IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

MECHANICAL BEHAVIOUR OF DISSIMILAR ALUMINIUM ALLOYS WITH EFFECT OF TOOL OFFSET BY USING FRICTION STIR WELDING

[1]Reddy Ravi Sankar, [2]J Kiran Kumar, [3]S Vamsi, [4]G S M Venkata Subbarao, [5]D Sai Mahesh

[1,2,3,4,5] B.Tech Final Year Student
[1,2,3,4,5] Department of Mechanical Engineering
[1,2,3,4,5] Visakha Institute of Engineering and Technology, Visakhapatnam, A.P, India.

Abstract: Friction stir welding (FSW) is a solid (not molten metal) joining technique in situations where the properties of the original metal must be preserved as much as possible. It involves mechanically mixing two metals together, softening them, and then forcing them together, like clay, mass, and grinding. In most cases, large parts that cannot be easily heated are joined afterwards to maintain the controlled properties of aluminum during this process.

Light metal alloys such as aluminium, magnesium and their compounds can now be joined by friction, which significantly stimulates welding. In this work, different aluminum alloy sheets AA2024 – AA7075 and AA6063-AA6069 were used for square tools. The tool parameters considered are 1600 rpm, 120 mm/min stroke and four offset values of 0 mm, 0.5 mm, 1 mm and 1.5 mm. Mechanical properties such as tensile strength, hardness and flexural strength were examined using standard testing procedures. It can be clearly seen the increase in the offset value due to the increase in tensile strength in the case of AA202-AA7075, but slight declines were observed in AA6063-AA6069. A higher hardness is observed in the compact and relatively economical HAZ, the smallest value in the base metal. The bending strength of the metal is lower, but between the 1.5mm thickness of the tape it provides better bending strength.

Index Terms: Friction-stir welding (FSW), AA2024, AA7075, AA6063, AA6069 and Mechanical Properties.

I. INTRODUCTION

Friction Stir Welding (FSW) is considered a solid state joining process because the heat generated by the process does not reach the melting temperature of the materials being joined. FSW has been around for more than 25 years, it was developed in 1991 at The Welding Institute (TWI) in the UK. FSW allows for the joining of materials that, by traditional welding technologies, are considered to be non-weldable, these are materials that traditional welding would have poor solidification microstructure, porosity in the fusion zone, and a significant loss of mechanical properties as compared to the base materials (i.e. dissimilar material, Mg alloys, some aluminum alloys, copper, titanium etc.). In the FSW process (see Fig.1.1), a non-consumable cylindrical tool with a shoulder and pin is used as a stirrer. The tool is fixed to a milling machine chuck and is rotated along the longitudinal axis (Fig.1.2 (a) shows the modified milling machine used in this study). The work pieces to be welded can be butted up or overlapped to one another and are then clamped to stay stationary and withstand the large applied forces (Fig.1.2 (b) shows the clamping system used in this study). The clamping prevents the workpiece from spreading. The rotating tool pin is then inserted into the work piece at the joint, and the shoulder is forced into contact with the work piece surface. The contact between the workpiece surface and the tool shoulder causes friction heating of the material being joined. The tool is then moved transversely along the joint.

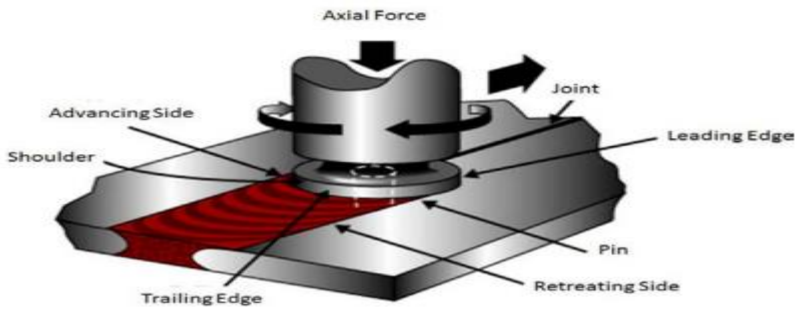


Fig.1.1: Schematic of the FSW

As the tool rotates and moves along the joint, the combination of the friction heating and the pin stirring causes the material is softened and stirred together forming a weld. This is done all while keeping the temperature below the melting point of the base materials. Once the tool reaches the end of the joint the tool is retracted out of the work piece. Four steps of the FSW have been shown in Fig.1.3.

Fig.1.2: (a) Modified milling machine & (b) Clamping system

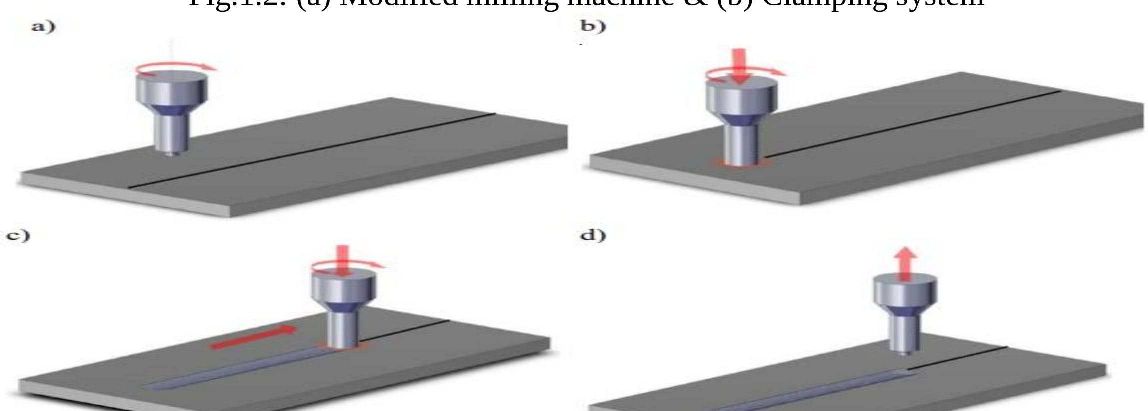


Fig.1.3. Four steps of the FSW including a) initial set up, b) tool plunging, c) traverse, d) tool withdrawal.

1.1 Working Principle

As depicted in a traversely fed cylindrical-shouldered tool with a profiled nib is continuously rotated and fed into a butt joint between two clamped pieces of butted material. The tool shoulder rides at the top of the work surface, and the nib is just a little bit shorter than the needed weld depth. The process two movements namely initial downward movement of tool outside the workpiece and lateral movement of the tool along the work piece.

Frictional heat is produced between the work parts and the wear resistant welding components. The heat produced by the stirring action causes the materials to soften without melting, combined with heat from the mechanical mixing process and internal adiabatic heat. A unique design on the pin's leading face drives plasticized material to the back as it is advanced, where clamping force helps to forge the weld into place.

1.2 Work piece Material

- **ALUMINIUM ALLOY AA2024:**

Table 1.1.Mechanical Properties of AA2024 & AA7075

Properties	
Density (g/cm^3)	2.77
Poisson's Ratio	0.33
Elastic Modulus (GPa)	70-80
Tensile Strength (Mpa)	185
Yield Strength (Mpa)	76
Elongation (%)	20
Hardness (HB500)	47
Shear Strength (MPa)	125
Fatigue Strength (MPa)	90

Properties	
Density (g/cm3)	2.8
Poisson's Ratio	0.33
Elastic Modulus (GPa)	70-80
Tensile Strength (Mpa)	220
Yield Strength (Mpa)	95
Elongation (%)	17
Hardness (HB500)	60
Shear Strength (MPa)	150
Fatigue Strength (MPa)	160

- **ALUMINIUM ALLOY 6063:**

Table 1.2. Mechanical Properties of AA6063

Properties	
Density (g/cm3)	2.7
Poisson's Ratio	0.33
Elastic Modulus (GPa)	70-80
Tensile Strength (Mpa)	90
Yield Strength (Mpa)	48
Elongation (%)	26
Hardness (HB500)	25
Shear Strength (MPa)	69
Fatigue Strength (MPa)	55

- **ALUMINIUM ALLOY 6069:**

AA6069 is a new entry to the family of 6000 series of heat treatable Mg Si-Cu aluminium alloys. Although the available data is insufficient to determine design mechanical property values for 6069, it does show that the alloy's ultimate and yield tensile strengths for the T6 condition are almost 40% greater than those of its sister alloy, 6061, and nearly identical to those of 6013- T6 sheet. It does not seem that 6061 has worse corrosion resistance than it. Currently used products include tubes for light bicycle frames and high pressure seamless gas containers that are manufactured by either hot or cold impact extrusion.

II. EXPERIMENTAL PROCEDURE

The edges of the sheets or plates that need to be connected are inserted into one another, and a non-consumable rotating tool with a specifically shaped pin and shoulder is moved along the connection line. The tool's two main purposes are to move the material to create the joint and to heat the work piece. By creating friction between the tool and the workpiece and causing the workpiece to flex plastically warmth is produced. The material surrounding the pin is softened by the localized heating and material is moved from the front to the back of the pin as a result of tool rotation and translation. This procedure results in the solid state production of a joint. Due of the tool's various geometrical characteristics, are given in Table.2.1

Table 2.1. FSW Parameters and Tool Dimensions

Process parameters	Values
Rotational speed (rpm)	1800
Traverse speed (mm/min)	120
Tool offset(mm)	0,0.5,1,1.5
Axial force (kN)	12
D/d Ratio of tool	3
Pin length (mm)	6 and 5.7
Tool shoulder diameter, D (mm)	18
Pin diameter, d (mm)	6

Work pieces were cut into the dimension of 100x50x6mm for AA2024 – AA7075 combination and 100x50x6 mm for AA6063 – AA6069 combination. Welding was done for the above discussed parameters. For each offset values three samples were welded. Experimental setup is shown.

Fig.2.1.Experimental setup for FSW

2.1 Plunge depth

At the preliminary stage of using designs the plunge depths used were 3.5mm the plunge depths varied from one shoulder diameter to the other, because of the different sizes of the shoulder diameters used. From literature, it was reported that when the tool is tilted, it gives rise to a shoulder plunge, Shoulder plunge, p can be calculated as:

$$P = 0.5\ D \sin \theta$$

Where, P = Shoulder plunge

D = Shoulder Diameter

θ = Tilt angle

The effective plunge depth is the sum of the nominal plunge depth and the shoulder plunge depth. The effective plunge depth used for the final weld matrix was 3.5 mm, as calculated below. The plunge rate is 0.5 mm/min and the position control setting was used to make all the welds.

For the 18 mm shoulder diameter tool,

the shoulder plunge is: P = 0.5 x 18 sin 30 = 0.47 mm

The nominal plunge depth used for welding was 2.65 mm,

The effective plunge depth = 2.65 mm + 0.47 = 3.12 mm.

2.2 Tool tilt

Tilting the tool so that the rear of the tool is lower than the front has been found to assist the forging process and the material flow during FSW. Welds were made by varying the tool tilt angles between 2.5^{O} and 35^{O}. The resulting weld top surface appearances. It was observed that at 1o tilt, the front end of the shoulder did not touch the material at the exit hole at 2.5deg. Tilt angles, there was significant flash. Therefore at 35^{0}. Tilt, which gave a good weld without visible defect and less flash, was chosen for the final weld matrix.

III. RESULTS & DISCUSSION

Friction Stir Welding was used to make butt joint between AA2024 – AA7075 and AA6063 – AA6069 with 4 types of offset values namely 0mm, 0.5mm, 1mm and 1.5mm. Mechanical tests like tensile test, bending test and hardness were conducted to evaluate their property. Also changes in microstructure were studied. All the results are discussed in detail in this chapter.

3.1 WELDING PROCESS

The tool often has a shoulder and a square pin on it. The pin's length is just a little bit less than the thickness of the plates that will be welded. In FSW, however, there are only three process variables; i.e., rotational speed, transverse speed and pressure that need to be controlled. Therefore, due to the excellence performance in welding technology as compared to fusion methods, FSW has been successfully used in many applications such as aerospace, shipbuilding, aircraft, and automobile industries. Fig.3.1. shows the Friction Stir Welding of AA6063 – AA6069 with 1.5mm offset

Fig.3.1. FSW with 1.5mm offset

Fig.3.2. Welded Specimens (AA6063- AA6069)

3.2 RESULTS OF TENSILE TEST

The experimentally evaluated transverse tensile properties of base metals (AA2024 and AA7075) are given in Table 3.1. Ultimate tensile strength of the AA7075 is observed as 582MPa whereas for AA2024 is 461 MPa. Percentage of elongation clearly shows AA7075 is harder to deform compared with AA2024. Tensile strength of weldment of AA2024-AA7075 is given in Table for different offset values.

Fig. 3.3. Tensile test specimen after test

It is observed that ultimate tensile strength of the weldment is comparatively smaller. But when the tool is advanced towards AA7075 increase in ultimate tensile stress is observed. Maximum value is achieved when the offset is 1mm from neutral line. When the tool is further moved to 1.5mm decrease in ultimate tensile stress is observed.

Table: 3.1. Mechanical test result of Base Metal 2024 – 7075

S.No	Base Metal	Yield stress (MPa)	Ultimate tensile strength (MPa)	Percentage of elongation (%)	Bending load (KN)
1	2024	367. 78	461.1	12.3	8.23
2	7075	520. 17	582.3	10.14	11.39

Fig 3.4.Graphical representation of Tensile strength Base metal AA7075 & AA2024

Table: 3.2 Tensile Strength of Weldment (AA2024 – AA7075)

Tool position	Force maximum KN	Ultimate tensile stress MPa
0 mm Offset	4.23	55.03
0.5 mm Offset	6.39	81.13
1.0 mm Offset	14.01	181.09
1.5 mm Offset	12.31	167.14

Table 3.3 Tensile Strength of Base Metal 6063- 6069

S.No	Tests	Sample (6063)	Sample (6069)
1	Max.force KN	15.17	12.89
2	Ultimate tensile stress MPa	181.69	151.53
3	% of EL	24.12	26.24
4	Yield stress MPa	132.53	104.51

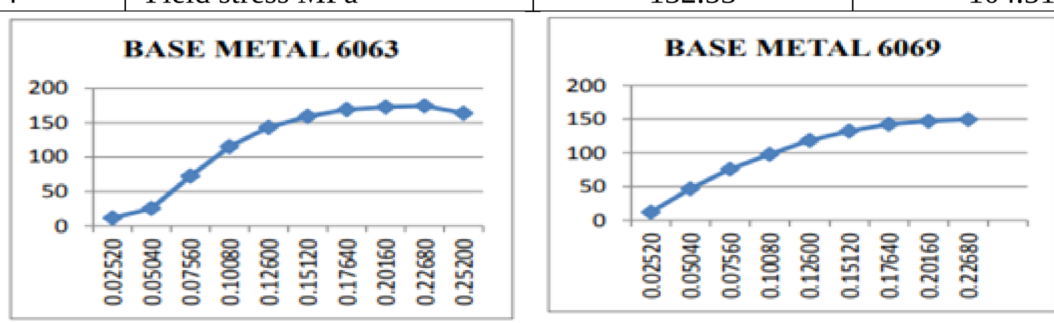


Fig.3.5. Graphical representation of Tensile Strength of Base Metal AA6063-AA6069

Table: 3.4 Tensile Properties of AA6063 and AA6069

Tool position	Force maximum KN	Ultimate tensile stress MPa
0 mm Offset	9.51	121.22
0.5 mm Offset	11.08	137.08
1.0 mm Offset	9.83	123.14
1.5 mm Offset	11.75	144.85

3.3 BENDING STRENGTH

3.3.1 BENDING STRENGTH OF AA2024- AA7075

Table: 3.5 Bending strength for AA2024-AA7075

METAL	BENDING LOAD (KN)
AA7075	11.58
AA2024	8.11
WELDMENT	
0.0 mm OFFSET	1.75
0.5 mm OFFSET	3.91
1.0 mm OFFSET	3.79
1.5 mm OFFSET	5.53

Bending strength of the weldment is observed as smaller value when compared with base metal. Maximum bending strength of weldment is observed when the offset in 1mm similar to tensile strength.

3.3.2 BENDING STRENGTH OF AA6063- AA6069

Table: 3.6 Bending strength for AA6063- AA6069

METAL	BENDING LOAD (KN)
AA6063	3.51
AA6.69	3.23
WELDMENT	
0.0 mm OFFSET	2.28
0.5 mm OFFSET	1.91
1.0 mm OFFSET	2.19
1.5 mm OFFSET	3.11

3.4 RESULTS OF HARDNESS TEST

Vicker's hardness test was conducted on the base metals and their weldments at different places and average values are calculated and shown in Table 3.7.

HARDNESS OF AA2024-AA7075

Table: 3.7 Hardness for AA2024- AA7075

WELDMENT	AA7075 BASE METAL	AA7075 HAZ	WELDZONE	AA2024 HAZ	AA2024 BASE METAL
0 mm Offset	114.13	124.6	144.10	122.81	114.03
0.5mm Offset	133.49	130.70	145.72	147.25	118.37
1.0mm Offset	105.46	124.81	147.13	126.07	103.13
1.5mm Offset	117.13	124.33	134.92	149.44	118.60

HARDNESS OF AA6063-AA6069

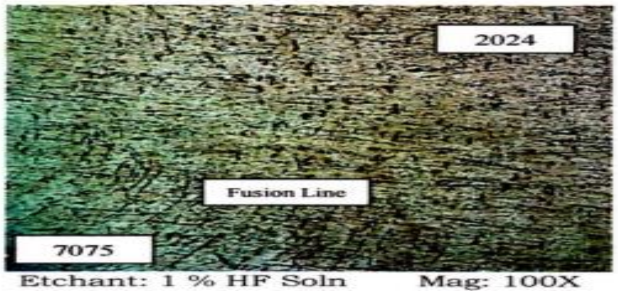
Table: 3.8 Hardness of AA6063-AA6069

WELDMENT	AA7075 BASE METAL	AA7075 HAZ	WELDZONE	AA2024 HAZ	AA2024 BASE METAL
0.5mm Offset	53.18	56.63	59.62	58.16	54.12
1.0mm Offset	56.89	59.51	70.363	59.61	55.85
1.5mm Offset	50.14	52.19	60.36	58.20	54.58

3.5 MICROSTRUCTURE

The optical micrographs of base metal and weld region of FSW joints of AA2024 – AA7075 are shown in Fig 3.6 A to D.

RESULTS OF AA2024-AA7075



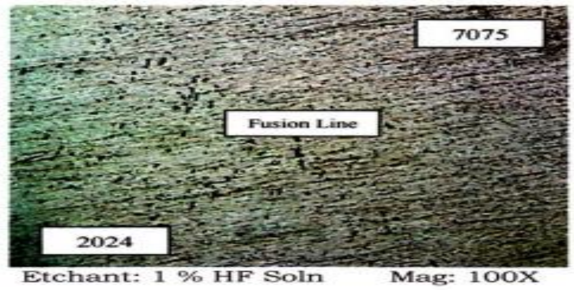
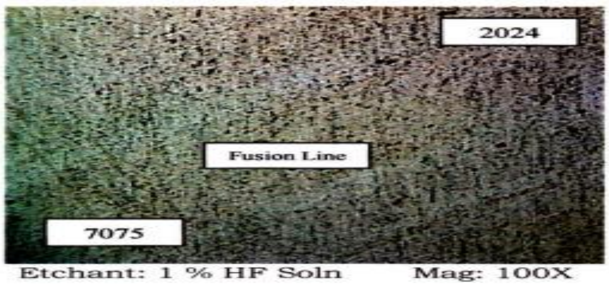
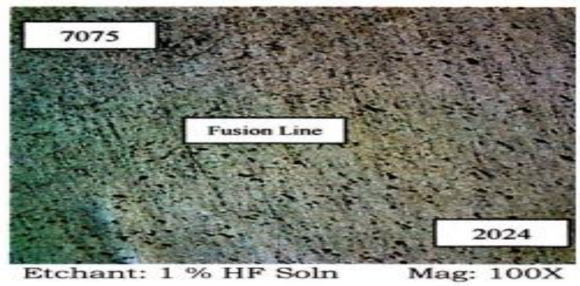


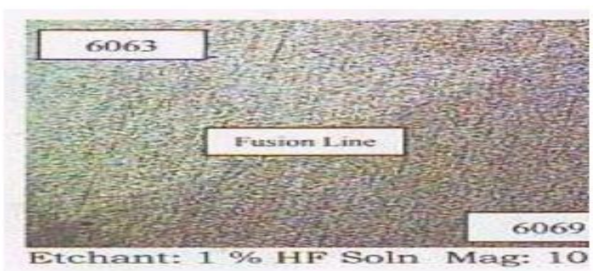
Fig.3.6 (A) 0 mm Offset, (B) 0.5 mm Offset





(C) 1 mm Offset (D)1.5 mm Offset

Microstructures of weldment of AA6063 – AA6069 are shown in Fig.3.7 A to C



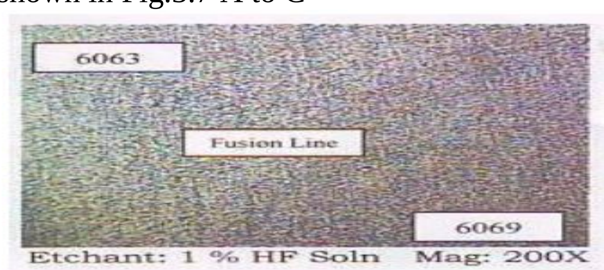


Fig.3.7 (A) 0 mm Offset (Magnification 100X) (B) 0 mm Offset (Magnification 200X)

(C) 0 mm Offset (Magnification 500X)

Displayed is the macrostructure of the cross-section of joints. There is no proof that all joints have widespread problems. The macrostructure of the joints shows a noticeable fluctuation in the width of the weld zone as a result of the welding operations' variable heat input. The base metal and weld region optical micrographs of the FSW joints are displayed. It is clear from the micrographs that no matter the welding procedure, the grains in the fusion zone are finer than those in the base metal. Finer grain is present in FSW joints near the weld.

3.6 DISCUSSION

The tensile properties (yield strength, elongation) of FSW joint is superior in yield strength and tensile strength of FSW joint is greatly used to enhance the endurance limit of their joint and hence fatigue crack initiation is delayed. Large elongation (higher ductility) of the FSW joint also impact greater resistance to fatigue crack propagation and hence fatigue is delayed. The combined effort of higher yield strength and higher ductility of the FSW joint offers enhanced resistance to crack initiation and crack propagation.

The microstructure of fusion zone of FSW joint consists of fine equalized grains compared to other joints. Due to high welding speed and fast recrystallization the fusion zone characterized by very fine grains that resulted in increase in hardness. A large number of precipitates distributed in the matrix are visible in the stir zone which is not observed in the base alloy.

Microstructure of the welded joints, the weld region of FSW joint consists of very fine dynamically recrystallised grains. Naturally, a material with fine grains will have a larger layer grain boundary area, which will increase its resistance to a developing fatigue crack. More resistance to the expanding fatigue fracture is provided by grain boundaries than grain interiors because of their high energy level of stored energy. To test the process, the FSW of the butt joint of two aluminium alloy sheets of pertinent dimensions was used.

The generated estimated distributions demonstrate a strong capacity of the model to predict the temperature distribution when compared to experimentally recorded ones. Also, while requiring much more computational effort, the results are quite similar to those that were already achieved. As compared to the other examined methodologies, the proposed procedure can then enable considerable time savings, producing a useful research and industrial tool for lengthy numerical investigations.

3.7 CONCLUSION

Analysis has been done on the mechanical characteristics of the dissimilar FSW AA2024-AA7075 and AA6063- AA6069 aluminium alloys. By moving the rotating tool on the AA7075 and 6063 tool advancing side, the variation in tensile strength, hardness, bending test, and microstructure has been measured as a function of the rotating tool distance from the weld line. The mechanical qualities of the welds were clearly shown to grow significantly with increasing distance from the weld line up to 1mm, after which a reasonable decline is noticed increasing such a parameter.

In the case of AA6063 – AA6069, It was amply established that as the distance from the weld line increases, the mechanical properties of the weld change significantly.

REFERENCES

[1] Cavaliere.P Panella.F,"Effect of tool position on the fatigue properties of dissimilar 2024-7075 sheets joined by friction stir welding", Journal of materials processing technology, 2 0 6 (2008) 249– 255.

[2] Prasad, R., Kumar, H., Kumar, P., Tewari, S.P., Singh, J.K.Microstructural, Mechanical and Tribological Characterization of Friction Stir Welded A7075/ZrB2 In Situ Composites (2021) Journal of Materials Engineering and Performance, 30 (6), pp. 4194-4205.

[3] Suhin, S., Robin Divahar, S., Edwin Raja Dhas, J., Anton Savio Lewise, K., Satyanarayana Gupta, M. Optimizing FSW process parameters using RSM and regression analysis for similar and dissimilar aluminium materials(2022) Materials Today: Proceedings, 64, pp. 368-373

[4] Cavaliere.P,Squillace.A,"Effect of welding parameters on mechanical and microstructural properties of dissimilar AA6082-AA2024 joints produced by friction stir welding" Material Science, Forum 519-521, 1163–1168 (Trans Tech Publications), 2006.

[5] Koilraj.M,Sundareswaran.V,Vijayan. S, Koteswara Rao.S.R, "Friction stir welding of dissimilar aluminium alloys AA2219 to AA5083 – Optimization of process parameters using Taguchi technique" Materials and Design 42 (2012) 1–7.

[6] Elangovan.K, Balasubramanian.V,Valliappan.M, "Influences of tool pin profile and axial force on the formation of friction stir processing zone in AA6061 aluminium alloy" International Journal of Advanced Manufacturing Technology 2008; 38:285–95.

[7] Rao, G.A., Kumar, B.R., Kumar, G.N., Mahender, P., Kumar, T.U. Study the effect process of parameters on friction welding of dissimilar metals AISI 304 steel and AA 2219 aluminium (2021) AIP Conference Proceedings, 2317, art. no. 030013.

[8] Prasad, R., Kumar, H., Kumar, P., Tewari, S.P., Singh, J.K.Filler Dispersion and Unidirectional Sliding Characteristics of As-Cast and Multi-Pass Friction Stir Processed ZrB2/AA7075 In-Situ Composites (2021) Journal of Tribology, 143 (8), art. no. 081701.

[9] Hamilton.C,Dymet.S and Sommers.A, "A thermal model of friction stir welding in aluminium alloys", International Journal of Machine Tools Manufacturing, 48,2008, 1120-1130.

[10] Assidi.M, Fourment.L,Guerdoux.S, Nelson.T, "Friction model for friction stir welding process simulation: calibrations from welding experiments", International Journal of Machine Tools Manufacturing, 50 (2) (2010) 143–155.

[11] Edwin Raja Dhas, J., Anton Savio Lewise, K., Laxmi, G. Submerged arc welding process parameter prediction using predictive modeling techniques (2022) Materials Today: Proceedings, 64, pp. 402- 409.

[12] Deepika, A.U., Abheendra, B., Harish, C.V., Surendra, N., Meghanath, G. Wetting and corrosion studies on SS304 material surfaces (2021) AIP Conference Proceedings, 2317, art. no. 020043.

[13] Khaled T. An outsider looks at Friction stir welding. Federal Aviation Administration. Report number: ANM-112N-05-06, 2005.

[14] Mishra RS, Mahoney MW. Introduction. In: Friction stir welding and processing. Mishra RS, Mahoney MW (ed.) Materials Park Ohio: ASM International; 2007.

[15] Mishra RS, Ma ZY. Friction stirs welding and processing. Materials Science and Engineering R. 2005; 50: p1-78.

[16] Rhodes CG, Mahoney MW, Bingel WH, Spurling RA, Bampton CC. Effects of friction stir welding on microstructure of 7075 aluminum. Scripta Materialia. 1997; 36(1): p. 69-75.

[17] Jata KV, Semiatin SL. Continuous dynamic recrystallization during friction stir welding of high strength aluminum alloys. ScriptaMaterialia2000; 43(8): p. 743-749.

[18] Dawes CJ, Thomas WM. Development of improved tool designs for friction stir welding of aluminum. 1stInternational FSW symposium, Thousand Oaks, CA, USA. June 1999. TWI (UK). Retrieved: CD-ROM.

[19] Steuwer A, Peel MJ, Withers PJ. Dissimilar friction stir welds in AA5083- AA6082: The effect of process parameters on residual stress. Materials Science and Engineering 2006; 441: p. 187-196.

[20] Fuller C, Mahoney M, Bingel W. A study of friction stir processing tool designs for micro structural modifications as demonstrated by aluminum fusions welds. 5th International FSW symposium, Metz, France. 14-16 September2004. TWI (UK). Retrieved: CD-ROM.

[21] Nelson TW, Hunsaker B, Field DP. Local texture characterization of friction stir welds in 1100 Aluminum. 1st, International FSW symposium, Thus and Oaks, CA. 14-16 June 1999.TWI (UK). Retrieved: CD-ROM.

[22] Stahl AL, Sorensen CD. Experimental measurements of load distributions on friction stir welding pin tools. Friction Stir Welding and Processing III. Jata 65 KV, Mahoney MW, Mishra RS, Semiatin SL, Lienert T (eds.) Minerals, Metals and Materials Society (TMS). 2005. p. 179-190.

[23] Guerra M, Schmidt C, McClure JC, Murr LE, Nunes AC. Flow patterns during friction stir welding. 2003. Materials Characterization2003; 49: p. 95-101.

[24] Thomas WM, Braithwaite ABM, John R. Skew-Stir™ technology.3rd International FSW Symposium. Kobe, Japan. 27-28 September 2001.Retrieved: CD-ROM.

[25] Thomas WM, Dolby RE. Friction stirs welding developments. 6th International conference on trends in welding research. Georgia, USA. ASM International. 15-19 April 2002.