Friction Stir Welding of Dissimilar Materials: A Review

Nilesh V. Desai[1], **Dr. K. H. Inamdar**[2]

[1]PG Student, [2]Associate Professor, Department of Mechanical Engineering,
Walchand College of Engineering, Sangli, (India)

ABSTRACT

Friction stir Welding is a solid-state joining process used for joining of different alloys of aluminium, magnesium etc. and also for hard materials like steels. The common defects observed in conventional welding are eliminated in this type of welding. The reality that joining of alloys could be usually faced problems in many sectors that includes automotive, aerospace, ship building industries, electronics etc. where fusion welding is not possible due to large difference in physical and the chemical properties of the components to be joined. In conventional welding processes defects like porosity formation, solidification cracking, and chemical reaction may arise during welding of dissimilar materials although sound welds may be obtained in some restricted cases with special aids to the joint design and preparation, process factors and filler metals.

Keywords: Friction Stir Welding, Microstructure, Rotational Speed, Tensile Strength, Welding Speed

I. INTRODUCTION

Friction Stir Welding (FSW) is invented by The Welding Institute (TWI), England, U. K. for joining of light metals in 1991. It allows considerable weight savings in lightweight construction compared to conventional joining technologies along with high strength. The process of friction stir welding has numerous advantages over the conventional welding technologies. FSW process is carried out in the solid phase below the melting point of the metals and is able to weld numerous materials including aluminium, bronze, copper, titanium, steel, magnesium, and plastic. It also yields significantly less distortion than the fusion welding processes, allowing for high cost reductions in many applications. Thus, the problems related to the solidification of a fused material are avoided. Materials classified as difficult to fusion weld like the high strength aluminium alloys used in the aerospace industry could be joined with a minor loss in strength [1].

1.1 Friction Stir welding process

The process is schematically represented in Fig. 1. The plates are abutted along the edges to be welded and the rotating pin is plunged into the plates until the tool shoulder is in full contact with the plates surface. Once the pin is completely inserted, it is moved with a small tilting angle in the welding direction. Due to the advancing and rotating effect of the pin and shoulder of the tool along the seam, an advancing side and a retreating side are formed and the softened and heated material flows around the pin to its backside where the material is consolidated to create a high-quality, solid-state [2,3].

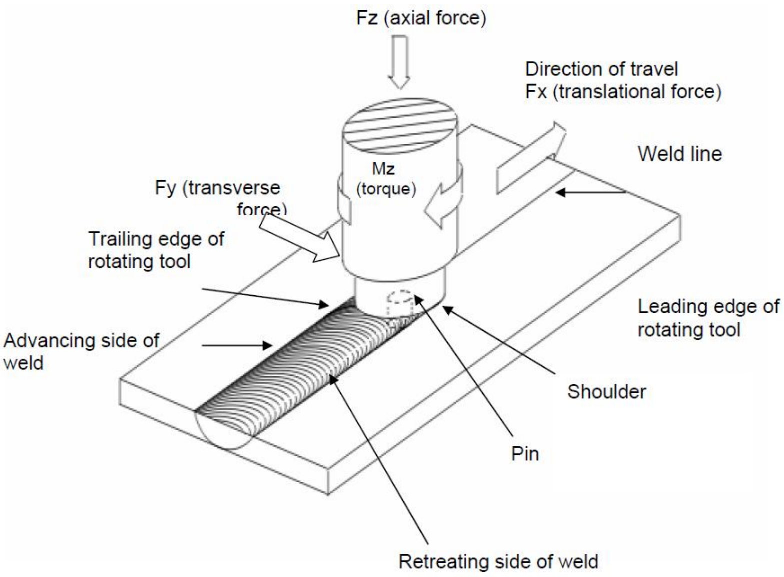

Fig. 1: Schematic Diagram of FSW Process [2]

II. PROCESS PARAMETERS

There are various factors that affect the quality of weld like welding speed, rotational speed, tool geometry, tool depth, tilt angle, offset distance etc. Some of the major influencing parameters are discussed below:

2.1 Rotational Speed and Traverse Speed

There are two tool speeds to be considered in friction-stir welding; rotational speed and traverse speed. These two parameters have considerable importance and must be chosen with care to ensure a successful and defect free welding joints. Increasing the rotation speed or decreasing the traverse speed will cause a hotter weld. In order to produce a quality weld, it is necessary that the material surrounding the tool is hot enough to enable the plastic flow required and minimize the forces acting on the tool. If the material is too cool then voids or other flaws may arise in the stir zone and in extreme cases the tool may break.

2.2 Tool Tilt and Plunge Depth

The plunge depth can be defined as the depth of the pin below the surface of the plate and is very important parameter for ensuring weld quality. Plunging the pin below the plate surface increases the pressure below the tool and helps to ensure adequate forging of the material at the rear of the tool. Tilting the tool by 2-4 degrees, to the rear side, has been found to assist this forging process. Due to proper plunge depth, the necessary downward pressure is achieved and also it ensures that the tool fully penetrates the weld. On the other side, an excessive plunge depth may result into pin rubbing on the backing plate surface.

2.3 Tool force

This is another important parameter in FSW process. There are three types of forces: vertical force, longitudinal force and lateral force. The vertical force will ensure the contact between shoulder and workpiece. The heat is generated because of friction between the shoulder and the workpiece. The longitudinal force is parallel to tool motion and is positive in welding direction. The force is generated due to resistance to motion and will get reduced as the temperature around the tool gets increased. The lateral force may act perpendicular to the tool traverse direction and is defined here as positive towards the advancing side of the process. A torque is required to rotate the tool, the value of which will depend on the down force and friction coefficient (sliding friction) and the flow strength of the material in the surrounding region (sticking friction). These forces combined with the thermal impact effect may induce the deformation of the fixture and the processed plates and affect the wear of the tool. These effects will subsequently complicate the formation of the residual stresses in the welding and the prediction of tool life.

III. LITERATURE SURVEY

A literature survey has been done for analyzing the process parameters and their effect on the response variables of the Friction Stir Welding.

Yazdipour and Heidarzadeh [4] studied the effect of tool traverse speed, offset and rotation direction during dissimilar butt friction stir welding of Al 5083-H321 and 316L stainless steel plates at constant rotational speed of 280 rpm. The tensile and hardness tests were conducted to evaluate the mechanical properties of the joints. The results showed that defect free joint with maximum tensile strength of 238 MPa was produced at a traverse speed of 160 mm/min, pin offset of 0.4 mm, and clockwise rotation condition. The reduction in tensile strength of the other joints was due to their surface and cross-sectional defects such as tunnel defect, voids, non-uniform distribution and large particles of the steel and micro cracks developed in the interface of the dissimilar parts.

Uzun et al. [5] worked on joining of dissimilar Al 6013-T4 alloy and 304L stainless steel using friction stir welding. The microstructure, hardness and fatigue properties of fiction stir welded 6013 aluminium alloy to stainless steel have been investigated. The weld nugget, the heat affected zone (HAZ), thermo-mechanical affected zone (TMAZ) were observed under optical microscope. Fatigue properties of Al 6013-T4 and 304L stainless steel joints were found to be 30% lower than that of the Al 6013-T4 alloy base metal.

Siddiquee et al. [6] performed friction stir welding on austenitic stainless steel plates on an indigenously retrofitted vertical milling machine. AISI-304 equivalent grade stainless steel was welded by FSW using tungsten carbide tools with tapered cylindrical (conical) pin. The results of ANOVA showed the order of importance in which the parameters have affected the UTS in terms of percent contributions i.e. welding speed with (56.83% contribution), shoulder diameter (27.44% contribution) and tool rpm(15.73% contribution).

Ramachandran et al. [7] studied the effect of tool axis offset from the joint interface and geometry of the FSW tool pin on the mechanical and metallographic characteristics of dissimilar FSW welded aluminium alloy and HSLA steel were. The constant FSW parameters used were; tool rotational speed of 500rpm, welding speed of 45 mm/min, and axial load of 7 kN and tool tilt angle of 1.50^o. The effect of tool axis offset was investigated by continuously changing the tool axis offset by keeping the tool traverse direction at an angle to the joint interface. FSW tool having TC pin with 100^o taper angle has produced the best joint at a tool axis offset of 2 mm towards the Al alloy.

Ataya et al. [8] studied aluminium alloys AA7075-T6 and AA5083-H-11, were friction stir welded at a constant rotation rate of 300 rpm and different traverse speeds of 50, 100, 150, and 200mm/min in similar and dissimilar joints. They observed that the dissimilar joints exhibited ultimate tensile strength ranged between 245 and 267 MPa and fracture strain ranged between 3 and 5.6%. A brittle/ductile fracture mode was dominating in the examined fracture surface of the dissimilar joints.

Sudhagar et al. [9] worked to select the optimum process parameters for friction stir welding of aluminium 2024 alloy based on multi-parameter optimization approach with input parameters like tool rotational speed, welding speed and tool offset. The response parameters measured are ultimate tensile strength, impact toughness and hardness of welded joint. The multi parameter optimization techniques namely Grey Relational Analysis and Technique for Order Preference by Similarity to Ideal Solution are used. The optimum conditions are tool rotational speed of 1000 rpm, welding speed of 80mm/min and tool offset at 0 mm.

Boumerzoug and Helal [10] studied the microstructure and strength properties of friction stir welded 6061-T6 aluminium alloy to ultra-low carbon steel using different advancing speeds of 100, 200, and 400 mm/min at constant rotation rate. The advancing speed effect on the microstructure and strength properties of the welded dissimilar materials has shown that phenomenon of grain refinement is developed in the aluminium side.

Khan et al. [11] studied mechanical and microstructural behaviour of friction stir welded similar and dissimilar sheets of AA2219 and AA7475 aluminium alloys. Friction stir welding process has been employed to join similar and dissimilar 2.5 mm thick sheets of AA2219-O and AA 7475-T73 aluminium alloys. Grain refinement is observed at the stir zone due to dynamic recrystallization caused by severe plastic deformation. Lowest strength for dissimilar joint is observed primarily due to non-homogeneous movement of base materials consequent to differences in mechanical and physical properties. Minimum hardness was found at TMAZ retreating side for all joints due to the thermal softening.

Meran and Canyurt [12] worked on stainless steel plates that were butt welded by FSW method using 7.5 kW vertical head milling machine. The average grain size in the stirred zone was between 3 and 7 μm, which is smaller than that in the base metal (BM). The average grain size in the HAZ was about 20 μm, which is half of that of the BM fine-grained microstructures are present the welded area. The dark bands observed in the weld zone were also detected the microstructure of the transition zone. Dark and narrow bands do not consist of pores or cavities.

Lakshminarayanan [13] studied relationships to predict the properties of friction stir welded stainless steel joints. The investigated properties are correlated with the macrostructure and microstructural characteristics of different zones of FSW joints to understand the influence of process parameters. Multi- criteria optimization is used to obtain optimum welding conditions that can yield enhanced properties of FSW joints. The optimized results indicated that, the properties can be enhanced with the use of rotational speed of 441 rpm, welding speed of 118 mm/min, and shoulder diameter of 17.5 mm.

Sadeesh et al. [14] carried out experiments on dissimilar AA2024 and AA6061 aluminium plates of 5mm thickness. Five different tool designs were used to analyze the influence of rotation speed and welding speed over the microstructural and tensile properties. Effect of welding speed on microstructures, hardness distribution and tensile properties of the welded joints were investigated. From microstructural analysis it is evident that the material placed on the advancing side dominates the nugget region. The minimum hardness is observed in HAZ of Al6061, where the welded joints failed during the tensile studies. From this research work, it is inferred that the rotational speed of 710 rpm and traverse speed of 28mm/min for cylindrical pin, is considered to be the most efficient. Furthermore, better mechanical properties were observed with 6 mm squared pin, rotational speed of 1000 rpm and traverse speed of 40mm/min. in addition, the cylindrical threaded and squared pin tool profile are found to be the best among other tool profiles that were considered.

Jiang and Kovacevic [15] demonstrated feasibility of FSW for joining 6061 aluminium alloy to AISI 1018 steel. The tensile failure happened at the boundary between the nugget and thermo mechanically affected zone of the base Al alloy, indicating that the weld has a higher joining strength. The average hardness of the nugget is higher than that of the base Al alloy. The temperature measurement showed that the maximum temperatures in the steel and Al alloy adjacent to the nugget are 613 and 491 degrees respectively. Due to localized melting of the Al alloy and the reaction of molten Al with steel pieces resulted in the formation of the Al–Fe intermetallic compounds, Al_3Fe_4 and Al_5Fe_2.

Chen and Kovacevic [16] performed experiments on Al 6061 and AISI 1018 steel having 6-mm thickness. Metallographic studies by optical microscopy, electron probe microscopy, and the utilization of the X-ray diffraction technique have been conducted. It was found that the intermetallic phases Al_3Fe_4 and Al_5Fe_2 exist in the weld zone. The tool was significantly worn during welding and is broken after travelling 100 mm at a rotational speed of 917 rpm. The wear of the tool significantly affects the structure of the weld, and the tool breakage was detected by the incorporated acoustic emission (AE) sensors. It appears that the joining of an Al 6061 alloy to AISI 1018 steel with a sound heterogeneous weld microstructure is feasible using this process and the tool breakage can be detected by the AE sensing technique.

Park et al. [17] investigated the effect of material locations on the properties of the FSW joints of two dissimilar alloys, 5052-H32 and 6061- T6 aluminium. The result of the microstructural analysis showed that the material mixing patterns in the FSW joints are quite different depending on the locations of the base metals. For the given aluminium alloys, the materials were more properly mixed when the 5052-H32 aluminium alloy was on the advancing side and the 6061-T6 aluminium alloy was on the retreating side than the case of the 6061-T6 aluminium alloy in the advancing side and the 5052-H32 aluminium alloy in the retreating side. The lowest value of the micro hardness measured in the HAZ of the 5052-H32 aluminium alloy side for the both FSW joints explains why the quasi-static tensile test specimens were fractured at the 5052-H32 side of joint for the both FSW joints.

IV. CONCLUSION

This paper has presented an overview on the effect of friction stir welding process parameters on the response variables like tensile strength, hardness and microstructure. It is highly efficient welding method that is particularly well suited for the materials which are difficult to weld by conventional fusion welding.

i. In FSW, tool rotational speed, traverse speed, tool forces are major affecting parameters. In addition to these parameters tool geometry, tool material, workpiece position also plays an important role in the quality of the weld.

ii. The FSW is mainly used for aluminium alloys, magnesium alloys but with proper selection of process parameters and tool material, the process can be used for welding of harder materials.

iii. By increasing rotational speed and reducing traverse speed heat input can be increased.

iv. For optimization of process parameters, Taguchi and ANOVA can be used. For multi-parameter optimization, Grey Relational Analysis and Technique for Order of Preference by Similarity to Ideal Solution can be used.

REFERENCES

[1] R. Mishra and Z. Ma, Friction stir welding and processing, Institute of Metal Research, Chinese Academy of Sciences, 2005, 1-78.

[2] B. R. Singh, A Hand Book on Friction Stir Welding Lambert Academic Publishing, UK, 2012.

[3] R. Nandan, T. D. Roy and H.K.D.H. Bhadeshia, Recent advances in friction-stir welding – Process, weldment structure and properties, Progress in Materials Science, 53, 2008, 980–1023.

[4] A. Yazdipour and A. Heidarzadeh, Effect of friction stir welding on microstructure and mechanical properties of dissimilar Al 5083-H321 and 316L stainless steel alloy joints, Journal of Alloys and Compounds, 2017, 595-603.

[5] H. Uzun, C. D. Donne, A. Argagnotto, T. Ghidini and C. Gambaro, Friction stir welding of dissimilar Al 6013-T4 To 304L stainless steel, Materials and Design, 26, 2005, 41-46.

[6] A. N. Siddiquee, S. Pandey and N. Z. Khan, Friction Stir Welding of austenitic stainless steel: a study on microstructure and effect of parameters on tensile strength, 4th International Conference on Materials Processing and Characterization, 2, 2015, 1388-1397.

[7] K.K. Ramachandran, N. Murugan and S. S. Kumar, Effect of Tool Axis Offset and Geometry of Tool Pin Profile on the Characteristics of Friction Stir Welded Dissimilar Joints of Aluminium Alloy AA5052 and HSLA Steel, Materials Science & Engineering, 639, 2015, 219-233.

[8] A. S. Ataya, S. Seleman and A. E. Ahmed, Friction stir welding of similar and dissimilar AA7075 and AA5083, Journal of Materials Processing Technology, 242, 2017, 77-91.

[9] S. Sudhagar, M. Sakthivel, P. J. Mathew and A. A. Daniel, A Multi Criteria Decision Making approach for process improvement in Friction Stir Welding of Al. Alloy, International Measurement Conference, 108, 2016, 36-64.

[10] Z. Boumerzoug and Y. Helal, Friction Stir Welding of Dissimilar Materials Aluminium AL6061-T6 to Ultra Low Carbon Steel, Multidisciplinary Digital Publishing Institute, 7, 2017, 42-51.

[11] N. Z. Khan, A. N. Siddiquee, Z. A. Khan and A. K. Mukhopadhyay, Mechanical and microstructural behaviour of friction stir welded similar and dissimilar sheets of AA2219 and AA7475 aluminium alloys, Journal of Alloys and Compounds, 2016, 151-171.

[12] C. Meran and O.E. Canyurt, Friction Stir Welding of austenitic stainless steels, Journal of Achievements in Materials and Manufacturing Engineering, 43, 432-439.

[13] A. K. Lakshminarayanan, Enhancing the properties of friction stir welded stainless steel joints via multi-criteria optimization, Archives of Civil and mechanical Engineering, 2016, 605-617

[14] P. Sadeesh, M. V. Kannan, V. Rajkumar, P. Avinash, N. Arivazhagan, K. R.Devendranath, S. Narayanan, Studies on friction stir welding of AA 2024 and AA 6061 dissimilar Metals, 7th International conference on materials for advanced technology, 75, 2014, 145 –149.

[15] W. H. Jiang and R. Kovacevic, Feasibility study of friction stir welding of 6061-T6 aluminium alloy with AISI 1018 steel, Proceedings of the Institution of Mechanical Engineers, 218, 2004, 1323-1331.

[16] C.M. Chen, R. Kovacevic, Joining of Al 6061 alloy to AISI 1018 steel by combined effects of fusion and solid state welding, International Journal of Machine Tools & Manufacture, 44, 2004, 1205–1214

[17] S. K. Park, S. T. Hong, J. H. Park, K. Y. Park, Y. J. Kwon and H. J. Son, Effect of material locations on properties of friction stir welding joints of dissimilar aluminium alloys, Science and Technology of Welding and Joining, 15, 2015, 331-336.