A Review on Tool materials, geometries and welding variables used for Friction Stir Welding

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ABSTRACT

Friction Stir welding Process is an Innovative solid state joining process which has been employed in different applications like Automotive, Rail, Aerospace, Marine industries for joining the various Aluminum, Magnesium, Zinc & Copper alloys. The various distinct parameters which plays a vital role while joining the alloys with help of Friction Stir Welding process are, selection of tool material, selection of tool geometries, selection of process parameters like tool rotational speed, tool traverse speed, axial force, weld angle, etc. Also these factors plays a major role to obtain a good quality welds. Many researchers have experimented on FSW and reported about the relations between welding properties as well as the various process conditions. The objective of this paper is to carry out critical literature review of tool materials, geometries & welding variables used for friction stir welding. This review is helpful for upcoming researcher to optimize process parameters in friction stir welding

Keywords: *Friction Stir Welding, Process parameters, FSW Tools, Advance Mfg. Process,*

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1. INTRODUCTION:

Wayne Thomas and his colleagues developed friction stir welding In 1991 and they suggest that joint efficiency obtained by the process is 90% acceptable and defect free and doesn't melt the workpiece as in case of fusion welding processes. After this newly discovered method of FSW, industries started implementing this technique for manufacturing of aluminium components. Thus, its eco-friendly and energy efficient behavior establish FSW as a green technology. [1] In Friction welding two pieces are joined by frictional heat, which is generated when a moving workpiece and a fixed component are thrust together to obtain the required heat and temperature for welding. Friction Stir Welding can be considered as a multi input multi output process, because the weld quality is directly influenced by the welding parameters during the welding process. The major problem faced by the manufacturer is to control of these input parameters during the weld for getting good welding joints with the required weld quality with minimal residual stresses and distortion [2]. The Friction Stir Welding is often a preferred joining technique for aluminum alloys as well as for other difficult-to-weld metals such as metal-matrix composites, magnesium alloys, and titanium alloys etc. The technique is now widely used in many industrial sectors such as transportation, marine, aerospace, railway[3].

2. FRICTION STIR WELDING PROCESS:

FSW is a solid-phase joining process in which a virtually wear free, rotating welding pin is traversed along the weld path between the work pieces to be joined. The rotation of the tool in the firmly clamped parts as shown in fig. 1 is to be joined to generate frictional heat, which causes the material to plasticize. The subsequent advance motion, combined with continuing rotation of the tool, mixes the plasticized material in the joining area, resulting in a high-quality weld seam. This process of the tool traversing along the weld line in a plasticized tubular shaft of metal results in solid state deformation involving dynamic re-crystallization of the base material.

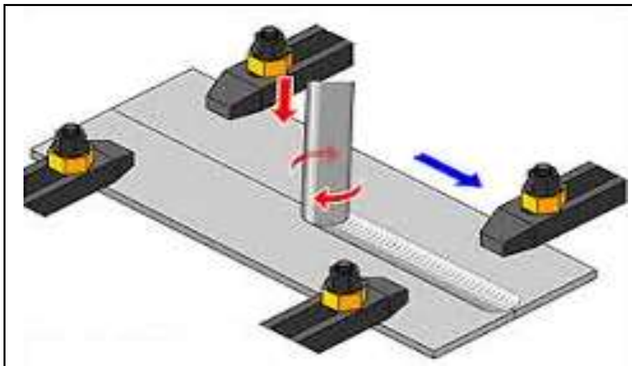

Fig.1 Clamping of Aluminum plates

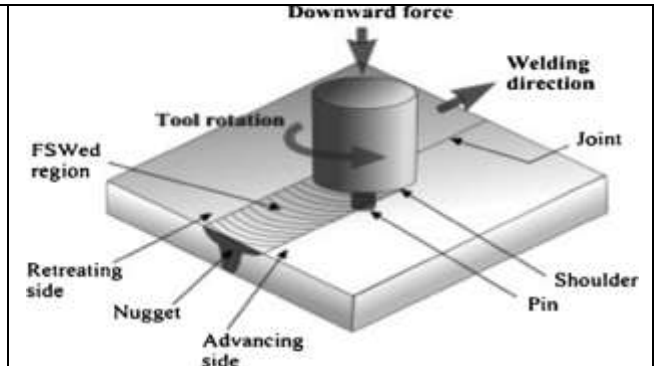

Fig.2 Friction stir processing [3]

The principle of operation of friction stir processing is shown in figure 2. which is suitable in the welding operation of non-ferrous metals with low melting points, such as aluminum and brass. The process can also be used for copper, titanium, magnesium, zinc and lead. As because of melting does not occur and joining takes place below the melting temperature of the material, a good-quality weld is created. This characteristic eventually reduces the ill effects of high heat input, including distortion, and eliminating the welding defects during solidification. The process was limited to low melting temperature materials because of tools could not hold up to the stress of stirring higher temperature materials such as high-strength materials, steels and its alloys.

3. MICROSTRUCTURE OF THE FSW JOINTS:

In order to facilitate a complete understanding of heat generation and material flow mechanics of FSW welding process, Fig. 3 and Fig. 4 shows the micrographs of different microstructure zones with advancing and retreating sides. The microstructure of the weld nugget is characterized by a dynamically recrystallized region of the base material due to the conjoint influence of heavy plastic deformation and locally high temperature[7,9].

The phenomenon of recrystallization in FSW weld nuggets is reported to be a continuous-dynamic-recrystallization. TMAZ is a region that undergoes plastic deformation at the "local" level coupled with a temperature rise that is lower than that of the weld nugget. HAZ is the region in which the material is affected by the heat generated during the process [5,9]. However, the material flow behavior is predominantly influenced by the FSW tool profiles, FSW tool dimensions and FSW process parameters[9].

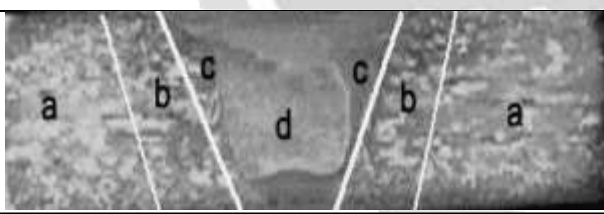

Fig. 3 – Different regions of FSW joint: (a) unaffected base metal, (b) heat affected zone (HAZ), (c) thermo-mechanically affected zone (TMAZ) and (d) friction stir processed (FSP) zone[4]

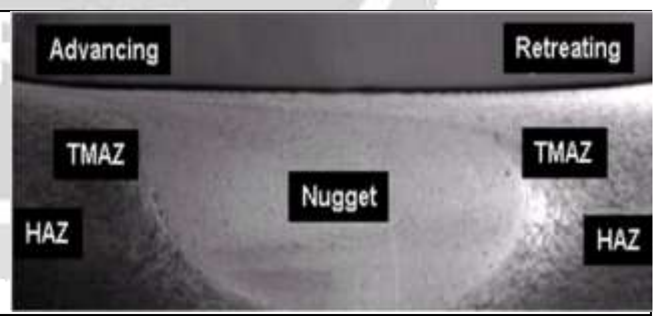

Fig.4 micrograph showing various micro-structural zones[9]

4. PROCESS PARAMETERS IN FSW:

There are various optimization studies for process parameters have been conducted by various researchers for the friction stir welding process. The process parameters are highly depends on the type of tool pin profile preferred for the stir welding. Fig. 6 shows the various types of tools normally experimented for the process are plain cylindrical, conical, threaded, hexagonal, triangular, square, whorl, MX triflute, flared triflute, skew, re-stir etc.

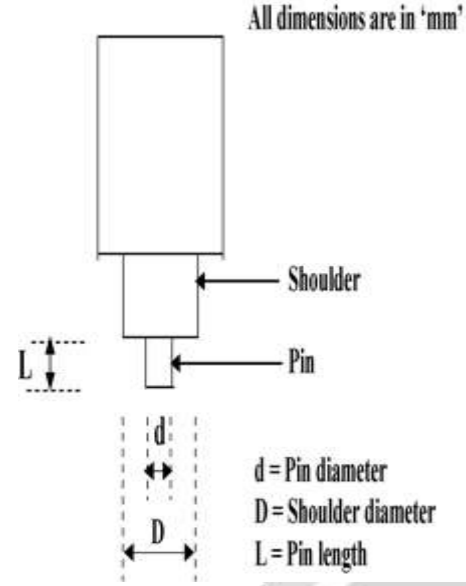

Fig. 5 – FSW tool dimensions [5]

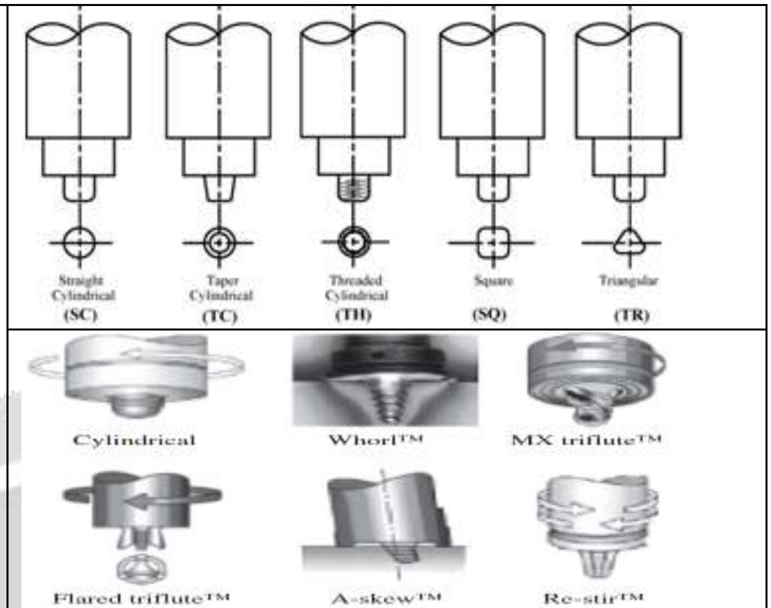

Fig. 6- Various Tool Pin Profiles [3]

The important geometric parameter required in the FSW tool design is the diameter of shoulder, which is currently designed according to trial and error methods. The various effects of shoulder diameter on thermal cycles, peak temperatures, power requirements, and torque during FSW processes are very complex and remain to characterization procedure could be used to optimize the FSW process. The material which is used for preparation of the tool pin profile for nonferrous metals are HSS or mild steel with special heat treatment. Tool material developments in this field provides advancement in design as well as material selection for respective applications.

5. REVIEW OF STUDIES ON TOOL MATERIALS, GEOMETRIES AND WELDING VARIABLES USED FOR FSW:

In these section different tools, tool shape and size, tool materials, operating parameters and the metals that were successfully joined together using FSW are presented. The various efforts and investigations of different researchers on different materials similar or dissimilar with respect to the FSW tool and its profile are compared for their respective findings. The table 1 presents a broader idea of material and profile of the FSW tool required for joining different metals for varied applications.

Table 1: Tool materials, geometries and welding variables used for FSW of several Aluminum and magnesium alloys

Tool material	Tool shape and size	Workpiece material	Operating parameters	Remarks	Ref. no.
H13 steel	SS: flat with scroll; SD: 10 mm; PL: 0–1.6 mm	6111-T4 Al alloy, 0.9 mm thick	2000 rev/min; dwell time: 2.5/S, plunge rate: 2.5 mm/S, FSSW	Obtained better quality with pinless tool	10
-	PS: Triflute, Trivex	7075-T7351, 6.35 mm	394 and 457 rev/min, 300–540 mm/min	Weld UTS: 470–488 MPa	15
Tool steel;	PS: threaded	7075-T7351, 6.35 mm,	190–457 rev/min, 0.3–1.4 mm/rev	Identified surface scaling and voiding	21
Tool steel	SS: concave, SD: 15 mm, PS: SC, SCT, triangular; PL: 4.7, 6 mm	Al alloys, 5 mm	600–1500 rev/min, 25–1000 mm/min 3° tilt	Peak joint efficiencies: 70–100%	17
H13 steel	SD: 10 mm, PD: 4 mm,	AZ31 Mg, 1.5 mm thick	1000–3000 rev/min, dwell	-	16

	PL: 1.8 mm, PS: SCT, 3F with M4 threads		time: 1, 4/S plunge rate:0–10mm/S FSSW		
H13 Steel	SD: 10–20 mm, Flat, PD: 3–8 mm; PL: 4.2 mm, PS: frustum and SC	7020-T6 Al alloy, 4 mm	1400 rev/min, 80 mm/min	Peak joint efficiency: 92%	23
H13 steel	SD: 25.4 mm, PD: 5.2–7.6 mm, PL: 1.8–7.1 mm	6061-T6 Al, 9.5 mm and 12.7 mm	650 rev/min, 150 or 200 mm/min, 3° tilt	-	13
H13 steel, 46–48 HRC	SD: 10 mm, PD: 4 mm; PL: 1.8 mm, PS: SCT, and threaded and unthreaded 3F	AZ31 Mg, 1.5 mm	1000–3000 rev/min, dwell time: 1/S plunge rate: 2.5 mm/S FSSW	Welds with 3F/threaded superior to those with SCT	18
-	SS: concave, SD: 26 mm, PD: 5.6 mm, PL: 5.9 mm, PS: SCT	6061-T6Al, 6.3 mm	286–1150 rev/min, 30–210 mm/min	-	22
H13 steel	SS: concave, convex, flat, SD: 12 mm, PD: 5 mm, PL: 1.6 mm	5754 Al, 1.32 mm	1500 rev/min, dwell time: 2/S; plunge rate: 20 mm/min, FSSW	-	25
-	PD: 3.1 mm, PL: 1.65 mm, PS: SC, LHT, RHT	AZ31B-H24 Mg alloy, 2 mm	1000–2000 rev/min, 300–1800 mm/min	Joint efficiencies: 74–83%	20
Tool steel	PD: 6 mm	A319 and A413 Al alloy, 6 mm	1000 rev/min 120 mm/min	No property degradation in weld metal	26
1.MS. 2.SS. 3.Armour steel, 4.HCS 5. HSS	SD: 15, 18, 21 mm, PS: SC, TC, Tri. & Sq. PL: 5.7 mm, PD: 6 mm	AZ31B Mg alloy, 6 mm	1600 rev/min, 40 mm/min, 0° tilt	Joint efficiencies: 48.8–96.7%	24
-	SS: scroll, cavity, Fillet, PD: 1.7 mm; PS: SC, PL: 1.2 mm	6082-T6 Al, 1.5 mm	1810 rev/min, 460 mm/min 2° tilt	Joint efficiencies: 76%	19
H13 steel	SD: 19 mm, PL: 2–3.5 mm, PD: 6.35 mm	AZ31B-H24 Mg alloy, 2 mm	1200 mm/min, 500–2000 rev/min	Joint efficiencies: up to 62%	14
High carbon steel	SS: concave, SD: 13 mm, PS: SC, TC3F, PL: 3.19 mm, PD: 5 mm	7020-T6 Al, 4 mm	300–1620 rev/min 100–900 mm/min 2.5° tilt	-	12

Note: SS:- Shoulder Surface shape, SD:- Shoulder Diameter; PD:- Pin Diameter; PL:- Pin Length; PS:- Pin Shape; SC:- Straight Circular; SCT:- Straight Circular Threaded; TC3F:- Tapered Circular with 3 Flats; UTS:- Ultimate Tensile Strength; FSSW:- Friction Stir Spot Welding.

6. THE CRITICAL WELDING PARAMETERS:

The various welding process parameters which are generally considered in friction Stir Welding are as follows:

7.1 Tool tilt and plunge depth : It is defined as depth of the lowest point of the shoulder below the surface of the welding plate and plunging the shoulder below the plate surface increases the pressure below the tool and helps ensure adequate forging of the material at the rear of the tool [6]. Tilting the tool by 2 to 4 degrees, such that the rear face of the tool is lower than the front face, will assist this forging process. It will gives the necessary downward force hence tool fully penetrates the weld addressing defects such as pin rubbing on the backing plate surface or a significant under-match of the weld thickness [7].

7.2 Tool rotation and traverse speeds : These two parameters have more importance and must be chosen with care to ensure a successful and efficient welding cycle [7]. Increasing the rotation speed or decreasing the traverse speed will result in a hotter weld also for good weld quality, and material surrounding the tool should be hot enough to enable the extensive plastic flow required and minimize the forces acting on the tool leading to tool breakage. On the other hand excessively high heat input may be harm the final properties of the weld joint.[6]

7.3 Welding forces : To prevent tool fracture and to minimize excessive wear and tear on the tool and associated machinery, the welding cycle is to be modified by finding the best combination of welding parameters. The different forces will act on the tool during welding, a downward force to maintain the position of the tool, the traverse force acts parallel to the tool motion, and torque is required to rotate the tool.[6,11]

7.4 Flow of material : Mode of material flow through extrusion chamber and frozen pin technique will lead to better forging of material. The above discussed process parameters plays a vital role in friction stir welding process [11]

7. CONCLUSIONS

This review of studies on FSW shows that there are number of research conducted on similar and dissimilar Al alloys, Cu, Mg, steel, titanium. From this review it is clear that material movement in the region of tool rotation is important to understand the optimization of FSW process parameters and design of tool geometry. Therefore, it is required to develop suitable tool designs with more robust FSW models of material flow for its better optimization. Shape and material of FSW tool are important factors that change the welding and metallurgical properties of joining metals. The selection of FSW tool material is also a important concern that may be required to address by comparative studies on steel, titanium, and their composites for joining different metals using FSW process.

The review also suggest that lot of work has been carried out with different FSW tools like Cylindrical, Concave Cylindrical Threaded, Cylindrical Taper, Straight Square, Tapered Square, Straight Hexagon, Straight Octagon, Tapered Octagon, threaded, without threaded, Trivex, Trapezoidal, Taper Threaded, Threaded Conical etc. with variety of independent parameters like Tool rotational speed, feed rate or welding rate, axial force, Tilt Angle, Dwell Time, Clamping Force, Plunge depth for the want of different dependent parameters like Tensile strength, Ultimate Tensile Strength, % of Elongation, Shear Tensile, Fracture Load, Hardness, Grain Size etc.

This literature review outlines that the tool wear is generally not considered as a serious issue in FSW of Al alloys. But for high melting point materials like steel and titanium and wearable materials such as metal matrix composites using FSW tool wear becomes a important issue that needs to be addressed. But, a very few researchers have reported on the FSW tool wear. This review suggest that tool designs for FSW with help of computational models and algorithms may provide suboptimal or near optimal design parameters of FSW tools.

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