Numerical Study of Friction Stir Welding on Different Aluminum with Different Profile Pin: A Review

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Abstract - In this review paper, friction stir welding of aluminum alloys by using different profile pins have been studied. Friction stir welding is a dynamically developed version of pressure welding processes by which high-quality welds can be produced. Tool geometry is one of the very important parameter because it affects the mixing of the material, which in turn determines the quality of weld. Tool design and selection of process variables are critical issues in the usage of the FSW process. The development of cost-effective and durable tools, which lead to structurally sound welds, is still awaited. Material selection and design intensely affect the performance of the tools. Several important aspects of FSW tools such as tool material selection & its importance, geometry and load-bearing ability, and process economics for applications, have been discussed in this study.

Key Words: *friction stir welding, aluminum sheet, pin profile, analytical, tool material, and tool geometry.*

1. INTRODUCTION

Friction stir welding is a process for solid-state joining by using a rotational tool, which moving along the interface of the joint, the heat is generating and resulting in a re-circulating plasticized material flow near the surface of tools. These plasticized materials are subjected to extrusion by the rotational probe of tools and movements of linear leading to the formation of the zoning of stir. This zoning of the stir formation can be affected by the behavior of material flow under the action of the rotational tool. It was developed by the Welding Institute (TWI) in 1991 in England [1]. The stirring of frictional tool consists of a pin or probe, and a shoulder as shown in Figure-1. When the tool come in the contact with plate, then material become softened due to the frictional heating between the tool pin and shoulder with the workpiece material and deformational heating. Abrasive wear, high temperature, and dynamic effects are the important factors regarding the friction stir welding tool [1]. tool materials must have the following properties: good wear resistance, high-temperature strength, temper resistance, and good toughness. Therefore, the selection of tool material is very important. Also, the geometry of the tool affects the welding quality along with the tool material [2]. The most important challenges of friction stir welding are the welding of high-temperature materials, welding having complex geometries, welding of dissimilar materials, tool material selection, development of tool materials, tool design [3].

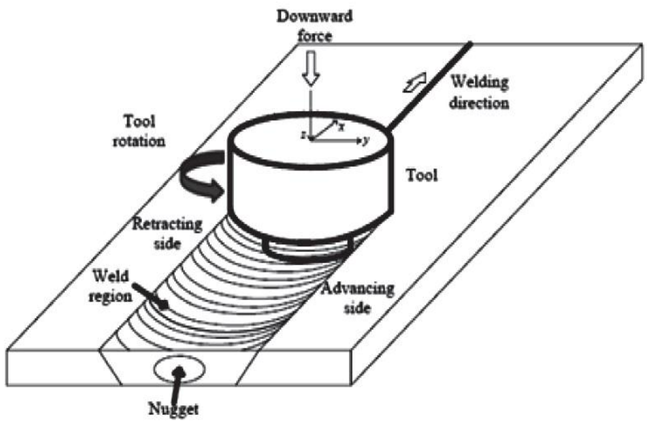

Figure: 1- Schematic drawing of friction stir welding.

1.1. Influence of Tool Material and Geometry on Weld Quality

The tool of FSW is composed of two parts: a tool body and a probe. The tool technology is the heart of the friction stir welding process. The tool shape determines the heating, plastic flow, and forging pattern of the plastic weld metal. The tool shape determines the weld size, welding speed, and tool strength [4]. The tool material determines the rate of friction heating, tool strength, and working temperature, the latter ultimately determines which materials can be friction stir welded [3]. Two different tool pin geometries (square and hexagonal) and three different process variables, i.e. rotational speeds and welding speeds were selected for the experimental investigation of AA6101-T6 alloy [2]. It was observed that the square pin profile gave better weld quality than the other profile [5].

Materials such as aluminum or magnesium alloys, and aluminum matrix composites (AMCs) are commonly welded using steel tools [7]. Steel tools have also been used for the joining of dissimilar materials in both lap and butt configurations. Tool wear during welding of metal matrix composites is greater when compared with welding of soft alloys due to the presence of hard, abrasive phases in the composites [6]. Total wear was found to increase with rotational speed and decrease at lower traverse speed, which suggests that process parameters can be adjusted to increase tool life [4]. They highlight the role of tool geometry in their investigation because tool geometry plays a major role in FSW. Proper selection of tool material and shape of the pin reduces the number of trials and tooling costs. In addition, this study also highlights the wear effect due to friction between sliding surfaces [9]. The effect of friction stir welding process parameters on the mechanical properties of the AA 2014-T6 alloy joints produced by friction stir welding has been discussed by Vagh and Pandya [8]. Effects of tool design, tool rotation speed & tool travel speed on mechanical properties have been analyzed using the Taguchi orthogonal array design of experiments technique. There are three different tool rotation speeds and three different tool traverse speeds. For each combination of tool rotation speeds and tool, traverse speeds three different types of tool pin profiles (threaded cylindrical pin, tapped pin, and threaded cone pin) have been used [10]. The study indicates that tool design is the main process parameter that has the highest statistical influence on mechanical properties. Figure-2 represents some type of profile pins of the FSW.

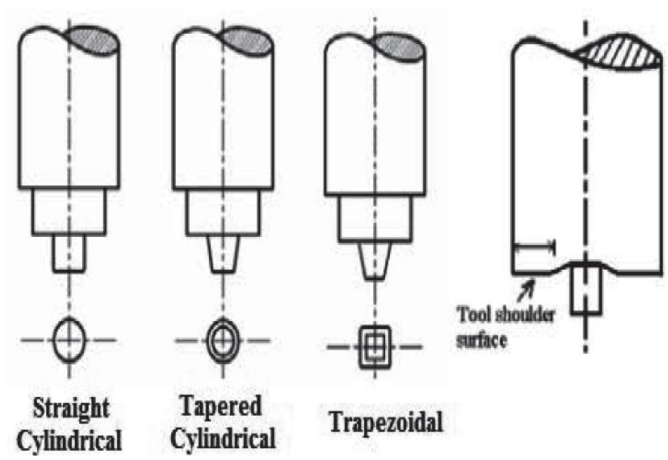

Figure:2- Different FSW tool geometries used in the experiment

2. LITERATURE REVIEW

Various researchers have carried out friction stir welding at different materials sheet with different pin profile, the summary of each research paper are:

Ravindra, Thube [2014] have studied the effect of parameter due to friction stir welding and tool pin profiles on the tensile properties. Five-tool pin profiles used to fabricate the joints, and it was founded from this study that, cylindrical pin profiled tool produced defect-free FSP region, irrespective of welding speeds. The three rotational speeds used to fabricate the joints, the joints fabricated at a rotational speed of 1400 rpm showed superior tensile properties, irrespective of tool pin profiles except triangular pin profiled tool. At high rotational speed (1800 rpm) cylindrical tool is the best; at the middle rotational speed, (1400 rpm) cylindrical and square tools are the best; while low rotational speed (900 rpm) triangular and square tool are the best. The 15 joints, the joint fabricated using a cylindrical pin profiled tool at a rotational speed of 1400 rpm exhibited maximum tensile strength and defect-free FSP region [10].

Srujana et al [2014] have carried out the work on the influence on the mechanical property of Friction stir welding and It was founded from this study that the influence of various tool pin profiles on mechanical properties and microstructures has been evaluated. The results indicate that the joints made by the triangular tool exhibited superior mechanical properties than others due to more grain refinement during the process [11].

Chandrashekar et al [2014] have reviewed the effect of different tool pin profiles like straight cylindrical, taper cylindrical, triangular, square, trapezoidal, and hexagonal tools on the mechanical property of friction stir welding. It was founded from this study that the joints of different tools pin profiles like straight cylindrical, taper cylindrical, triangular, square, trapezoidal, and hexagonal tools, etc., with different rotational speeds, weld speeds, and axial force were reviewed in this research work. Based on the literature survey, Tool shoulder-to-pin diameter ratios play an important role in stir zone development. The diameter of the pin is equal to the thickness of the parts to be welded and its length is slightly shorter than the thickness of the part. tool material properties such as strength, fracture toughness, hardness, thermal conductivity, and thermal expansion coefficient affect the weld quality, tool wear, and performance. Heat generation rate and plastic flow in the workpiece are affected by the shape and size of the tool shoulder and pin. Although the tool design affects weld properties, defects, and the forces on the tool. The pin cross-sectional geometry and surface features such as threads influence the heat generation rates, axial forces on the tool, and material flow. Tool wear, deformation, and failure are also much more prominent in the tool pin compared with the tool shoulder. There is a need for concerted research efforts towards the development of cost-effective durable tools for the commercial application of FSW to hard engineering alloys [12].

Pasha et al [2015] have studied the effect of the tool pin profile on the mechanical property of the dissimiliar material joints. It was founded from this study that the pin cross-sectional geometry and surface features such as threads influence the heat generation rates, axial forces on the tool, and material flow. Tool wear, deformation, and failure are also much more prominent in the tool pin compared with the tool shoulder [13].

Juárez et al [2016] have modified profile pin for friction stir welding and it was founded from this study given that, a modified expression have been proposed to calculate heat generation from the taper probe surface. The fracture for tensile specimens, using the SHBH pin profile, took place systematically outside the welding zone. The Vickers microhardness along the welding zone for the SHBH welded specimens was higher when using low rotational speeds of the tool, for the testing welding speeds. Low plastic deformation is observed for the fracture surfaces of specimens with tunnel defects, indicating that low resistance is opposed during the tensile tests. The fracture surface of tensile specimens without tunnel defect shows appreciable plastic deformation around the peripheric rectangular area, indicating the resistance of the material to tensile loading [14].

Sharma et al [2017] have carried out the stirring of the materials during friction stir welding and it was found from this study that, the tool pin profile critically influences material movement pattern. Consequently, the microstructure and microhardness in the dissimilar FSW of Al-Cu also vary accordingly. Especially, flat faces on the lateral profile of the pin produce pulsating action under which material movement takes place with ease which increases the material transport. Square and cylindrical cam profiles result in the defect-free joining of Al-Cu mainly due to better stirring assisted pulsating action. Square tool pin provides the good pulsating action in the region between in-circle and circum-circle of square pin profile. Beyond this region, good stirring is observed. The combined result of pulsation and stirring produces better material transport and stirring. In dissimilar FSW of Al-Cu, the softer Al gets stirred more and creates clear flow lines in the stir zone. Square tool pin profile exhibits good quality joint, and microhardness among the other selected tool pin profiles [15].

Hussain et al [2017] have carried out the study on join due to friction stir welding and it was founded from this study that, Five different pin profiled friction stir welding tools were developed effectively which are suitable for the FSW of aluminum alloys. FS welded joints fabricated with tapered cylindrical tool exhibited the highest tensile strength (162 MPa), whereas triangular tool showed the lowest tensile strength (115.6 MPa). The maximum impact strength of the FS welded joint is found to be 26 joules for the tapered cylindrical tool. A tunnel defect is found on the advancing side of the joint fabricated using a triangular pin profile due to the improper flow of material and ineffective consolidation [16].

Waheed et al [2017] have carried out the effect of pin tools due to FSW and it was founded from this study that, the analytical models have been developed to investigate the effects of different tool pin profiles of flat and tapered shoulder geometries on the peak temperature in friction stir welding. The results showed that the amount of heat generation and the peak temperature are directly proportional to the number of edges in the pin profiles in such a way that the heat generated and peak temperature in the profiles increases from the triangular pin profile to the hexagonal pin profile. Also, the rate of heat generation and the peak temperature in the flat shoulder are greater than in the tapered/conical shoulder. The results in this work have been validated with experimental and past theoretical results and good agreements were achieved [17].

Emamian et al [2017] has carried out the details of friction stir welding and it was founded from this study that, the most recent research reveals that the FSW pin profile has a significant effect on material flow and mechanical properties. In addition, the geometry of profiles is effective on heat generation. Some scholars are convinced that there are direct relations between heat generation and hardness, higher temperature, will produce higher hardness. Moreover, some researchers claim that other main FSW parameters such as rotational speed have a higher influence on microstructure and mechanical properties. But the role of tool geometry and pin profile is inevitable, it can also be concluded that among all shapes that are considered, some of them are not compared with each other and they provide defect-free welds separately. In most research, square pin profiles produce sound joints. However, in other studies, threaded cylinder or threaded taper provides proper joints. Above all, there is an equal result among all studies in which threaded shapes are most effective on tool performance [18].

Garg, Bhattacharya [2018] have carried out the effect of friction stir welding spot and It was founded from this study that, Microstructure observation revealed that the depth of the stir zone formed below the tool pin surface is almost similar with different tool pin profiles for the same plunge depth (*hp* = 0.4 mm) but a wider stir zone is observed with a circular tool pin. With an increase in total plunge depth (*hp*) from 0.4 mm to 0.6 mm the size of the stir zone formed around the intersection of tool pin and shoulder increases for circular tool pin profile. For square and triangular tool pins (i.e. with higher swept volume rate) due to the stronger stirring and intermixing, a comparatively larger stir zone is observed at the tool pin and shoulder intersection region. Grain size measurement indicates the formation of finer equiaxed grains in the stir zone as compared to other zones due to the continuous dynamic recrystallization of grain structure. Grain size measurement also indicates that the average grain size measured in the stir zone for different tool pin profiles is comparable but significantly finer than the grain structure of the base metal [19].

Krishna et al [2018] have carried out the effect mechanical property of Friction stir welding and It was founded from this study that, Tool pin profile plays an important role in mechanical properties such as tensile stress, yield stress & elongation. Straight cylinder tool pin profile an added advantages over other profiles. To gain better hardness, the Straightness Square tool can be employed by positioning Al7075 on the receding side [20].

Varma et al [2020] have carried out the Hardness of the Friction stir welding and It was founded from this study that, High hardness of 130 VHN1kg was obtained with the weldment fabricated using a concave triangular threaded probe at 1200 rpm at the retreating side boundary zone. Low hardness of 49.8 VHN1kg was obtained with the weldment fabricated using a concave triangular threaded probe at 1200 rpm at the weld nugget zone. The knockdown in hardness is due to low peak temperatures observed during welding and the formation of secondary precipitates and voids at the weld zone [21].

Jayaprakash [2021] have carried out the different friction stir welding at different aluminum. From the ANOVA test, using a cylindrical taper tool, the maximum ultimate tensile strength was attained as 267 MPa. Using a triangular tool, the maximum ultimate tensile strength obtained was 286 MPa. Using a straight cylindrical tool, the maximum ultimate tensile strength of 275 MPa was attained. From this analysis, it can be seen that all the tools provided the maximum tensile strength with consideration of a rotational speed of 1200 rpm, welding speed of 30 mm/min, and axial force of 3 kN. With the increase of rotational speed from 1200 rpm to 1400, the tensile strength rapidly decreased. By using a cylindrical taper tool, the minimum and maximum microhardness were obtained as 42 HV and 75 HV. Implementation of a triangular tool provided the minimum and maximum microhardness of 48 HV and 86 HV. However, application of a straight cylindrical tool provided the minimum and maximum microhardness of 46 HV and 82 HV. Therefore, the triangular tool offered the maximum tensile strength and microhardness of the investigation [22].

3. CONCLUSIONS

After studying the above research paper related to friction stir welding, found some conclusions regarding that overviews of friction stir welding's cost-effective and long-life tools are available for the FSW of aluminum and other soft alloys. The pin cross-sectional geometry and surface features such as threads influence the heat generation rates, axial forces on the tool, and material flow. The fracture for tensile specimens, using the Straight Hexagon Bolt Head (SHBH) pin profile took place systematically outside the welding zone. The bolt-head at the end of the pin reduces the material flow downward, contributing to the reduction or elimination of the tunnel and other defects.

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