

A Review on Friction Stir Welding of Dissimilar Metals

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ABSTRACT

Effective welding techniques were developed as a result of the need for stronger and lighter constructions. Among these, friction stir welding is relatively new technology and has been extensively investigated in recent decades. In this method, welding is accomplished by the friction between a revolving tool and the materials to be fused. Friction stir welding and processing (FSW) is a new and innovative joining technique that does not require melting, casting or solidification of the weld zone. It is a versatile, eco-friendly and energy efficient method that can join high-strength aerospace aluminum alloys and other metals that are hard to weld by conventional method. This research work aims at the FSW process in dissimilar metals, such as i) optimizing the welding process parameters, , traverse speed, tool material, design, tool rotation speed and tilted angle (ii) mechanical properties of joints.

Keywords—FSW, weld speed, tilt angle, TRS.

I. INTRODUCTION

Friction stir welding (FSW) is a novel welding technique that does not require melting, casting or solidification of the weld zone, it was first introduced by The Welding Institute (TWI), Cambridge, UK, in 1991[1]. It is a cost-effective and efficient method for joining materials that are difficult to weld by conventional methods such as aluminum alloys and magnesium, etc. As welding occurs solely through the forging effect and no material melting occurs, the mechanical qualities of the materials to be bonded are not diminished during friction stir welding. It also avoids the problems of defects like gas bubbles or cracks that can happen in traditional welding methods that involve melting the metal. Moreover, it's a green process because it doesn't emit any harmful gases or smoke that come from heating and vaporizing the metal. The types of defects that can occur in FSW are different from those in traditional welding methods. Some common defects in FSW are onion rings, tunneling, porosity, lack of consolidation, excessive flash, kissing bonds and root flaws. These defects can be avoided by adjusting the welding parameters according to the material properties, such as thermal conductivity and mechanical strength. The quality and performance of FSW depend on several parameters, such as shape and material of the tool, the welding speed, the travel speed of the tool, tilt angle, axial load, shoulder diameter and the material properties of the work-piece[2]. Fig.1 shows the FSW process with different parameters. The friction stir welding procedure helps to form a weld by converting mechanical energy to thermal energy without the need for heat from outside sources. This approach can also be used to weld incompatible and difficult-to-weld materials. Here how FSW works:

A. Frictional Heat Generation: FSW is a technique that joins two pieces of material by using a rotating tool that creates heat and pressure without melting or consuming the material. The tool has a special shape that creates heat and pressure between the material pieces, softening and mixing them.

B. Plasticization: The material does not melt from the heat generated by friction. Instead, it becomes softer and more pliable, allowing it to be shaped by the tool.

C. Mechanical Stirring: As the tool rotates, it presses and mixes the softened material. The material flows around the tool and joins together along the joint line. This creates a strong bond in the solid state.

D. Weld Formation: The tool moves along the joint line, creating a weld bead that connects the two material pieces. The material does not melt at any point during this process.

FSW is performed by two different joint types, such as the lap joint and the butt joint. It does not require shielding gases and welding materials with minimal distortion and no porosity. FSW is crucial for the purpose of welding lightweight metal alloys like magnesium, copper and aluminum alloys which aid in automotive, aerospace, and marine applications. Tool is crucial to the processes involved in connecting materials. [3][4][5]. The FSW involves heating the two dissimilar materials via friction, and as a result, residual stresses are created. This is important because the linear coefficient thermal expansion of the welded work piece has a significant impact on the welding's fatigue behavior [6].

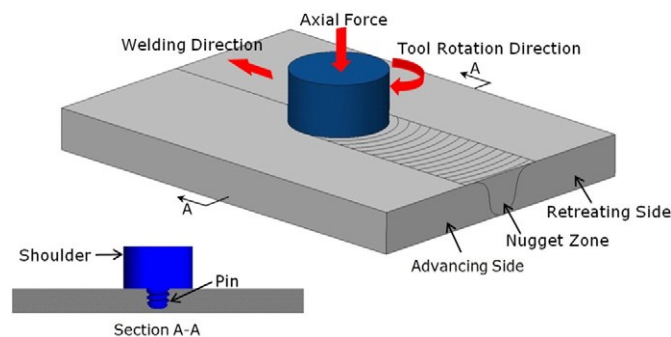


Fig.1. A schematic diagram of FSW with parameters [7]

II LITERATURE ON FSW IMPORTANT FACTORS

E. Tool design, tool material and tool tilt angle

The current study must pay special attention to the tool material, quality, and tool pin profiles. Typically, the selection of tool materials is determined by the work piece's hardness.

Won-Bae Lee et al.[8] Welded titanium and stainless steel employing the friction stir welding technique with composite carbide as a filler material. They demonstrated the significance of this tool material's excellent wear resistance and persistent toughness. They discovered by contrasting the strengths of two different tools—one composed of Ti6Al-4 V alloy and the other of WC-Co alloy.

P.S. Gowthaman et al.[9] used tap screw- threaded pin tool made up of AISI H13 and studied the mechanical properties and corrosion properties of AA2024 /AA7075 dissimilar metal welded joints with the varying TRS from 1000 to 1400rpm, welding speed 20mm/min and 40mm/min and maintain 4KN axial force kept constant. The results shows that the tensile strength, yield strength increased when weld speed decreased from 20 mm/min and 1000rpm. No corrosion was found for the welds in the period of 48hrs.

Amir Ghasvand et al.[10] examined the impact of plunge depth, tool offset, and tilted angle on AA6061-T6 and AA7075-T6 aluminum alloy joints. In ABAQUS, the FSW process was numerically simulated using the coupled Eulerian-Lagrangian (CEL) technique. A central composite design (CCD) based on response surface methodology (RSM) was used to assess and design the tests. It was discovered that increasing the plunge depth resulted in a significant rise in the maximum process temperature due to increased contact surfaces and frictional interaction between the tool and work piece.

S. Delijaicov et.al [11]examined tri-dissimilar junctions using titanium alloy Ti6Al4V with aluminum alloys 2024-T4 and 7475-T6. A butt weld was produced by positioning the Al alloys at the top of the welding process. The titanium alloy was layered over the Al alloy to form a lap welding at the bottom of the weld. Rotation, weld speed, and tilt parameters were changed. The tool's measurements were 20 mm for shoulder diameter and 80 mm for length, and it was manufactured of H13 steel. Residual stress and micro hardness on the aluminum side exhibit a high correlation; reduced micro hardness due to a high residual stress value. On the Ti side, residual stress is temperature dependent; The high temperature resulted in a low stress value.

Mohammed M. Hasan et al. [12] studied the FSW of AA7075-AA6061 alloys using the RSM with central composite design in relation to the rotational and axial speed, tool tilt angle, and tool shape. They used five concave-shouldered tools with various probe profiles. They discovered that a sound weld with a high weld strength, a wider nugget area, and superior surface quality can be produced using a welding tool with a threaded truncated cone pin and single flat.

Sadeesh P et al. [13]welded the AA2024 and AA6061 by friction stir welding with different Rotation speed (710,1000rpm), weld speed 28,40 mm/min and maintained tilting angle 2° using different tool geometries (cylindrical pin , stepped pin, squared pin, cylindrical threaded pin and tapered pin).From the results UTS 209 MPa ,194 MPa and micro hardnes 105.15 HV,135.6 HV were recorded for cylindrical threaded pin and squared pin profiles respectively. For a squared pin, the joint efficiency is 87%, while for a cylindrical threaded pin, it is 80%.

Uttam Acharya et al. [14] studied the effect of force and torque produced during friction stir welding to evaluating and controlling the final weld's quality. AA6092/ 17.5SiCp-T6 composite plates with a 6 mm thickness are welded using a taper pin tool, at 1000, 1500, and 2000 rpm tool rotational speeds, with a 2 mm/sec fixed traverse speed and a tilt angle of 2°. Tensile strength was used as a measure to examine the impact of particle size in the weld zone. A greater strength and elongation was attained by the welded sample with the finer-sized particles.

P. Xue et al. [15] welded 1060 aluminium and pure copper with Rotation speed 600rpm), Traverse speed 50(mm/min) by using large taper pin tool geometry. The tensile shear force increased to 2680 N, when the Al plate at advancing side and the joints failed in the Al side's Hazardous Area in the lap Al-Cu joint.

Omar S. Salih et al. [16] understanding of how the mechanical and metallurgical characteristics of AMC are affected by FSW with different tool rotation speed (1500, 1800 and 2100 rpm) and traverse speed (25,50 and 100 mm/min) to generate AA6092/SiC/17.5p-T6 AMC joints. The tool was made of AISI H13 with a 6° flat edge, featureless concave shoulder that measured 16 mm in diameter. It also had an M6 threaded cylindrical pin with a domed end that was 2.8 mm long. The joint that was welded at a rotation speed of 1500 rpm and 100 mm/min traverse speed had the best tensile characteristics out of all the weld joints that were examined and microstructural characteristics are controlled by FSW settings, the best joint performance was obtained when a tool rotation speed of 1500 rpm and a traverse speed of 25, 50 mm/min were combined.

F.Friction stir welding parameters

The input process parameters influence the process control, form, size, and mechanical properties of the weld. In FSW, the process variables are axial force, welding speed(WS), tool rotation speed(TRS), rake angle, and tool geometry. These variables determine the frictional heat generated and the weld quality.

K. Kalaiselvan , N. Murugan [17] studied the impact of FSW parameters(tool rotation speed , Traverse speed ,axial force) on the tensile strength of composite joints made of AA6061-B₄C The current study concentrated on how FSW factors affected the Al-B₄C composite joints' tensile strength. From the findings, the joint that was produced with a 12% reinforcement, an axial force of 10 kN, a weld speed of 1.3 mm/s, and TRS of 1000 r/min exhibited a greater tensile strength in comparison to the other joints.

Mohammadreza Aali [18] examined the impact of spindle rotation on the qualities of the weld using a novel form of titanium alloy, Ti4Al2V, and discovered that the weld's hardness increased as rotational speed increased and also further discovered that in order to prevent certain flaws like pitting, the tool's transverse and rotational speeds should be properly coordinated.

J. Zapata et al.[19] studied the impact of WS, residual stresses and rotational speed on the AA2024-T3 and AA6061-T6 dissimilar friction stir welds. From the results authors found the magnitude of the longitudinal residual stresses decreases as the rotating speed increases and when compared to the impact of rotational speed, the welding speed had little or no impact on residual stress.

J.F. Guo et al. [20] used FSW to join AA7075/ AA6061 alloys under various process settings Rotation speed (1200rpm), Traverse speed 2,3,5mm/min and tilt angle of 2.5° by using threaded conical probe geometry. In the weld, the AA6061 and AA7075 alloys have both shown a little decrease in micro hardness when compared to their respective base metals. The greatest UTS recorded in condition D5 was 245 MPa, which is 32% greater than what is needed according to the AWS standard for FSW.

Madhav Raturi et al.[21] examined the impact of process variables such as feed rate, TRS and pin geometry as well as the use of preheating, on dissimilar FSW between Al6061-T6 and Al 7075-T651 alloys. When appropriate tool pin profiles are employed, the TRS and feed rate are observed to be the most significant factors.

Sheng Zhao et al.[22] Studied the effect of geometry of the tool on AA6061 FSW to TRIP steel with different Rotation speed (1800,1200rpm), Traverse speed 60,120(mm/min) by using large and small taper pin tool.

Y.J. Kwon et al [23] performed dissimilar FSW between 2mm thickness of Mg and aluminium alloy plates and maintained tool rotation speed from 800 to 1600 rpm and at a constant weld speed of 300 mm/min. Defect-free welds were obtained at tool rotation rates of 1000, 1200, and 1400 rpm, and the surface morphology of the welds got smoother as the tool rotation speed was raised. The maximum UTS was achieved 132 MPa at 1000 rpm.

G. Material of the welded samples

Yongxian Huang et al. [24] welded the ultra-thin 6061-T4 sheet was successfully via micro friction stir welding (μ FSW). Tensile strength was first increased with increasing welding speed and then dropped at higher welding speeds than 500mm/min. When the triflat pin was used, the maximum values of the FSW joint's tensile strength and elongation were 220.3 MPa and 11.7%.

Shalom Akhai et.al [25] goal of this work is to use response surface methodology (RSM) to analyse the strength of the weld results of Al6061 and 8011 composites that were created by FSW. The RSM technique was used, taking into account the following process parameters: axial force (AF) of 5, 6, and 7 KN; WS of 75, 100, and 125 mm/min; and rotating speed (RS) of 1,200, 1300, and 1400 rpm. This study found that, during run no. 8, with parameters of RS 1400 RPM, WS 100 mm/min, and AF 7 KN, the best welding strength of AA6061 and 8011 aluminum amalgams produced was 127 MPa.

T Vuherer et al.[26] studied the fatigue and mechanical characteristics of the alloyed AA-2024 aluminium alloy, which is welded using the FSW technique. The welding regime B-II with the middle welding speed of 116

mm/min corresponds to the best mechanical characteristics (ultimate strength, yield stress). According to the experimental results of the fatigue testing, the welding regime B-II (welding speed 116 mm/min) for both the LCF and HCF region corresponds to the highest fatigue strength.

Pradeep Johnson , N. Murugan [27] studied 3mm-thick AISI 321 stainless steel sheets were joined using FSW. When compared to the base metal, the weld joints that were created at 500 and 700 rpm had substantially higher strengths, measuring roughly 88% and 93%. Consequently, the weld stir zones' hardness was considerably higher than the base metal's hardness. FSW samples showed superior hardness, better yield strength, and consequently increased tensile strength and decreased ductility to base metal.

Table .1 Welding parameters ,mechanical properties of FSW dissimilar joints

| S.no | Material | Tool Rotation Speed (rpm) | Weld Speed (mm/min) | Axial Force (KN) | Tilt angle/offset (°/mm) | Tool Geometry | Tool Material | UTS (MPa) | YS (MPa) | Hardness (HV) |
|------------------------------|--|---------------------------|---------------------|------------------|--------------------------|--|-----------------------|--|----------|---|
| Suryakanta Sahu [28] | magnesium (AZ31B) alloy and dual-phase steel (DP600) | 800 and 1600 | 50,100, and 150 | | 2° | Cylindrical Pin | tungsten carbide tool | | | |
| S. Jayaprakash Retacted [29] | aluminium alloys 5083 and 7068 | 800, 1000, 1200, 1400 | 30,40, 50,60 | 3, 4, 5, and 6 | | Taper cylindrical tool, Triangular tool, straight cylindrical tool | High speed tool (HSS) | Taper 276MPa, Triangular 286 MPa, Straight 275 MPa | | Taped 75HV, Triangular 86 HV, Straight 82HV |
| Neves Manuel [30] | AA2017-T4, AA6082-T6, and AA5083-H111 | 500 | 60,120,230 | | | threaded pin, pyramidal pin, progressive threaded pin, progressive pyramidal pin | H13 steel | 562TP-230 304 MPa | | |
| Janusz Torzewski [31] | AA7020/AA5083 | (400, 800, and 1200 | 100, 200, 300 | 17 kN | 2° | threaded conical pin | --- | 303 MPa, 800 rpm and 200 mm/min | 157 | |
| Yongseng Meng [32] | AZ31B magnesium alloy and Q235 low carbon steel | 650, 750, 850, and 950 | 55, 65, 75, and 85 | | 3° | truncated cone-shaped stirring pin with threads | W-Re cemented carbide | 189.4 MPa 850rpm ,75mm/min | | |

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|---------------------------------------|---|----------------------|---------------|------------|-----------|--|---|--|--|-------------------------------|
| Ban glo ng Fu[33] | 6061-T6 aluminu m alloy to AZ31B magnesi um alloy | 600– 800 | 30–60 | | 0.3 mm | frustum- shaped right- hand threaded pin | H13 tool steel | 175 MPa was obtaine d at 700 rpm and 50 mm/min | | |
| G. Mr udu la[3 4] | Al6061- T6 and 6082-T6 | 900 and 1200 | 30 | 5 | 2° | tapered cylindrical and threaded tool | H13, D2 and SS316 | 178.75 N/mm ² when H13 tool used | 149.33 N/mm ² when SS-316 is used | 11.8 when D2 is used |
| K Pal ani [2] | 8011- H24 and 6061-T6 aluminu m alloys | 1200 | 50 | - | - | hexagonal pin profile , addition of SiC and Al ₂ O ₃ nano particles | D2 grade steel | 98.58 % SiC nanopar ticles,94 .28 with Al ₂ O ₃ | | |
| Nav neet Kh ann a [35] | AA 6061-T6 and AA 8011-h14 | 1070 | 50 | 2°/1m m | | tapered pin tool | high- carbon high- chromi um tool steel | 77.88 MPa | | 21.96% |
| S. Bal am uru gan [36] | AA6061- T6 and AA5052- H32 | 800, 950, 1100 | 30, 60, 80 | - | - | square, cylinder, triangle | H13 tool steel | 181 MPa Square tool with 1100 rpm and 60 mm/min | - | - |

IV.CONCLUSIONS

From the several research articles the following conclusions are drawn

- Friction stir welding is the ideal method to utilize when combining various aluminum alloys that are long in length and where a high-quality weld is required.
- Friction stir welding is used to try to weld materials with high melting points. Some of these materials, such as magnesium, titanium and steel have been successfully welded using the friction stir welding procedure.
- Furthermore, the amount of heat generation and strength of FSW joints are significantly influenced by welding parameters such tool rotation speed, weld speed and axial force.
- Rotation speed has the biggest impact on joint efficiency, while traverse speed and axial force have varying effects on the tensile strength of AMC joints.
- Different tools are employed depending on the melting temperature of the work pieces to be welded.
- The life of the tool and joint efficiency may be increased by using innovative tool designs with frustum shapes, or self-optimized shapes, surface heat treatment procedures, and pin surface coating with a substance that is compatible with the substrate.

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