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A Review on Effect of Tool Parameter in Finite Element Analysis of Friction Stir Welding on Aluminium Alloys

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Abstract **Friction stir welding (FSW) is a relatively recent solid state welding technique for welding aluminium alloys. The welding parameters play a very important role in achieving optimal results in friction stir welding. Temperature variation, material flow, microstructure, plastic deformation and joint strength are all affected by tool shape, shoulder diameter, pin diameter and tool tilt angle. Finite Element Analysis of Friction Stir Welding also saves money and resources since the best welding variables can be achieved with less effort. Main purpose behind this review paper is to discuss various effect of tool parameter in Finite element analysis of friction stir welding on alluminium alloys.**

Keywords — Friction Stir Welding, Finite Element Analysis, Alluminium Alloys, Tool Geometry and Profile, Simulation

I. INTRODUCTION

In 1991 W. Thomas of The Welding Institute (TWI), UK, developed a solid phase joining technique called friction stir welding, which is used to connect a wide variety of parts and geometries. FSW process is divided into three steps, a non-consumable rotating shouldered-pin tool is first inserted into the joint formed by the two sheets until the shoulder makes contact. The sheets are heated by plastic deformation and friction as the tool rotates at a high speed. Second, because the tool continues to rotate without translating, the material heats up due to friction. Finally, the tool moves along the line of the joint, heats the material even more, moves it from the tool's front edge to its trailing edge, and produces the weld.

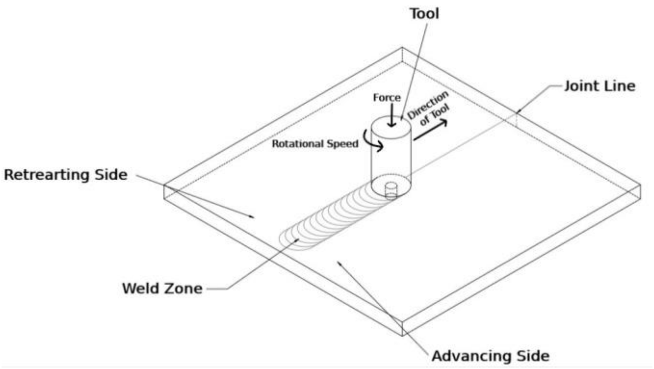

Fig-1: Friction Stir Welding Process

FSW has been used to join alluminum alloys, magnesium alloys, and copper alloys, some of which were previously classified as practically unweldable using traditional welding methods. Welding of high melting point materials such as steels, Ti alloys, Ni-based super alloys, metal matrix composites, and polythene has recently been added to its list of applications. FSW has been expanded to be used in a variety of applications such as automotive, aerospace, railway, ship building/marine, oil and gas, construction, etc. as an efficient and effective welding process known as an environmentally friendly technique due to the use of no filler material. Because of its environmental friendliness, energy efficiency, and usability, FSW is referred to as "green technology." FSW produces a fine microstructure as well as a solid, precise weld joint.

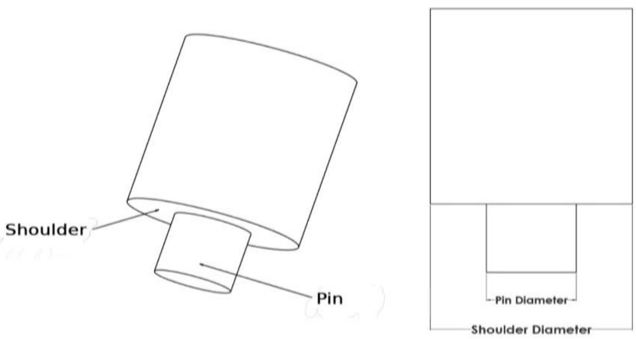

Fig-2: Tool Geometry

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The most critical part of process construction is a FSW tool which consists of a shoulder and a pin as shown in Fig-2. The pin is the primary source of material flow and the secondary source of heat production, while the shoulder is the primary source of heat generation.

The tool shoulder's job is to provide heat by applying a large compressive force and to keep the softened, plasticized metal under it contained. The tool probe's aim is to transfer highly plasticized material from the front to the rear of the probe, as well as to move the material vertically. The weld formation, weld consistency, and weld mechanical properties, among other things, are all influenced by the geometry of the shoulder and pin. Cylindrical pin, tapered threaded cylindrical pin, threaded cylindrical pin, square pin, cylindrical tapered pin, square tapered pin, triangular pin, hexagonal pin, conical pin, and polygon pin are some tool pin geometries used in friction stir welding.

Numerical modelling has been used to model and analyses the heat transfer mechanism and temperature distribution, and fluid flow in the FSW process. Despite the fact that it is a new welding technology, FSW has been extensively studied numerically and experimentally. Various researchers have proposed thermo mechanical finite element model for the simulation in various software. Finite element analysis research has been carried out using ANSYS, ABAQUS, FIDAP, FORGE 3, DEFORM 3D, HYPERWORKS, LS-DYNA, SYSWELD, and other FEM software. It was discovered that ANSYS, DEFORM-3D, and ABAQUS implemented better thermo-mechanical models than all other commercial software.

II. Literature Review

V. Malik, N. K. Sanjeev, H. S. Hebbar, and S. V. Kailas (2014) investigated the effect of various tool pin profiles in friction stir welding using finite element simulations considering the material properties of AA2024-T in ABAQUS by using frustum and straight type pins with six different profiles: circular, triangular, square, rectangle pentagonal and hexagonal type during FE simulation. As a result, they discovered that the straight square profile tool pin uses less power than the other five profile pin tools while retaining the same temperature. Frustrum square tool pins can minimise welding power consumption. Frustrum category tool pins with more peripheral faces consume less welding power in compare to straight category tool pins. Less defect was found for frustum type pins when compared to straight pins, so frustum pins should be used for better production output [1].

L. Long, G. Chen, S. Zhang, T. Liu, and Q. Shi (2017) performed the finite element analysis for friction stir welding on AA6061 in Deform 3D using tool tilt angle as 0 and 2 degree. The tilt angle was found to raise the peak temperature in the welding tool's surrounding region, causing the material in this area to soften significantly. The tilt angle was discovered to improve material flow from the rear retreating side to the rear advancing side. The lateral frictional driving force is increased as a result of the increased compressive force in the rear side of the welding tool caused by the tilt angle, which helps to facilitate material flow. When zero tilt angle is used, computational analysis predicts that wormhole defects will occur in the rear advancing side of the weld nugget, while wormhole defects will not occur when a tilt angle of 2 degree is used [2].

R. Jain, S. K. Pal, and S. B. Singh (2018) using finite element simulations investigated the influence of pin shape material flow and force in friction stir welding of AA2024 by taking conical, threaded and cylindrical pins. Result predicted that threaded pin generates much lower plunging force as compared to both the cylindrical and conical pins. In comparison to conical and threaded pins, simulations predict a higher welding force for cylindrical pins. In comparison to the smooth conical pin, higher material velocity is expected for the threaded pin, implying a higher slip rate in the former [3].

S. K. Hussein (2016) used the finite element method to calculate heat generation in friction stir welding from various probe and shoulder profiles. For simulation, five different types of probes were used: cylindrical, quasi cone, hexagonal, and multi-cylinder, as well as shoulders profiles of cylindrical, cylindrical - flat slot, cylindrical - double flat slot, cylindrical - single half circle slot, and cylindrical - double half circle slot. The simulation revealed that a hexagonal probe with fins in the tool arm and circular slots in the shoulder produced the most heat in the tool model during simulation. The heat produced can be increased by increasing the number of fins in the tool arm and the number of slots in the shoulder [4].

H. Li, D. MacKenzie, and R. Hamilton (2010) used a finite element approach to investigate the effect of tool form on friction stir welding on AA2024 aluminium alloy. They used five different shoulder surface angles tool as 0°, 2°, 5°, 8°, and 10°, as well as four different pin radii R pin as 1 mm, 1.5 mm, 2 mm, and 2.5 mm. It was observed for the same plunge speed, the greater the pin radius, the larger the contact area, and hence the higher the force encountered by the tool. For small radius pin tools, increasing the shoulder surface area decreases the peak reaction tool force, whereas for larger radius pin tools R pin as 2 and 2.5 mm, shoulder surface angle had little effect on peak tool forces and temperature distribution. It was found that increasing the pin radius increases the size of the HAZ, TMAZ, and nugget field [5].

J. F. Villegas and J. V. Dominguez (2017) used three different geometric profiles to investigate the effect of tool profiles on thermo-mechanical modelling of friction-stir welding: spiral shoulder shape, concentric shoulder shape,

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and flat shoulder shape. The temperature distribution showed that the spiral shaped shoulder reached the highest temperature, followed by the tool with a concentric shoulder shape, and then the tool with a flat shoulder shape, owing to its larger area of contact and higher torque in the process. Shear stress was generated when the tool and joint came into contact due to rotation speed and the viscoplastic resistance of the joints [6].

Z. Zhang, Y. L. Liu, and J. T. Chen (2009) investigated the influence of shoulder size on temperature rise and material deformation in friction stir welding using a thermo-mechanical coupled simulation in Abaqus with shoulder diameters of 16, 20, and 24 mm. It was discovered that increasing the shoulder diameter to 24 mm, increases the contact area, which increases the temperature and welding quality. Temperature variance, rather than material deformations, can become the key factor in microstructural evolutions, resulting in an increase in average grain size as temperature rises [7].

M. Abbasi, B. Bagheri, and R. Keivani investigated the thermal analysis of friction stir welding on AA6061-T6 using three types of probes: straight cylindrical, tapered cylindrical, and semi spherical, with pin angles of 0, 5, 10, and 15 degrees. The pin profile's static and dynamic values are verified by simulation, based on the static to dynamic volume ratio. Plain cylindrical probes have a ratio of 1, tapered cylindrical probes have a ratio of 2.3, and semi-spherical probes have a ratio of 3.1. When this ratio increases, more material deforms plastically, and the temperature rises accordingly [8].

M. H. Shojaeefard, A. Khalkhali, M. Akbari, and P. Asadi (2015) using the finite element process investigated the friction stir welding tool parameters using different pin diameters and shoulder diameters. Increase in shoulder diameter increase peak temperature, which increases joint strength but lowers weld quality since the HAZ (heat affected zone) expands. Pin diameter has little effect on thermal distribution, but it does influence material flow and plastic deformation. The maximum strain and plastically deformed area increase as pin diameter increases, improving weld quality but increasing HAZ. To avoid HAZ expansion, use a tool with the appropriate pin diameter and shoulder diameter [9].

A. M. Sadoun, A. Wagih, A. Fathy, and A. R. S. Essa (2019) investigated the influence of tool pin side area ratio on temperature distribution in friction stir welding for 7075-O Al alloy using semi-spherical, cylindrical, and neck pin tool pin geometry. The shoulder heat generation ratio was found to be 80 percent for semi-spherical pins, 84.81 percent for cylindrical pins, and 89.13 percent for neck pins. As the surface area of the pin side increases and the shoulder heat generation ratio decreases, the temperature distribution in the semi-sphere improves [10].

III. Summary

Increased shoulder diameter increases contact space, which raises temperature and welding efficiency but reduces weld quality. Since it covers more surface area, the spiral shaped shoulder profile can improve temperature distribution. The most important factor in microstructural evolutions is temperature variation, because as the temperature rises, the average size of grain increases. Increased pin diameter improves weld strength which increase material flow and plastic deformation, but it also increases Heat Affected Area. Increased pin diameter increases the heat affected area, thermo-mechanically affected zone and nugget zone. The tool pin side has an effect as well. As the surface area of the pin side increases and the shoulder heat generation ratio decreases, the temperature increases. The tilt angle was discovered to improve material flow from the back retreating side to the back advancing side.

IV. Conclusion

We can conclude from the above review paper that in finite element analysis of friction stir welding on aluminium alloys, tool parameters like shoulder profile, pin profile, shoulder diameter, pin diameter and tilt angle of tool have an influence on temperature distribution, microstructure zones, material flow, plastic deformation, and weld quality of joint.

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