Review on Friction Stir Welding Tool Parameters

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Abstract

Friction Stir Welding (FSW) is a green novel technology of joining similar or dissimilar materials. During the FSW welding process, non-consumable rotating tool moves on meting surfaces to form a joint. Metals join due to the frictional heat between tool and workpiece. This heat exactly generates between features tool shoulder and upper portion of the workpiece and its intensity depends on parameters like tool geometry, welding parameters, joint type, tool tilt angle, material of tool, etc. This review paper presents the study of the effect of welding parameters like tool shoulder geometry, tool pin probe geometry, diameter of both pin and shoulder, eccentricity of the pin probe on welding of any material. So, finally the optimized tool shoulder and pin diameter has also been identified.

Keywords: Friction Stir Welding, FSW Tool, Welding parameters, Tool rotation speed, Tool traverse rate

I. Introduction

First attempt of friction stir welding (also known as solid state welding technology) was carried out at The Welding Institute (TWI), UK in 1991 by Wayne Thomas. FSW is combination of extruding and forging process. Since last 20 years, FSW has got more attention in high technology production industry like marine, automobile, aerospace, rail etc. Due to energy efficient and green behaviour, FSW is also considered as a non-conventional environment friendly technology. During the welding process, non-consumable cylindrical tool rotates along the meting surface of metal which to be joint. This non-consumable tool consists mainly two parts: (a) Pin probe and (b) Shoulder. At initial stage, tool pin plunge at the junction of mating surface till the shoulder surface not touch the upper surface of the workpiece to generate the initial heat. Out of the total generated heat during the welding process, 70 % heat is produced by the shoulder geometry and rest is by tool pin probe geometry. During the process, material melt up to plastic state only. So, FSW gives so many benefits over other conventional welding processes.

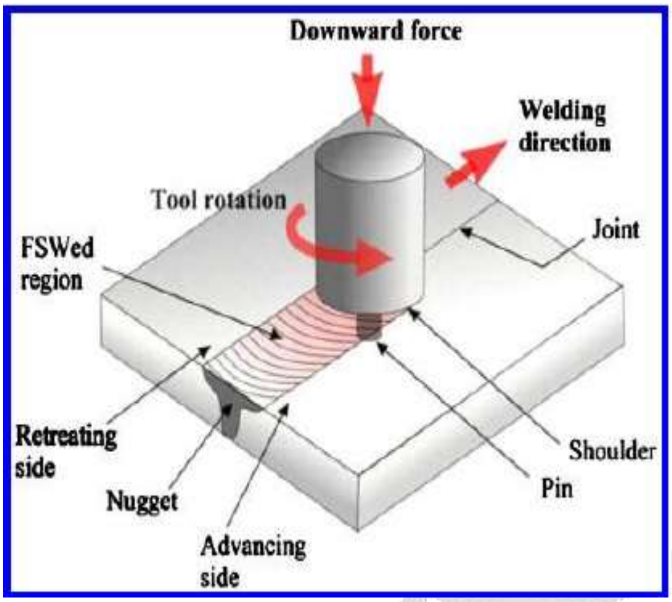

Figure 1: Principal of Friction Stir Welding [1]

Figure 1 shows the schematic diagram of the FSW process. Here, tool moves on the material from the retracting side to advancing side. The nature of this material flow is totally depending up on tool shoulder and pin diameter and geometry of the FSW tool.

II. FSW Tool Parameters

Each and every independent parameter significantly affect the quality of the welding. These parameters which influence the weld zone quality like welding parameters, machine parameters, tool parameters etc. This review paper mainly focuses on identifying the effect of tool parameters like tool geometry, tool dimensions, tool tilt angle etc. on weld quality through review of literature. These tool parameters significantly affect the heat generation rate, material flow, mechanical properties of the weld zone.

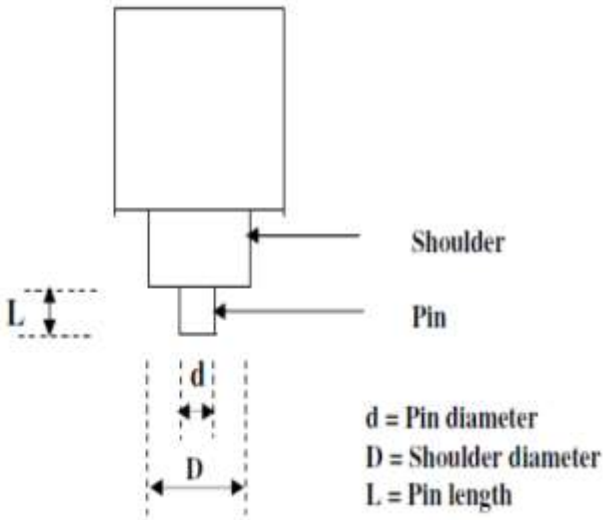

Figure 2: FSW Tool [2]

Figure 2 shows the design of the FSW tool. Here, D represents the shoulder diameter and d represents the diameter of the pin probe. If D/d ration should be maintaining equal to 3 then the sound quality of the weld can achieve. [3] There are basically two types of FSW tool available: 1) Conventional tool 2) Retractable FSW tool. In conventional tool, shoulder and pin are made in one single piece. There creates the problem of key hole generation at the end of welding process and leads to wastage of material. To overcome this problem NASA has developed retractable pin tool. In retractable pin tool, at the end stage of the welding, pin retract, and the shoulder fill whole the key hole which developed by pin.

III. Investigational Reviews on FSW Tool Parameters

With the advent of the Friction Stir Welding process, so many studies have done on FSW tool to get the sound quality of the weld. This paper encapsulates the information provided by researchers so far on the effect of different FSW tool parameters on welding quality.

Lima et al. (2003) [4] and Oosterkamp et al. (2004) [5] showed that at the best surface of the FSW district, a metal movement happens because of the activity of the rotating tool shoulder. Movement of material close to the highest point of the FSW area, around the upper 33%, affected by the shoulder instead of the pin geometry. Tool shoulder diameter has a direct relation to the heat generation rate. As tool shoulder dimeter increases heat generation rate increase due to the high friction between shoulder surface and workpiece upper surface After crossing a specific range of tool shoulder diameter tensile strength of the weld zone also decreases. Because as shoulder dimeter increase as TMAZ and HAZ zone increase. K. Colligan et al. (2008) [6] explored the material stream conduct of aluminium composites FSW and suggested that two impacts oversee the production of the metal stream in the friction stir processing zone. To start with the expulsion procedure, where the functional powers and the movement of the tool probe, the metal after it has experienced the plastic misshaping. The second is due to the revolution of the pin that serves as the main impetus for the stream. Because of high estimations of viscosity, the stirring impact is considerably more unmistakable in correlation to the expulsion driven stream. Elangovan and Balasubramanian (2008) [7] found the relation between the different pin profile and shoulder diameters. They use straight cylindrical, threaded cylindrical, tapered cylindrical, square and triangle pin profile with 2.5, 3.0 and 3.5 D/d ration to weld the 6061-aluminium alloy. They said that if the D/d ratio maintained equal to 3 then the chances of getting sound defect free weld increase.

Research identified that out of five tools investigated in study, square pin tool gives the best result in welding. J. Mohammadi et al (2014) [8] applied the FSW weld of aluminium and magnesium by using two different tool pin geometry. They found intermixing on the upper surface of the stirred zone with an increment of tool rotation speed. Giuseppe Casalino et al. (2014) [9] analysed the result of number of experiments with shoulder coated carbide tool to improve the quality of the weld on 5754H11 aluminium alloy. Changes in the hardness of friction stir welded zone of aluminium then base metal have been reported by the researchers. It has been concluded that shoulder size influences the microstructural grain and hardness profile of the weld zone. Further, it has been pointed out that with the increase in shoulder size, the contact area between shoulder and upper surface of the workpiece also increases. Heat generation rate become high resulted in change in properties of the weld material.

Yahya Bozkurt et al. (2018) [10] also checked the influence of the coating on tool on properties of FSW welded AA2124 aluminium alloy material. The work has been carried out with uncoated simple tool, CrN coated tool and AlTiN coated tool as shown in figure 3. The wear of the uncoated tool has been observed in this study. The mixing of burs of tool wear partials in weld zone created the defective weld and resultant in decrement in strength. Also, it has been pointed out that coated tool gives the best properties of the welded joint as compare to uncoated tool. Akeem Yusuf Adesina et al. (2017) [11] observed the effect of Cathodic arc PVD AlCrN coating on tool. They noticed 10 times lesser the wear has been noticed as compare to uncoated tool. Also, they got the higher recrystallization and grain growth of weld zone in comparison with uncoated tool.

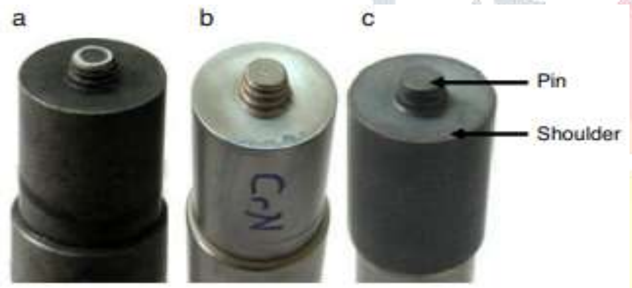

Figure 3: FSW coated tool [10]

The FSW weld of two dissimilar metal copper and aluminium has been taken into consideration by Kush P.Mehta et al. (2016) [12]. In this investigation it has been identified that as pin diameter increased from certain limit then cold condition was observed at weld zone persists due to the less are covered by the shoulder which results in surface tunnel defect. Marathe Shalin et al. (2016) [13] studied welding of AA 6061 plate by using three different tools having different pin geometry as shown in figure 4. Through this experiment it has been conclude that tapered pin tool gives a good UTS compared to another two-round geometry due to increase in contact area. Also, they point out that tool shape is the most important parameter which significantly affects` the UTS of the weld zone.

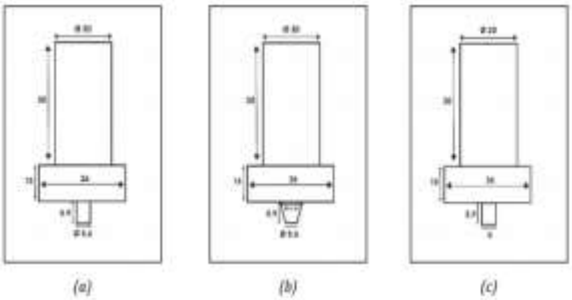

Figure 4: (a) Cylindrical pin tool; (b) Tapered pin tool; (c) Square pin tool [13]

S. Shashi Kumar and N. Muruga (2017) [14] analysed the effect of two tools which are made from two different materials. Based on the result, it has been identified that tool degrades due to the wear during the welding process. The weld quality also gets affected the weld quality due to the circulation of tool wear debris in weld zone. Kalmeshwar Ullegaddia et al (2017) [15] showed that concave tool shoulder requires more axial force as compare to other shoulder geometries, because during the welding by concave shoulder plasticized material stores in to the cavity of the shoulder and the tool works as a reservoir of the plasticized material. This soften material try to push the tool away from the original position. L.H. Shah et al. (2018) [16] observed the influence of tool pin eccentricity on FSW welded AA6061 aluminium alloy. They concluded that eccentricity improve the metal flow of the weld nugget zone and it improves softening of soft region due to offset setup of tool. It has also been highlighted that by using eccentricity in tool, the strength and elongation of workpiece has not been trading off. V. Shokri et al. (2017) [17] also pointed out that tool offset is key parameter at low tool rotation speed. If it is maintained between 0 to 0.5 mm then, it gives good mechanical properties of the welding zone. Researchers mentioned that with the high tool offset, the frictional heat generation is high and this in turn requires higher heat input. As the pin eccentricity of the tool increase up to a certain value then it gives coarse grain structure said by Yuqing et al (2014) [18].

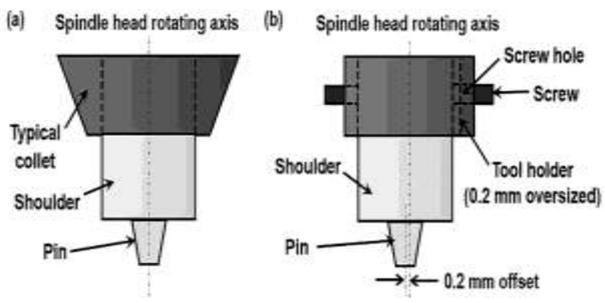

Figure 5: eccentricity setup [16]

I. Galvão et al. (2013) [19] pointed out that flat shoulder required lesser spindle torque then other geometries of shoulder during the welding of thin copper sheet by three different shoulder geometries as shown in figure 6. Flat shoulder givesx1 defective or low strength weld compare to other. As shoulder diameter and rotational pin diameter increase, the flow velocity of material will also increase as said by S. Ugender et al (2014) [20]. Increment in shoulder diameter improve the flowability of material near the weldment surface whereas increment in pin diameter improve the flowability of material inside the weldment surface. M. Dehghani et al. (2013) [21] showed that while performing the FSW process with higher tool shoulder diameter and higher tool rotation speed then there is a chance of reduction in thickness of the weld zone. K. Kumar and Satish V. Kailas (2008) [22] studied the role of FSW tool on material flow and weld formation. They observed two type of material flow: one by pin driven flow and second one shoulder driven flow.

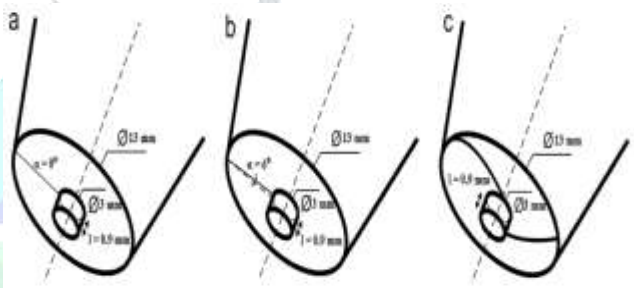

Figure 6: (a) Flat (b) conical concave and (c) scrolled shouldered tools [19]

Pin move the material layer by layer whereas shoulder move material in bulk. Because of these two-different material flow, one can observe the onion ring formation on the appearance of the weld zone. Luis Trueba et al. (2014) [23] developed six different raised and recessed shoulder features as shown in figure 7. They found that raised features gave good potential in producing high quality of the weld. The tools used in this experiment made from by additive manufacturing technology. So, it gives good wear resistant property to tool.

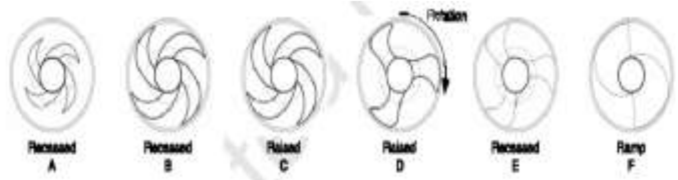

Figure 7: Schematic diagram of the six-unique tool shoulder geometry [23]

If the shoulder diameter increased from the 18 mm then it gave defective weld said by K. Ramanjaneyulu et al. (2013) [24]. Perumalla Janaki Ramulu et al (2012) [25] also pointed out that at this range of the shoulder diameter improve the formability of the friction stir welded blank. Also, shoulder diameter plays main role for the microstructure softening due to frictional heating. [26] So, Tool geometry and dimensions strongly influence the surface appearance, mechanical quality or soundness of the weld, material flow, het generation. However, in present global environment, tool design is the prime important for all the individual researcher.

TABLE 1: TOOL PARAMETERS USED TO WELD ALUMINIUM ALLOY

W/P Material	Tool Material	Tool Shape & Size	Remarks	Reference
AA2124	HSS (uncoated tool, coated tool with CrN, AlTiN)	SD: (Flat) 18 mm PD: (Threaded) 6 mm	Wear of coated tool is less.	10
AA6111	H13 Die Steel	SD: (Flat with scroll) 10 mm PD: (Straight cylindrical) 3 mm	Better weld with pinless tool	27
AA7020	Steel	SD: (Flat) 10 -20 mm PD: (frustum & straight cylindrical) 3 – 8 mm	Weld Joint efficiency 92 %.	28
6082 Al	H13 Die Steel	SD: (scroll, cavity, Fillet) PD: (Straight Circular) 1-7 mm	Got nearly 76 % efficiency. Cavity gave good properties.	29
6061 Al	H13 Die Steel	SD: 25.4 mm PD: 5.2 – 7.6 mm	-	30
6082 Al	Steel	SD: (Flat) 30 mm PD: (Triangle, square & Hexagonal) 10 mm	Reduction in grain size compare to the BM with Hexagonal pin tool.	31
6061 Al	H13 Die Steel	SD: (Concave) 26 mm PD:	-	32

		(Straight circular Threaded) 5.6 mm		
5754 Al	H13 Die Steel	SD: (Concave, convex, flat) 12 mm PD: (Straight Cylindrical) 5 mm	-	33
6082 Al	Steel	SD: (Flat) 40 mm PD: (Taper Cylindrical) 20 -11.4 mm	Grain boundary cracking	34
6082 Al	HS6-5-2 high-speed steel	SD: (Grooved spiral & Flat) PD: (Cylindrical threaded, cylindrical threaded with 3 grooves and cylindrical)	Triflute pin gave sound weld.	35
6082 Al	Steel	SD: (Flat) 14 mm PD: (Cylindrical Threaded) 6 mm	Stress increase the chances of cracking.	36
6082 Al	56NiCrMoV7-KU	SD: (scroll, cavity, Fillet) 6 mm PD: (Straight Cylindrical) 1.7 mm	Cavity increase the strength.	37

SD: Shoulder Diameter **PD**: Pin Diameter

IV. Conclusion

Since, the last 20 years, there are significant development in FSW process have been achieved. Different types of tool have been created or designed throughout the history of the FSW.

In comparison with the fusion welding process, FSW gives significant benefits in improvement of ultimate tensile strength, hardness, toughness, ductility, fatigue and other so many properties of weld material.

The outcome of this study to understand the role of the tool parameters in FSW welding process with specifically tool shoulder and pin geometry and diameter, tool pin eccentricity and tool material.

Now a day's design of tool geometry is a prime focus of all researchers who are working in the field of FSW with the objective of getting sound weld joint but less information available in literatures. Existing literatures revels that scroll type shoulder geometry is mostly used to weld the material. Which gave the best surface appearance as well as good mechanical properties. Also, it greatly influences the bulk material flow from the retarding side to advancing side. Pin geometry is mainly influence the initial heat of FSW process and layer to layer material flow. Based on the past literature, threaded cylindrical pin and square pin features are widely used to join the weld metal. Besides that, triflut type pin have also been designed to weld. If the ratio of shoulder diameter to pin diameter is maintained nearer to 3 then there is chance of better weld. From this literature review, optimized shoulder and pin diameter is 18 mm and 6 mm respectively.

Also, it is found that to reduce the wear of tool which affect the weld zone by interrupting the tool material debris in weld metal, so many researchers done a coating of hard material. Due to coating, wear of tool become reduce. Eccentricity of the pin probe improves the tensile strength, hardness and other mechanical properties.

Now, it can be effectively concluded that tool geometry is most significant parameter for the efficient welding of any material.

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