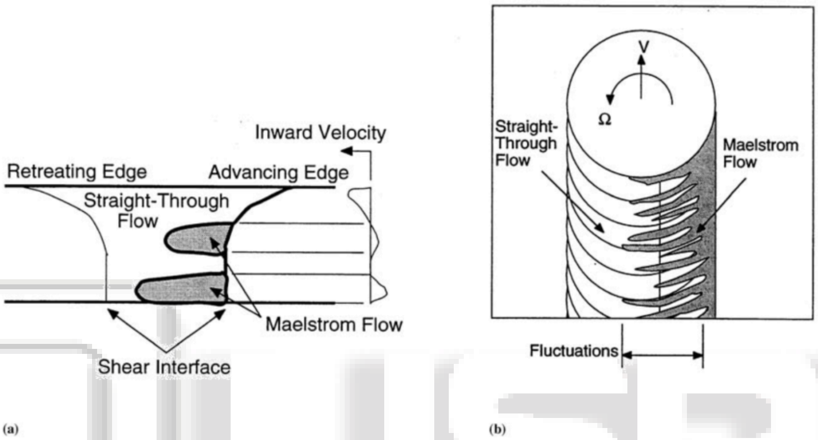

Fig. 2.4: (a) Side view of flow streams (b) Plan view of flow streams [18]

In the Arbegast metal working model, five zones are considered: preheat, initial deformation, extrusion, forging, and postweld cooldown. The rotating weld tool preheats the metal in advance, following which the rotating motion results in initial deformation zone. Here, the softened metal is forced upward into the shoulder and then into extrusion zone. Here, the metal in front is moved into the exiting wake of the weld inside the cavity formed by the pin moving forward. The interleaving in this model occurs between the upper and lower extrusion zones. Thus, the metals passes to the forging zone and then into the cooldown zone, where the cooling occurs thorugh passive or forced means.

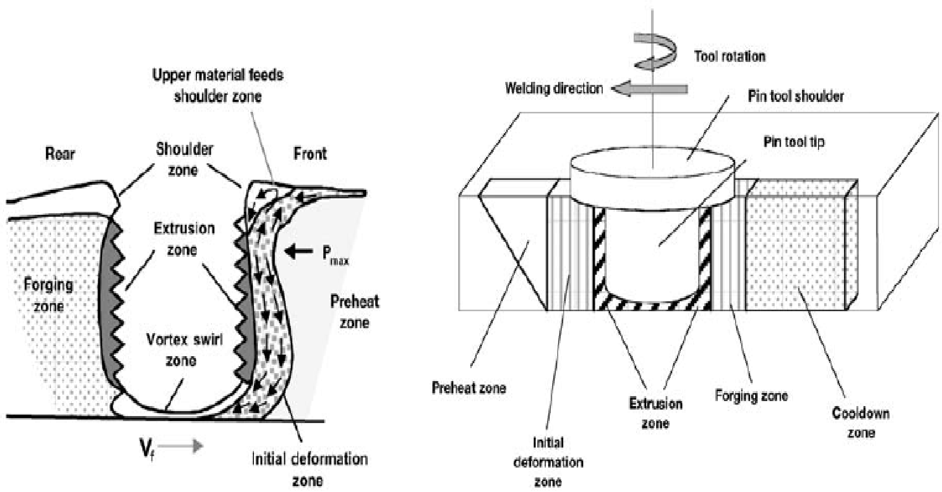

Fig. 2.5: Arbegast Metal Working Model[18]

A. *FSW Tool*

As stated by Y. N. Xhang(et. all) [9], the basic concept of FSW is simple. A rotating tool with a specially designed probe (pin) and shoulder is inserted into the abutting edges of the sheets or plates to be joined and traversed along the joint line. The material is softened by frictional heating, and the forging pressure from the shoulder reconsolidates the material behind the tool. Friction stir processing (FSP) is a variant of FSW that involves traversing of the friction stir tool through the material in the absence of a joint interface.

The friction stir welding tool consists of a pin and shoulder. The pin enters into the work piece creates frictional and deformational heating and softens the work piece material. The shoulder then comes in contact to the work piece which results in heating, expands the zone of softened material, and constrains the deformed material. Now, in order to produce welds of good quality the tool material is to be selected accordingly.

From the literature reviewed, G. Padmanaban (et. all) stated that the tool pin profiles which are threaded has better results[11]. Also, M.I. Costa (et. all) stated that the tool pin profiles with lower shoulder to pin diameter have better results[13].

Thus, the tool pin profiles with threads and greater conical angles have the more benefits.

IV. Rotational and Transverse Speeds

As stated by Fei Xhang (et. all) [12] , samples made of a super high strength aluminum alloy with high Zn content were friction stir welded with rotation rates of 350–950 rotations per minute and welding speeds of 50–150 mm/minute. The effect of welding parameters on the microstructure and mechanical properties was investigated. It was observed that the grain size of the nugget zones decreased with the increasing welding speed or the decreasing tool rotation rate. The greatest ultimate tensile strength of 484 MPa and largest elongation of 9.4 were obtained at 350 rotations per minute and 100 mm/minute and 350 rotations per minute and 50 mm/minute, respectively. The ultimate tensile strength and elongation deteriorated drastically when rotation rate increased from 350 to 950 rotations per minute at a constant welding speed of 100 mm/minute.

Also, Lina Yu(et. all) [17] had studied the effects of tool pin profiles and rotational and transverse speeds on the design of the weld. The rotational speed was kept between 1000-1500 rotations per minute and the transverse speed was kept between 250-1000 mm/minute. It was observed that the tensile strength in the stir zone was better than the base material in all the rotational and transverse speed variations. With increase in the transverse speed, the diameter of the intermetallic compound decreases.

The mechanical properties were tested by universal testing machine and microstructural properties were tested by electron microscopes.

As studied by A. Dorbane (et. all) [4], 1400 rotations per minute rotational speed and 500 mm/minute translational speed resulted in the optimum joint quality, based on the analysis of the weld integrity and microstructure. Both Mg-rich and Al-rich sides of the stir zone revealed grain refinement, with the Stir Zone grain sizes reducing to 2.43±0.87 μm and 0.94±0.24 μm on the Mg and Al sides, respectively. Room temperature joint efficiency of the welds prepared in the current study were between 18 – 55% while at elevated temperature the joint efficiency were between 58 – 79% for the different parameters. The micro hardness showed a lower hardness values (55 – 65HV) in the magnesium base material and higher values (120 – 135HV) in aluminum base material, with a transition in the stir zone and some peaks due to the Inter Metallic Compounds in the SZ. Here, HV is Vickers Pyramid Hardness.

V. Conclusion

This review of literature for the FSW process has been done in order to understand the importance of process parameters, tool pin profiles, temperature distribution, metal flow, and the load applied. This shows that the changes in these considerations helps to design the best weld in terms of mechanical and microstructural properties. Also, it has been observed that the optimum rotational speed is 350 rotations per minute and optimum translational speed is 100 mm/minute. Also, the optimum tool pin profile is the with threads, with greater number of sides(hexagon) and with low shoulder to pin diameter.

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