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An Overview of Friction Stir Welding (FSW)

Desai Abhi[1*] and Chaudhary Vijaykumar[2]

[1*]PG Student, Mechanical Engineering, C. S. Patel Institute of Technology, CHARUSAT, Anand, Gujarat, India, abhidesai1996@gmail.com
[2]Department of Mechanical Engineering, C. S. Patel Institute of Technology, CHARUSAT, Anand, Gujarat, India, vijaychaudhary.me@charusat.ac.in

ABSTRACT

The new process, Friction Stir Welding (FSW), facilitates a variety of splices for many industrial applications. It is an attractive technique for solid material bonding, unlike conventional welding methods, which have the ability to produce welds with higher integrity and minimal induced distortion and residual stress. In this report, the operation of FSW, important parameters, history, benefits and limitations were discussed. Along with a critical review of the literature, other applications of this process are presented. Ultimately, it has been recognized as a condition for research work on materials such as cubic boron nitride, mild steel of tool profile, and boundary, and for achieving better quality welding.

KEYWORDS: Welding, joint, parameter, material, tool profile

***Corresponding author**

Abhi T Desai

Department of Mechanical Engineering,
C. S. Patel Institute of Technology, CHARUSAT University,
Anand- 388120, Gujarat, INDIA.
Email: abhidesai1996@gmail.com, Mob No – 8154907819

INTRODUCTION

Friction Stir Welding (FSW) is widely applied to aluminium alloy joints to find a wide range of industrial applications to produce lightweight parts in shipbuilding, aerospace, automotive and other manufacturing industries. Aluminium alloys welded with conventional processes are very susceptible to weld cracking, depending on the alloying element. Fusion welding of aluminium is generally assumed to be more difficult than welding steel due to oxide, reflectivity, low melting point alloying elements, and so on. Also, the high expansion coefficient is sensitive to the distortion, and the shrinkage of the aluminium alloy is an iron alloy. FSW can be used to combine all common aluminium alloys, including the 2xxx, 7xxx, and 8xxx series, which are typically challenging or impractical, using a common melting welding process.[1]

FSW is a solid state process that enables long length welding without melting the base material and provides important metallurgical advantages compared to fusion welding. The stirring and forcing also results in a fine grain structure in the weld, resulting in a weld joint of good quality. In order to improve weld quality and minimize weld defects, it is important to study the relationship between friction stir welding parameters, heat generation and material flow during the welding process. This chapter lists a broad review of literature related to FSW of aluminium alloys. Review monitoring techniques such as FSW process parameters, heat generation, tool design, acoustic emission, electric motor currents and soft computing methods.[2]

LITERATURE REVIEW

Optimization of process parameters for friction stir welding of heterogeneous aluminium alloys (copper, aluminium and magnesium alloys) using Taguchi technology (Taguchi L16 rectangular design experiment) The ratio of tool diameter to shoulder diameter and pin diameter for optimization to examine traverse speed, tool geometry and joint tensile strength. The results were analyzed with the help of analysis of variance (ANOVA). The optimum level of tool rotation speed was 700 rpm, the feed rate was 15 mm / min, the ratio between tool shoulder diameter and pin diameter was 3, Produces a satisfactory butt weld.[3]

The material taken for the study is a high-density polyethylene sheet, which determines the welding process parameters for the ultimate tensile strength of the weld as a thermoplastic material, providing excellent joint efficiency. The optimization techniques applied are Taguch's L9 orthogonal array, signal-to-noise ratio and ANOVA. The described results contribute 73.85% to the total weld parameters for the weld strength when the tool rotation speed is 3000 rpm, with the smallest tool tilt angle. Experimental study on the process parameters and optimization of friction stir welding. They identified various process parameters such as tool rotation speed, weld speed and axial force, which play an important role in determining the joint properties of aluminium alloys. They adopted Response Surface Methodology (RSM) and ANOVA to optimize process parameters. The result of the test is an ultimate tensile strength and the yield strength increases with increasing tool rotation speed, welding speed and tool axial force. The total elongation increases as the rotational speed and the axial force increase, but decreases as the welding speed increases continuously. The maximum tensile strength was 197.50MPa, the yield strength was 175.25MPa, the total elongation was 6.96, and the rotation speed was 1199rpm, the welding speed was 30mm / min, and the axial force was 9KN.[4]

Friction Stir Welding Of Aluminium Alloys

The main focus of the FSW was to weld aluminium alloys from the beginning, even when applicable to alloy steels of copper, magnesium, titanium, nickel and molybdenum. Aluminium alloys are used extensively in aerospace, marine and automotive applications, so weldability must be studied for friction stir welding.

Further research has been conducted to understand the mechanical properties of friction stir welded dissimilar aluminium alloys and other metals such as steel, magnesium, and aluminium composites. Kwon et al[5] performed FSW of different metals with different aluminium and magnesium. Strain rate hardening is similar for both materials at various strain rates and exhibits excellent material flow characteristics and load carrying capacity. Moreira et al[6] studied the weld ability of aluminium alloy 6061-T6 by 6082-T6 by FSW, and the mechanical properties were compared with the base material. Minak et al[7]compare weld quality of friction stir welded aluminium alloy matrix composites with basic materials and correlate with microstructure modification. Chen et al[8]investigated the weldability, microstructure evolution and mechanical properties of AA6063 aluminium alloys and composites. More than 60% joint efficiency after artificial aging was observed and increased to over 80%.

It can be seen that the aluminium alloy FSW has achieved maturity that enables commercialization of this technology. Much more research work needs to be done to optimize the process to improve weld quality.

Mechanical properties and microstructural studies

The evolution of microstructures due to FSW and its consequences depends on several factors. Some of the factors include FSW process parameters, base metal, construction and temper, tool geometry and tool materials. The mechanical properties and microstructure studies performed on aluminium alloys are presented in this section.

Rhodes et al[9] used FSW to join the AA7075 plate at a welding speed of 5 in / min and study the microstructure change of the alloy due to FSW. The nugget was recrystallized, the dislocation density was lowered and the hardening precipitate dissolved.

Mahoney et al[10] studied FSW and subsequent thermal aging effects on the longitudinal and transverse properties of 7075T651 aluminium alloys. HAZ has been found to be the weakest area in which the yield strength and ultimate tensile strength are reduced in the longitudinal tensile test. Thermal aging after welding increased the fraction of fine cured deposits to improve strength, but loss of ductility was observed. The free precipitation free zone (PFZ) at grain boundaries caused intergranular cracks. The transverse tensile test shows the softening due to the thermal effect by showing shear mode fracture off the nugget. Thermal aging after welding reduced transverse tensile strength and elongation.

Flores et al[11]welded 1100 aluminium alloys including casted and 50% cold-rolled stainless steel microstructures of equiaxed orthopedic cell structure under friction stir welding. Even if fine particles and deformation of the precipitate occurred in the molded workpiece, the hardness of the welded part hardly changed. The dislocation density of the FSW region was smaller than the dislocation density of the base plate, indicating that the workpiece microstructure has little effect on the FSW process relative to the tool rotation speed (TRS).

Sutton et al[12] studied the microstructural properties of FSW AA2024 Al alloys. Microstructural bands rich in hard particles and poor areas are observed alternately and are associated with the onion ring pattern. The band gap is directly related to the entry of the welding tool per revolution. Well defined changes in particle size, micro hardness and concentration of base metal impurity particles (i.e., constituent particles) between different regions of the friction stir joint of AA2024 were recorded. This strip-like microstructure affects the fracture process of the welded material and the fracture path follows a region of high particle density.

Krishnan[13] discussed the impact and importance of the formation of onion rings and the nature of friction stir welding. Friction heating by tool rotation and metal extrusion due to tool forward movement forms an onion ring. The spacing of the onion rings is the same as the forward movement of the tool in one revolution. The gap is wide at the center and narrow at the edges. The interval is inversely proportional to TRS.

Sato et al[14]Aluminium alloys 6063 friction-stir welded at different rotational speeds under tempering conditions of T4 and T5. Increasing the rotational speed increases the maximum temperature of the weld, causing the particle size to increase exponentially. 6063-T5 showed a decrease in hardness near the center of the weld while the hardness was homogeneous at 6063-T4. The increase in hardness due to aging after welding was small in the agitation area of the weld produced at low rotational speed due to the increase in the volume fraction of PFZ.

Peel et al[15] welded AA5083 aluminium alloy under various conditions by friction stir welding. We studied the effect of welding speed on microstructure, mechanical properties and residual stress. Welding properties were dominated by heat input rather than mechanical deformation. Recrystallization of the weld zone and increase of the weld velocity reduced the weld zone size. Residual stresses in the weld zone were subjected to tensile forces both in the transverse direction and in the longitudinal direction. The maximum longitudinal residual stresses increased with the welding speed.

Liu et al[16] studied the relationship between weld parameters and tensile properties of FSW 2017-T351 joints. For micro- and macro-defect-free FSW joints, the tensile properties of the custom joints depend only on the micro hardness distribution through the joint. If the weld pitch is greater than 0.13 mm / rev, a void defect will occur at the joint. When the pitch was less than 0.13 mm / rev, defects did not occur and tensile properties were higher. Ineffective joints failed at or near the interface between Nugget and TMAZ when moving forward. Defective joint failed at welding center. At the optimum pitch of 0.07 mm / rev, the maximum strength of the joint is equal to 82% of the base material.

Heat generation and operating regimes

Friction stir welding is different from conventional welding processes such as arc welding and laser welding using external heat or power. In the FSW, the join process uses self-generated columns. Heat generation is a complex feature of process variables such as traverse feed, rotational speed, and tool down force, material and tool design. Heat generation facilitates fine particle formation and tool movement. According to Colegrove et al[17], heat is generated due to material shear at the FSW tool pin interface. The total heat generated by the tool pin is the sum of the heat generated by the material shear and the frictional forces at the contact surface.

Song and Kovacevic[18] observed that a certain amount of heat dissipated through the base plate and the FSW tool. The relationship between the process parameters and the heat generated at the tool shoulder and the work piece interface has been established. Peel et al[19] found that welding properties are relatively dominant to thermal input rather than mechanical deformation, and the relationship between weld cracking, tool feed rate and weld strength for tool size has been established. Khandkar et al[20] introduced a process model of temperature distribution for FSW processes. Colegrove et al[21] conducted process modelling using computational fluid dynamics, which was used to investigate the sensitivity to heat, tool forces, and size of deformation area depending on tool design and FSW process conditions.

It has been understood that the heat generation and subsequent material flow are the important characteristics of FSW, which decides the quality of the weld joints.

Flow mechanism and tool design

The fundamental phenomenon of the friction stir process is the flow of soft material around the tool. The material in the weld zone is extruded between the rotating pin and the cold material around it, giving a very small deformation.Nandan et al[22]describe flow mechanism can be explained using a two-dimensional simulation that describes the streamlined form around the rotating tool for normal flow of material, as in Figure 1. The wire shows that there is a rotating area and clearly indicates the recirculation flow around the tool pin.

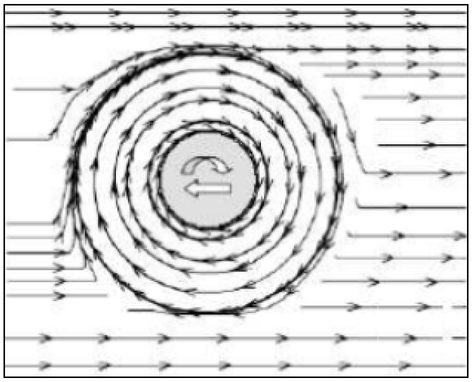

Figure 1.Simulated Stream Traces On Top Surface Of A 304 Stainless Steel Plate During FSW Process

The FSW plastic flow model was used to predict the flow rate around the tool pins. The velocity was estimated from the strain rate obtained from the correlation between particle size and strain rate. The material flow and compression at the retraction side are well influenced by the FSW process parameters, and the joint mechanical properties are improved. Numerical modeling of plastic flow has proven to be useful for FSW tool design and weld quality optimization[23].

Research has been conducted to determine the optimal dimensions of the FSW tool's shoulder and pin diameters based on plate thickness and material type. Colligan[24] found that profile pins cause additional heating and widespread plastic flow to the workpiece on either side of the butt joint as the tool rotates. Elangovan and Balasubramanian[25] analyzed the effect of tool pin shape and tool rotation speed on friction stir treatment and observed that FSW welding parameters and tool pin shape play an important role in determining weld quality. Elangovan et al[26] investigated the effects of rotational speed and pin profile of FSW tool on the formation of Friction Stirring (FSP) zone in AA2219 aluminium alloy. FSW joints are machined using FSW tools with different tool pin profiles, such as cylindrical, tapered, threaded, triangular and square. The pin length of the welding tool should be less than the working plate thickness to avoid contact with the backing plate surface and bringing debris into the weld[27]. Deqing et al[28] produced high-quality welds with the FSW tool pin diameter equal to 1/3 of the shoulder diameter. Mustafa and Adem[29] examined the effect of tool tools on the welding process. The quality of material flow and weld joints is mainly influenced by tool geometry and process parameters.

The tool pin geometry smoothes the work flow and prevents welding defects. Padmanaban and Balasubramanian[30]analyzed the FSW tool as a finite element method for tool length and diameter optimization. Weglowski and Pietras[31] analyzed the effect of specific tool geometry, speed and spindle torque on the heat generation during a friction stir process. Palanivel and Mathews[32] studied the influence of the pin profile and weld rate on the tensile properties of welded joints to dissimilar aluminium alloys. Karthikeyan and Mahadevan[33] studied welding quality of 6063 aluminium using square and pentagonal friction stir welding tool profiles.

The design of the FSW tool is essential for achieving the proper welding process and the tool pin profile improves the weld nugget structure with excellent tensile strength and hardness.

Effect of process parameters

FSW process parameters that affect weld quality for a given material and work plate thickness using a given FSW tool are down force, tool tilt angle, tool plunge, rotational speed, and traversing feedrate. Experimental studies have been conducted to explore a set of process variables to produce a robust weld with no macro defects in the FSW process.[34]

Experimental studies have been conducted to study the effects of process parameters such as fatigue life, tensile strength, weld cracking, and feed rate for FSW, spindle speed and tool size of FSW[35]. The tensile properties and fracture locations of the joints were significantly affected by the welding process parameters. There has been a notable change in the mechanical properties of FSW within a certain range of tool feed rates.[36]

The rotational speed of the spindle is considered as the most important process variable. The tool rotation stirs and mixes the material around the rotating pin, resulting in the proper heat to soften the material. Properly plasticized material prevents void formation and tool breakage. Suresh et al[37] conducted an empirical study to investigate the effects of tool rotation speed and pin profile on yield strength and elongation of welded joints. Tra[38] investigated the effect of tool rotation speed and welding speed on the mechanical properties of the FSW joints of AA6063-T5. Sivashanmugam et al[39] investigated the effect of rotating speed on the tensile strength and microstructure of the tool by performing friction stir welding butt welding of aluminium alloy sheet to the mild steel plate. The maximum tensile strength of the weld joint was observed to be 86% of the base metal aluminium.

CONCLUSIONS

Friction stir welding is a recent trend in the fabrication of metal bonding processes especially for aluminium alloys. Many studies on aluminium alloys have been conducted. In addition, various engineering industries add importance to aluminium and aluminium-based alloys as well as mild steel and alloys. This paper emphasizes the principle of FSW and important factors affecting weld quality, and critical analysis realizes possible machining studies other than aluminium alloys such as mild steel (workpiece) and cubic boron nitride (tool).

REFERENCES

1. Gibson, Brian T., et al. "Friction stir welding: Process, automation, and control." *Journal of Manufacturing Processes* 2014; 16(1): 56-73.
2. Mishra, Rajiv S., and Z. Y. Ma. "Friction stir welding and processing." *Materials science and engineering: R: reports* 2005; 50(1-2): 1-78.
3. Bozkurt, Yahya. "The optimization of friction stir welding process parameters to achieve maximum tensile strength in polyethylene sheets." *Materials & Design* 2012; 35: 440-445.
4. G.Elatharasan, V.S.Senthil Kumar, “An experimental analysis and optimization of process parameters on friction stir welding of AA6061-T6 aluminium alloy using RSM”, Proceedia Engineering 2013;64: 1227-1234
5. Kwon, Y. J., Ichinori Shigematsu, and Naobumi Saito. "Dissimilar friction stir welding between magnesium and aluminium alloys." *Materials Letters* 2008; 62(23): 3827-3829.
6. Moreira, P. M. G. P., et al. "Mechanical and metallurgical characterization of friction stir welding joints of AA6061-T6 with AA6082-T6." *Materials & design* 2009; 30(1): 180-187.
7. Minak, G., et al. "Fatigue properties of friction stir welded particulate reinforced aluminium matrix composites." *International Journal of Fatigue* 2010; 32(1): 218-226.
8. Chen, Thaiping. "Process parameters study on FSW joint of dissimilar metals for aluminium–steel." *Journal of materials science* 2009; 44(10): 2573-2580.
9. Rhodes, C. G., et al. "Effects of friction stir welding on microstructure of 7075 aluminium." *Scripta materialia* 1997; 36(1).

10. Mahoney, John M., and Stewart B. Rood. "Streamflow requirements for cottonwood seedling recruitment—an integrative model." *Wetlands* 1998; 18(4): 634-645.
11. Murr, L. E., et al. "Intercalation vortices and related microstructural features in the friction-stir welding of dissimilar metals." *Materials Research Innovations* 1998; 2(3): 150-163.
12. Sutton, Michael A., et al. "Banded microstructure in 2024-T351 and 2524-T351 aluminium friction stir welds: Part II. Mechanical characterization." *Materials Science and Engineering: A* 2004; 364(1-2): 66-74.
13. Krishnan, K. N. "On the formation of onion rings in friction stir welds." *Materials science and engineering: A* 2002; 327(2): 246-251.
14. Sato, Yutaka S., Mitsunori Urata, and Hiroyuki Kokawa. "Parameters controlling microstructure and hardness during friction-stir welding of precipitation-hardenablealuminium alloy 6063." *Metallurgical and Materials Transactions A* 2002; 33(3): 625-635.
15. Peel, M., et al. "Microstructure, mechanical properties and residual stresses as a function of welding speed in aluminium AA5083 friction stir welds." *Acta materialia* 2003; 51(16): 4791-4801.
16. Liu, H. J., et al. "Mechanical properties of friction stir welded joints of 1050–H24 aluminium alloy." *Science and technology of welding and joining* 2003; 8(6): 450-454.
17. Colegrove, Paul A., and Hugh R. Shercliff. "3-Dimensional CFD modelling of flow round a threaded friction stir welding tool profile." *Journal of materials processing technology* 2000; 169(2): 320-327.
18. Song, M., and R. Kovacevic. "Thermal modeling of friction stir welding in a moving coordinate system and its validation." *International Journal of machine tools and manufacture* 2003; 43(6): 605-615.
19. Peel, M., et al. "Microstructure, mechanical properties and residual stresses as a function of welding speed in aluminium AA5083 friction stir welds." *Acta materialia* 2003; 51(16): 4791-4801.
20. Khandkar, M. Z. H., Jamil A. Khan, and Anthony P. Reynolds. "Prediction of temperature distribution and thermal history during friction stir welding: input torque based model." *Science and technology of welding and joining* 2003; 8(3): 165-174.
21. Colegrove, Paul A., Hugh R. Shercliff, and Rudolf Zettler. "Model for predicting heat generation and temperature in friction stir welding from the material properties." *Science and Technology of Welding and Joining* 2007; 12(4): 284-297.

22. Nandan, R. G. G. R., et al. "Three-dimensional heat and material flow during friction stir welding of mild steel." *Acta Materialia* 2007; 55(3): 883-895.
23. Jata, KVa, and SLa Semiatin. *Continuous dynamic recrystallization during friction stir welding of high strength aluminium alloys*. No. AFRL-ML-WP-TP-2003-441. Air force research lab wright-patterson afb oh materials and manufacturing directorate, 2000.
24. Colligan, K. "Material flow behavior during friction welding of aluminium." *Weld J* 1999; 75(7): 229s-237s.
25. Dubourg, L., and P. Dacheux. "Design and properties of FSW tools: a literature review." *Proceedings of the 6th International Symposium on Friction Stir Welding, Saint Sauveur, Quebec, Canada*. 2006.
26. Elangovan, K., and V. Balasubramanian. "Influences of pin profile and rotational speed of the tool on the formation of friction stir processing zone in AA2219 aluminium alloy." *Materials Science and Engineering: A* 2007; 459(1-2) : 7-18.
27. Chao, Yuh J., X. Qi, and W. Tang. "Heat transfer in friction stir welding—experimental and numerical studies." *Journal of manufacturing science and engineering* 2003; 125(1): 138-145.
28. Deqing, Wang, Liu Shuhua, and Cao Zhaoxia. "Study of friction stir welding of aluminium." *Journal of materials science* 2004; 39(5): 1689-1693.
29. Padmanaban, G., and V. Balasubramanian. "Selection of FSW tool pin profile, shoulder diameter and material for joining AZ31B magnesium alloy–an experimental approach." *Materials & Design* 2009; 30(7): 2647-2656.
30. Boz, Mustafa, and Adem Kurt. "The influence of stirrer geometry on bonding and mechanical properties in friction stir welding process." *Materials & Design* 2004; 25(4): 343-347.
31. Padmanaban, G., and V. Balasubramanian. "Selection of FSW tool pin profile, shoulder diameter and material for joining AZ31B magnesium alloy–an experimental approach." *Materials & Design* 2009; 30(7): 2647-2656.
32. Węglowski, M. St, and A. Pietras. "Friction stir processing-analysis of the process." *Archives of metallurgy and materials* 2011; 56(3): 779-788.
33. Palanivel, R., P. Koshy Mathews, and N. Murugan. "Development of mathematical model to predict the mechanical properties of friction stir welded AA6351 aluminium alloy." *Journal of engineering science and technology review* 2011; 4(1): 25-31.
34. Karthikeyan, P., and K. Mahadevan. "Using Square and Pentagonal Profiled Tools." *Journal of applied sciences* 2012; 12(10): 1026-1031.

35. Threadgill, P. L., et al. "Friction stir welding of aluminium alloys." *International Materials Reviews* 2009; 54(2): 49-93.
36. Seidel, T. U., and Anthony P. Reynolds. "Two-dimensional friction stir welding process model based on fluid mechanics." *Science and technology of welding and joining* 2003; 8(3): 175-183.
37. Ericsson, Mats, and Rolf Sandström. "Influence of welding speed on the fatigue of friction stir welds, and comparison with MIG and TIG." *International Journal of Fatigue* 2003; 25(12): 1379-1387.
38. Suresha, C. N., B. M. Rajaprakash, and Sarala Upadhya. "A study of the effect of tool pin profiles on tensile strength of welded joints produced using friction stir welding process." *Materials and Manufacturing Processes* 2011; 26(9) : 1111-1116.
39. Tra, Tran Hung, Masakazu Okazaki, and Kenji Suzuki. "Fatigue crack propagation behavior in friction stir welding of AA6063-T5: Roles of residual stress and microstructure." *International Journal of Fatigue* 2012; 43: 23-29.
40. Sivashanmugam, M., et al. "A review on friction stir welding for aluminium alloys." *Frontiers in Automobile and Mechanical Engineering-2010*. IEEE, 2010.