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Effect of Tool Pin Profile on Mechanical Characteristics of Friction Stir Welded Al Alloys: A Critical Review

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Abstract - *Friction stir welding technique is a solid state joining method in which the wok piece that is being welded does not recast or melts. It utilizes a rotating non-consumable tool to produce frictional heat and permanent deformation at the welding area, thereby influencing the creation of a welding joint while the work piece material is in the solid state. The main merits of FSW are non-existence of melt-related defects, low distortion, and high strength of joint. However, the alloys of Al are mainly utilized in aerospace, automobile and industry because of their good corrosion resistance and mechanical characteristics. But, the quality and strength of FSW joints is mainly influenced by tool pin profile. Hence, this review paper reviews the effect of various tool pin profiles on the mechanical characteristics of FSW aluminum alloys.*

Keywords-*Friction stir welding (FSW), Tool pin profile, Merits, Applications.*

1. Introduction to Friction welding

Welding is a procedure of fabricating two or more comparable or divergent work piece with the use of pressure/heat. Filler materials likewise might possibly be utilized. Keeping in mind the end goal to fabricate two or more bits of metal through any welding technique, the most vital necessity is heat. Pressure might likewise be utilized however in numerous methods, is not crucial. There are mainly two sorts of welding technique namely fusion welding (liquid state welding) and solid state welding. In the fusion welding technique, there is no need of pressure, but a filler metal is constantly utilized. On the other hand, in solid state welding technique, pressure is used alongside heat and there is no need of filler materials. However, Friction welding is a type of solid state welding methodology, which depends on the establishment of molten bridge, twisting and on the stream of metal. [1]

The fundamental rule of friction welding includes the concurrent use of relative motion &pressure by and large in a rotational style, b/w the parts to be welded. Thus, the heat generated due to friction increases the interface temp. of the materials to their melting temperature, while at the same time the applied pressure which is ⊥cular to the plane of movement works to expel the heated work material along with oxide films and any soil from the interface, taking the parts to be welded into intimate touch. [2].

1.1 Types of Friction welding

1.1.1 Friction Stir Welding

FSW is a solid-state joining technique initially invented and empirically confirms by Wayne Thomas along with a group of his friends at the Welding Institute UK & patented by the TWI in 1991. Thereafter, this welding process is utilized to join high strength metal alloys that were not possible or ambitious to connect with conventional process. This method was originally used for Al alloys, but later it was observed suitable for welding a several materials. In FSW technique, a non-consumable revolving tool, comprising of a shoulder with pin, is pushed down into the joint axis where the frictional temperature is adequate to increase the temp. of the work piece to the span where it is permanently deformed as depicted in fig. 1.

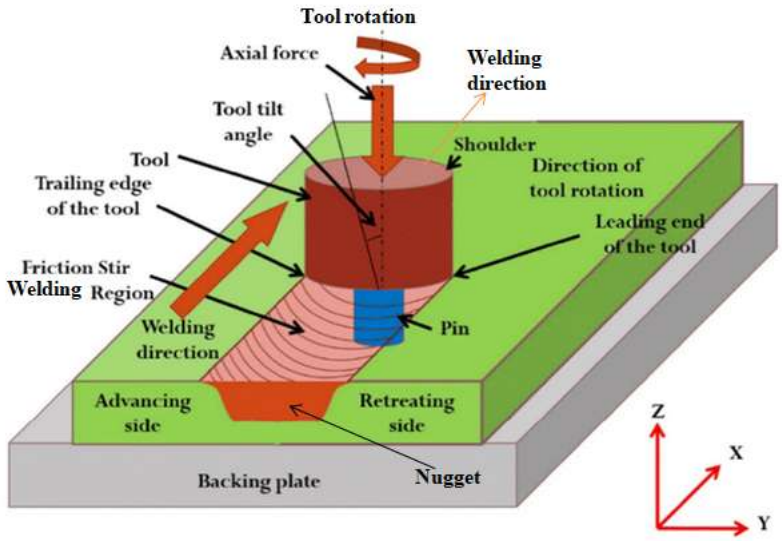

Fig. 1.1 Schematic drawing of FSW [3]

1.1.2 Rotary Friction Welding (RFW)

In RFW, friction welds are built by holding a revolving part in touch with a non- revolving part while under a steady or growing axial load. The interface achieves the proper welding temperature, at which point rotation is stopped and weld finished. It is used for welding of numerous carbon steel vehicle axles and sub-axles. The procedure is likewise utilized to weld suspension rods, drive shafts, steering columns, gear box forks and engine valves, etc in which the capacity to join unique materials. [4]

1.1.3 Linear Friction Welding (LFW)

In LFW the relative motion is linear across the interface, instead of rotary and is mainly used to weld blades on to discs in the aerospace industry. Now a day, low cost LFW machines are being developed for the welding of brake plates, wheel rims and engine components [3].

1.1.4. Merits of Friction stir welding over conventional welding

1. It can be comfortably automated on simple milling machines hence it need less training and setup cost.
2. FSW can be operated in horizontal and vertical since there is no weld pool.
3. Good weld presentation.
4. Weld controlling can ensure hundred percent weld quality.
5. Friction welding produces a hundred percent x-sectional weld area.
6. Far Superior weld integrity Compared to MIG welding
7. Limited operator training requires.
8. Friction welding is a solid state method and does not suffer from inclusion and gas porosity.
9. Friction welding required no consumable therefore becomes more cost effective overtime.
10. No post machining is needed for friction welded components in many cases.

11. Dissimilar work materials can be welded with no alloying of the material.

1.1.5 Applications of FSW

1. FSW is used in automotive field.
2. Shipbuilding and marine Industries (Helicopter landing platforms, superstructures & hulls)
3. Aerospace Industry (wing structures for space vehicles and fuel container etc.)
4. Railway Industry. (Tankers, High-speed trains and side & roof panels etc)
5. Personal computers. (i.e. Apple's iMac computer body)
6. Land Transportation
7. Robotics

8 Other Industry Sectors.

Friction stir welding is yet to be utilized for hard alloys like titanium and steels alloys due to its attractive properties [5-9]. Earlier, FSW tool have been designed usually by trial & error method [10]. But now a day FSW tool is designed by focusing on tool geometry[10,11]. Presently, tools with different profiles such as cylindrical/ tapered pins using or without using threads have been constructed and mainly used [10]. In addition, more complicated pin shapes, likea convex external surface or triangular cross-section have also been studied [11]. However, the effects of distinct tool pin profiles have been investigated. Elangovan and Bala-subramanian [12] investigated the influences of tool shoulder dimession and exhibited that only a tool along with a precise shoulder dia. resulted in the maximum strength of the welds during FSW of AA-6061 alloy. However, the experimental study did not give any instructions for the tool design geometry. A lot of investigations had been done by distinct researchers to enhance the strength and quality of FSW joints by changing the tool pin shapes and tool shoulder dia.. The present review paper investigates the effect of different pin profiles on the mechanical characteristics of Al alloys, joined with FSW.

2. Welding Parameters

The main Friction Stir Friction Welding process variables, which affect the microstructure &joint strength, are discussed below:

(i). Tool rotation & traverse speeds (rpm):The speed at which the spindle of the machine rotates or the speed at which the tool rotates over the work piece is termed as tool rotation speed. Whereas, the speed at which the rotating tool moves in forward direction is known as tool transverse speed. Its unit is millimeter per minute.

(ii). Tool Geometry*:* The Tool Geometry (dimensions and the shape) of the tool performs a vital role in deciding the quality of the weld. The main tool parameters include Tool Pin Profile/Shape, Diameter Tool Shoulder and Tool Pin, Length of Tool Pin, Tool tilt and Depth of Plunge.

(iii) Tool design: The welding speed and quality of the weld is mainly relying upon tool design. Hence, it is important that the material of tool should be adequately tough, strong, having less thermal conductivity, oxidation resistance and hard wearing, at the welding temp.

(iv)Welding forces*:* Following forces act on the tool during welding [13].

(a) Downward Push: is needed to maintain the tool location at /below the material surface.

(b) Lateral force: act in ⊥cular to the tool traverse direction.

(c) Transverse force: act parallel to the direction of tool motion and is +ve in the transverse direction.

(d) Torque: is needed to revolve the welding tool. The value of torque depends upon and friction coefficient and downward force.

***(v) Heat flow and generation*:** Normally, for all welding technique, it is necessary to enhance the travel speed, temperature around the tool and decrease the heat input. Since, it will improve productivity of the welding and possibly decrease the consequence of welding on the mechanical characteristics of the weld.

(vi)Axial Load: The load at which the tool is plunged into the work material is termed as axial load. It will decide the quantity of heat generated at the weld joint. Too much load can generate hotter welds and fewer loads can produce colder welds which can affect the joint properties.
Distinct tool pins profiles can be used, such as straight cylindrical, threaded cylindrical, tapered cylindrical, square & triangular were the tool pin profiles used on AA2219 aluminum alloy [14]. Different tool profile such as Tapered Square, Paddle Shape, Tapered cylinder with Grooves, Tapered Hexagon& Straight Cylinder were the tool pin profiles used on AA2024-T6 and AA5083-H321 Al alloys [15].

3. Influence of tool pin profile

FSW tool pin profile shows an important role in the material flow & in turn maintains the speed of welding of the friction stir welding process. Normally the tool pin has threaded cylindrical plain, flat surfaces and frustum tapered profile. Various researchers have used pin profiles of different shapes.

Fujii, H., et al. (2006a) analysed the consequence of tool shape on the microstructures and mechanical characteristics of the welded Al plates. From the result it was observed that for 1050H24 whose resistance to deformation is very less. In addition, a columnar tool generates weld with the sufficient best mechanical characteristics, since this welding tool shape produce no defect. On the other side, 6061-T6 whose resistance to deformation is comparatively low and shape of tool have no effect on mechanical characteristics and microstructures of the weld joints [16]. **Barcellona, A.,et al**. [17] has considered an industrial alloy, namely AA2024- T4 &AA7075-T6, because such alloys had experienced precipitation hardening operations planned to enhance the material mechanical properties. During the experimentation the authors have found that Al alloys are usually very ambitious material to be thermally evaluated. **Ren S.R., et al. [**18] investigated the consequence of weld parameters on the tensile property and fracture role of Al Mg-Si alloy welded with FSW. The authors have observed that the traverse speed provide to be a dominant factor in calculating the tensile characteristics& fracture mode of the weld joint. **Elangovan K.,et al** [19] showed that the AA2219 Al alloy have better tensile characteristics irrespective of FSW pin profile. **Patil H.S., Soman, et al.** [20] reported that the joint made with taper screw thread pin have better tensile strength in comparison to tri-flute pin profile, regardless of welding speed in AA6082-O Al materials .**Suresha, C. et al.** [21] concluded that in FSW of AA7075-T6 work piece material the conical pin provides superior properties than square pin profile. **Galvao, et al.** [22] investigated that the tool shoulder configuration are highly influenced the material flow rate and formation of intermetallic compounds in dissimilar Cu-Al materials. The authors suggested concave shoulder pin profile for different Cu-Al FSW system. **Akinlabi, et al.** [23] experimentally prove that the diameter of shoulder effect the material flow and heat generation of different C11000-AA5754 friction stir welding system that further affects characteristics and the formation of intermetallic compounds. **Kumar, A. and Raju, L. S.** [24] concluded that the square pin profile compared with triangular, pentagonal and hexagonal gives superior mechanical characteristics because in FSW of pure Cu material having dynamic to static ratio of 1.56 resulting in more pulsating effect. **Aval H J. et al.**[25] concluded that the square frustum of conical pin profiles have uniform material blending as compare to conical with two groves in FSW of dissimilar AA5052-H32 & HSLA steel material. P.Shashindar, P.Laxmi Naga Prasad, D. Srinivas concluded that the silicon carbide particles added welded joints are superior compared to aluminum oxide added welded joint of aluminum alloy 6061.

Kumar, et. al [26] had examined the effect of distinct pin profiles on the mechanical characteristics of dissimilar Al alloys 2014 & 6082, welded with FSW. During this process a non-consumable FSW tools of high C, high Cr steel were utilized. The tools utilized to weld the joints had three different tool pin profiles namely hexagonal, square, and pentagon) as shown in Fig. 2.

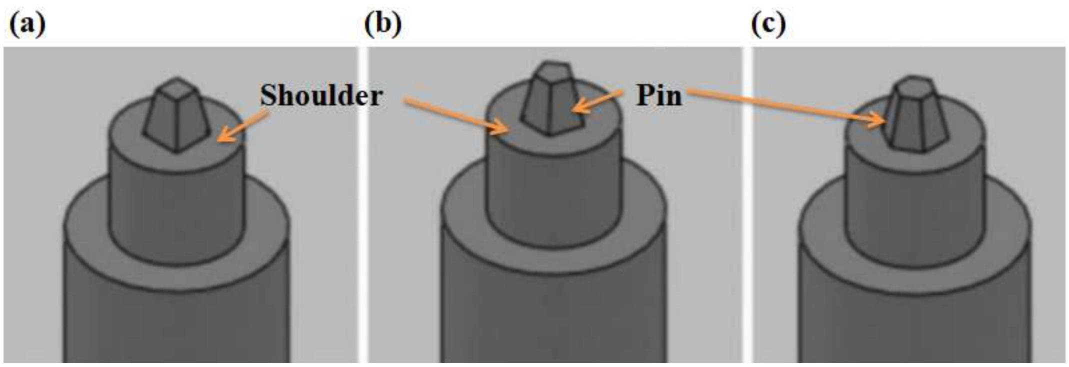

Fig. 2: Different tool profiles: (a) square pin profile (b) Pentagonal pin profile (c) Hexagonal pin profile [20]

The ultimate tensile strength (σ_{ut}) of the samples was determined by using universal testing m/c of 25 KN load. Among all the tool pin profile the joint welded by pentagonal pin profile have better tensile characteristics, whereas the joint fabricated by using square pin profile have poor tensile characteristics. The different tool geometry mainly used to find the optimal probe shapes are shown in Fig. 3.

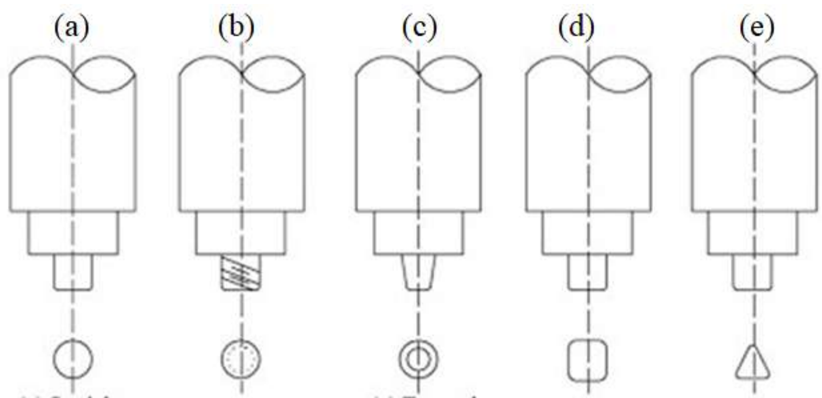

Fig. 3: Different tool geometries: (a).Straight - cylindrical (b). Threaded -cylindrical (c).Tapered – cylindrical.(d).Square (e). Triangular

IV) Conclusions

From the above review which studies the consequence of tool pin profile on weld strength and quality of FSW joints the following conclusions are drawn:

1. Tool pin profile determines the direction for the flow of plasticized material starting from the leading edge to the trailing edge of the FSW revolving tool.

2. The tool pin profile having flat faces generates pulsating stirring action and produce excellent plastic flow of material.

3. The cylindrical, tapered and threaded pin profiled tools not generate any such pulsating action.

4. The joints made by threaded tool profile have higher ductility in comparison with the joints made by using cylindrical tool profile.
5. Moreover it has been found that a straight pin profiled tool has large contact area in comparison with tapered tool profile. This results in uniform flow of material from advancing to retreating side.

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