Optimization And Characterization of Friction Stir Welding of Aa6061/Aa8011 Dissimilar Joints

R. Thamizhini[1], K.T. Thilagham[2], and, D. Noorullah[3]

[1]*PG Student, Department of Metallurgical Engineering, Government College of Engineering, Salem-11*

[2]*Assistant Professor, Department of Metallurgical Engineering, Government College of Engineering, Salem-11*

[3]*Head of the Department, Department of Metallurgical Engineering, Government College of Engineering, Salem-11*

Abstract: **Friction stir welding tool geometry plays a critical role in material flow and governs the transverse rate at which FSW can be conducted. The tool serves three primary functions, i.e., (a) heating of the work piece, (b) movement of material to produce the joint, and (c) containment of the hot metal beneath the tool shoulder. This experimental study on dissimilar aluminum alloys AA 8011 and AA6061 friction stir welded with tapper cylindrical tool pin by using FSW process. Taguchi L9 orthogonal array was used to optimize the welded joints. Here maximum tensile strength 122 N/mm^2 and minimum hardness was 44.6 HRB was achieved. Due to higher speed, minimum feed rate and maximum axial force necessitated the maximum tensile strength. Microstructural analysis showed significant grain refinement in the weld zone due to dynamic recrystallization. Subsequently, SEM analysis revealed dimple-like fracture indicating ductile failure. Finally, using Taguchi design, the best control factor and ANOVA was identified for the tensile and hardness parameters. When the speed is high and the axial force is low, the weld bead appears to have a fine texture and defect-free.**

Keywords: Friction stir welding, dissimilar joints, tensile strength, optimization.

I. INTRODUCTION

Friction-stir welding (FSW) is a solid-state joining process in which the metal is not melted during the process. Friction stir welding also produces a plasticized region of material, but in a different manner. A non-consumable rotating tool is pushed into the materials to be welded and then the central pin, or probe, followed by the shoulder, is brought into contact with the two parts to be joined. The rotation of the tool heats up and plasticizes the materials it is in contact with and, as the tool moves along the joint line, material from the front of the tool is swept around this plasticized annulus to the rear, so eliminating the interface. That is, at the contact sites, mechanical energy is converted to thermal energy without the use of extra heat. A FSW tool's primary purpose is to heat the work pieces before causing flow and restraint beneath the shoulder. FSW offers several benefits, including heating the work piece's surfaces, causing plastic deformation, swirling, and mixing the materials around the pin to establish the connection, allowing the material to flow, and lowering heat under the shoulder. Friction stir welding, as opposed to traditional welding, has several advantages over that process, including energy efficiency, no material waste, environmental friendliness, good mechanical properties, minimal pollution, and flexible joining techniques.

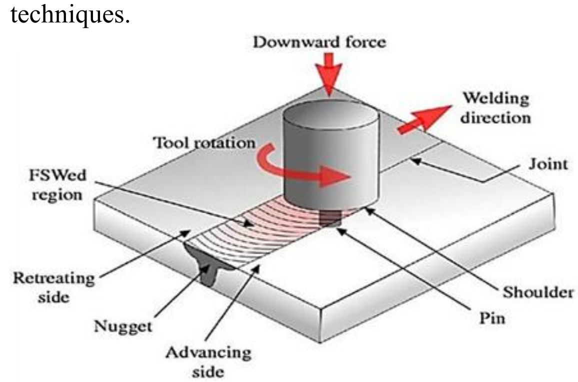


Figure. 1.1 FSW Process

When the direction of the rotating tool and the direction of the welding are the same, the retreating side is the opposite of the advancing side. The tool progresses at a specific rotational speed and travel speed while the pin is tilted at a specified angle, controlling the weld look, and thinning it out. When mixing, the mixing pin transfers the substance from the tool's front edge to its rear edge. The stirring process is brought on by pin rotation, which shatters the oxide layer. The pin length must be less than the thickness of the work piece to ensure complete closure to the bottom portion of the joint.

ALUMINIUM-6061

AA6061 has a good surface finish, high corrosion resistance, is readily suited to welding and can be easily anodized.

Applications of Aluminum AA6061

1. Shipbuilding, Motorboats, Truck bodies, & towers, Rail coaches.
2. In joining thin sheets of AA8011skin to thicker AA6061 stringers for structural integrity.
3. For connecting AA6061 frames and beams in fuselages.

ALUMINUM- AA8011

Apart from iron, aluminum is currently the next most widely used metal in the world. This is due to the fact that aluminum has a unique combination of attractive properties. Properties such as its low weight, corrosion resistance, and easy maintenance of final product, have ensured that this metal and its alloys will be in use for a very long time.

Applications of Aluminum AA8011

1.Power lines, Consumer electronics, Household and industrial appliances.
2.Aircraft hydraulic skin, Spacecraft components & Ships.
3.In repair and maintenance operations, AA6061 and AA8011 can be used together to patch or replace damaged components.

II. FSW PROCESS PARAMETERS

(a) Tool Rotation Speed

During the FSW process, the tool rotation speed (TRS) has a big impact on the quantity and rate of heat generation and, consequently, the material flow. Because of the advancing material's inadequate thermal softening, the tool will generate less heat as it advances, resultingin defect formation. As a result of poor tool rubbing, low rotational speeds of the tool result in inadequate production of heat and heat generation rate. As a result, there are defects in the fabricated joint. Higher tool rotation speeds result in nugget zone defects in FSW joints. As a result of the high rubbing force, excess heat is generated, causing turbulence in the flow of materials. Additionally, excessive plasticization makes the material soft, resulting in poor friction over the tool. Therefore, the content will slip, and defects will occur.

(b) Tool Transverse Speed (TTS)

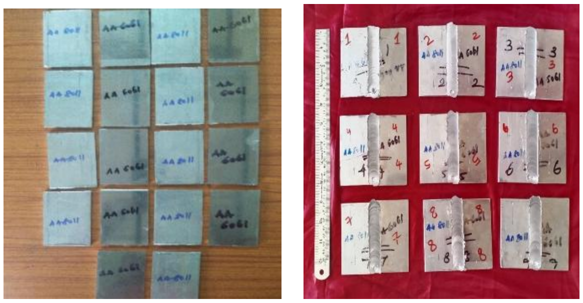
The rotational speed of the FSW tool as it moves down the welding line is known as the welding or tool transverse speed (TTS). Using high tool transverse speed (TTS) to fabricate FSW joints, defects occurred in the stir zone due to insufficient heat and material flow. The brief period of time when stirring limited the extent of thermal softening and plasticization, resulting in defective stir zones. Long stirring times at low transverse speeds result in high heatinput, which produces more significant thermal softening around the tool. Excess plasticization of material results in a reduction of the material's and tool's friction. The stir zone's defect formation was aided by the slipping state.

(c) Axial Force

Under axial force, the rotating tool generates heat, the primary welding heat source. By applying axial force, reduction in friction at this temperature between the shoulder of the nuggetindicated that frictional heat was the primary heat source. Because the upper surface of the plates to be connected and the tool shoulder are in close contact, the nugget zone is widened near the top of the surface because of the high temperature caused by higher axial forces. Whensufficient axial force is required to form a good weld, the plunge depth of the tool is directly affected by the axial force. FSW is characterized by temperature, and the axial force greatly influences temperature during friction stir welding.

III.EXPERIMENTAL DETAILS

Nine plates of AA6061 and AA8011 plates were taken with 100mm length, 50mm breath and 4mm thickness. These dissimilar plates welded by Friction stir welding using Taguchi optimization.



(a) (b)

Figure:1.2 Weld plates Before and after image100*100*4mm

TAGUCHI METHOD

DESIGN OF EXPERIMENT

Basically, experimental design methods were developed original fisher. However experimental design methods are too complex and not easy to use. Furthermore, a large number of experiments have to be carried out when the number of the process parameters increases, to solve this problem, the Taguchi method uses a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only.

Table:1 Process parameters and their levels

S.NO	SPEED rpm	FEED mm/min	AXIAL FORCE kN
1	800	5	5
2	1000	10	6
3	1200	15	7

DESIGN OF ORTHOGONAL ARRAY

Taguchi Orthogonal array is designed in minitab-17 to calculate S/N ratio.

Table: 1.1 L9 Array formation

SL.NO	SPEED rpm	FEED mm/min	AXIAL FORCE kN
1	800	5	5
2	800	10	6
3	800	15	7
4	1000	5	6
5	1000	10	7
6	1000	15	5
7	1200	5	7
8	1200	10	5
9	1200	15	6

IV. RESULTS AND DISCUSSION

ROCKWELL HARDNESS TEST

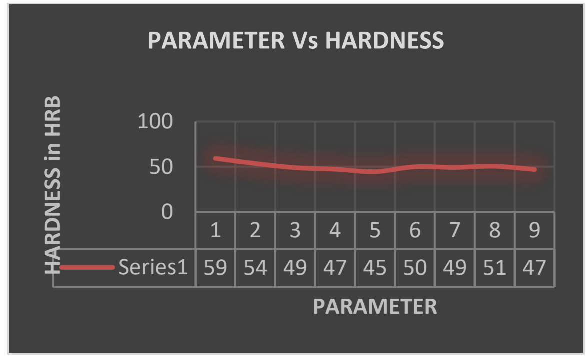


Figure: 1.3 Hardness graph

Hardness values were noted for three areas like keyhole, middle and end. The average of these three regions were taken. For the load given S_5 test plates found minimum hardness compared to others (44.6 HRB). All values are in the range of 44.6 to 59.3.

TENSILE TEST

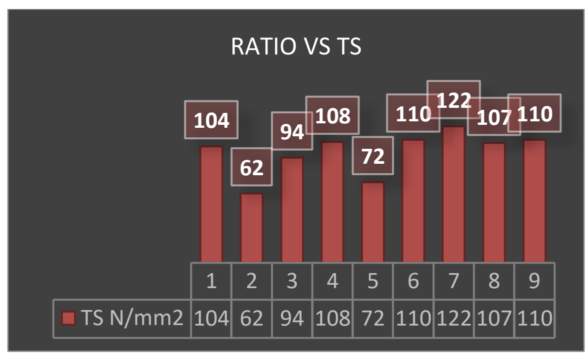


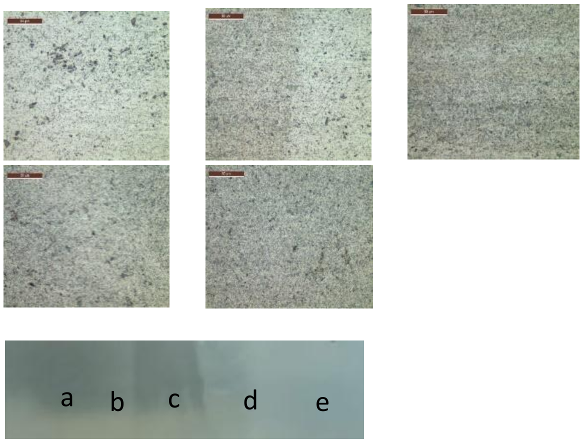
Figure: 1.4 Tensile strength graph

During the process maximum tensile strength achieved on 7th test plate. Higher speed, minimum feed rate and maximum axial force achieved maximum tensile strength.

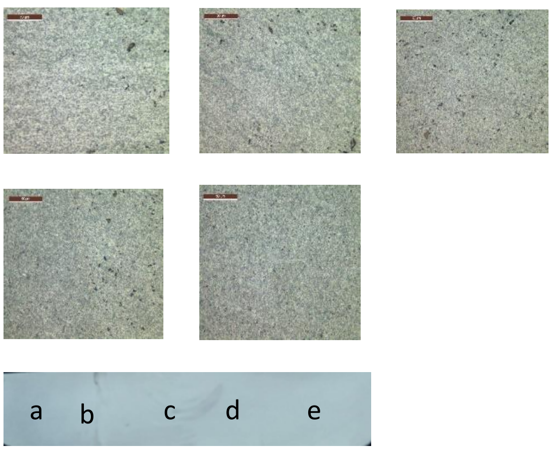
MICROSTRUCTURAL ANALYSIS:

- Etchant: Keller's reagent (190ml water, 5ml HNO_3, 3ml HCL, 2ml HF)
- Etching Time: 15sec
- Magnification: 500X

Test plate 2: Speed: 800 RPM, Feed:10 mm/min, Axial force: 6KN



Test plate 6: Speed: 1000 RPM, Feed:15 mm/min, Axial force: 5KN



Test plate 7: Speed: 1200 RPM, Feed:5 mm/min, Axial force: 7KN

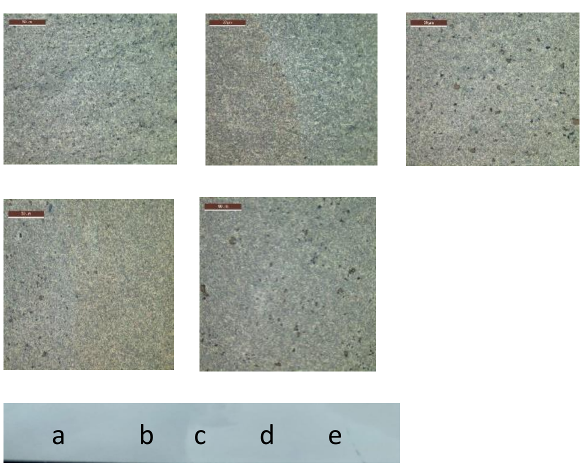
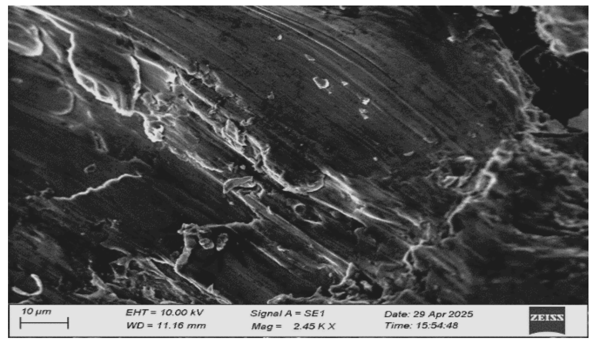


Figure 1.5: Microstructure of different zones for Test plates 2,6,7 a) AA6061 BM b) AA6061 HAZ c) SZ d) AA8081 HAZ e) AA8011BM

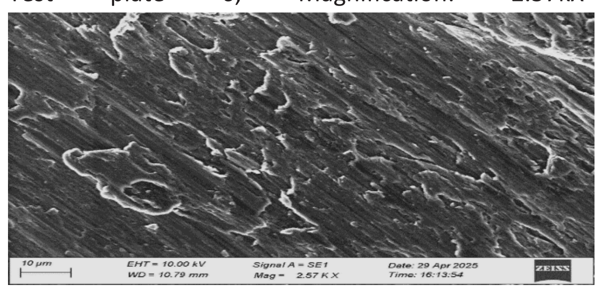
The microstructure of AA6061BM reveals α-solid solution of Al-Mg-Si with Mg_2Si precipitates and AA8011 shows α-solid solution of Al-Fe-Si. The Stir zone shows fine grained structure indicating better mixing of materials due to dynamic recrystallization.

SEM (SCANNING ELECTRON MICROSCOPY):

Test plate 2, Magnification: 2.45kX



Test plate 6, Magnification: 2.57kX



Test plate 7, Magnification: 2.29kX

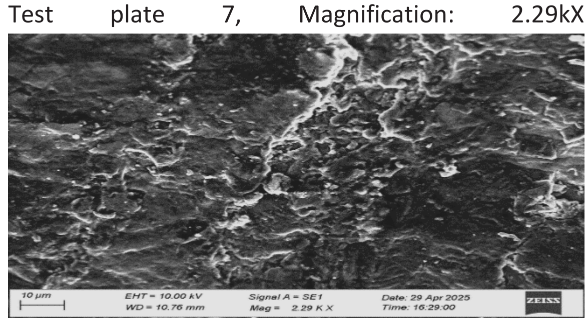


Figure1.6: SEM images of Test plate 2,6,7

Test plate 2 showed smooth flow lines indicating no major tearing or dimples is visible shows ductile fracture. Test plate 6 showed moderate roughness, presence of small dimples, mixed surface morphology shows partial bonding. Test plate 7 showed deep dimples, plastic flow patterns, void coalescence visible indicating Ductile fracture. Among all trials Test plate 7 exhibited the highest tensile strength indicating complete material mixing. However, hardness decreased slightly due to possible grain coarsening.

ANGLE DISTORTION

Angular distortion represents a specific type of perm. anent deformation that commonly occurs in welded components.

Table:1.3 Angle Distortion

TEST PLATES	1st	2nd	3rd	4th	5th	6th	7th	8th	9th
ANGLE DISTORTION	1.820°	1.182°	0.908°	1.995°	1.669°	1.457°	1.071°	0.921°	0.778°

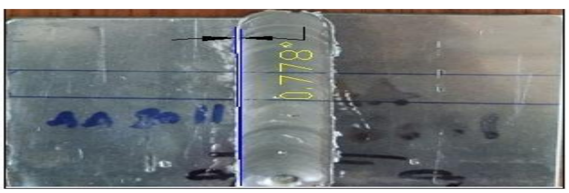


Figure: 1.7 Angle Distortion plate

Angle distortion analyzed through AUTOCADD software. During the inspection, test plate no 9 obtained minimum deviation and maximum angle distortion found on test plate no 1 from the axis.

V.CONCLUSION

The joining of two dissimilar aluminium alloys AA6061 and AA8011 using friction stir welding process by the influence of welding parameters is successfully performed and following interferences are drawn.

1.Friction stir welding of dissimilar aluminium alloys AA6061(advancing side) and AA8011(retreating side) are alloys of 4mm plates have been welded.

2.The maximum tensile strength 121 MPa was found at tool rotational speed 1200 rpm, feed 5 mm/min and axial force 7kN.

3.The minimum hardness 44.6 was found at tool rotational speed 1000rpm, feed 10mm/min, axial force 7kN.

4.The microstructure reveals α-solid solution of aluminium with its intermetallics.

5.SEM showed deep dimples, plastic flow patterns, void coalescence visible indicating Ductile fracture. This indicates complete material mixing. However, hardness decreased slightly due to possible grain coarsening.

6.Angle distortion analyzed through AUTOCADD software. During the inspection, test plate no 9 obtained minimum deviation and maximum angle distortion found on test plate no 1 from the axis.

7. From this research work, it is inferred that the rotational speed of 1000 rpm, feed of 5 mm/min and axial force of 7KN, for tapper cylindrical pin, is considered to be the most efficient for tensile strength.

REFERENCE

[1]. Jitender Kundu, Hari Singh Friction stir welding of dissimilar Al alloys: effect of process parameters on mechanical properties Engineering Solid Mechanics (2016) 125-132.

[2]. Gurel Çam, Vahid Javaheri & Akbar Heidarzadeh Advances in FSW and FSSW of dissimilar Al-alloy Plates journal of adhesion science and technology 2023, vol. 37, NO. 2, 162–194.

[3].Getachew Gebreamlak, Sivaprakasam Palani and Belete Sirahbizu Mechanical characteristics of dissimilar friction stir welding processes of aluminium alloy [AA 2024-T351 and AA 7075-T651] Manufacturing Rev. 11, 19 (2024) G. Gebreamlak et al., Published by EDP Sciences 2024.

[4]. Meghnath Sen, Sachindra shankar, Somnath Chattopadhyaya Investigations into FSW joints of dissimilar aluminum alloys https://doi.org/10.1016/j.matpr.2019.09.218.

[5]. Sadeesh Pa, Venkatesh Kannan M, Rajkumar V, Avinash P, Arivazhagan N, Devendranath Ramkumar K, Narayanan S Studies on friction stir welding of AA 2024 and AA 6061 dissimilar Metals Procedia Engineering 75 (2014) 145 – 149.

[6]. R. Raja, A. Parthiban, S. Nandha Gopan and Derese Degefa Investigate the Process Parameter on the Friction Stir Welding of Dissimilar Aluminium Alloys Volume 2022, Article ID 4980291, 8 pages https://doi.org/10.1155/2022/4980291.

[7]. Essam B. Moustafa, Mazen Sharaf, Ghazi Alsoruji, Ahmed O. Mosleh S. S. Mohamed and Hossameldin Hussein Microstructural and Mechanical Characterization of the Dissimilar AA7075 and

AA2024 Aluminum Alloys Reinforced with Different Carbide ParticlesWelded by Friction Stir Welding 2023, 7, 448. https://doi.org/ 10.3390/jcs7110448.
[8]. D. Devaiah, K. Kishore, P.Laxminarayana Effect of Welding Speed on Mechanical Properties of Dissimilar Friction Stir Welded AA5083-H321 and AA6061-T6 Aluminum Alloys [Vol-4, Issue-3, Mar-2017] https://dx.doi.org/10.22161/ijaers.4.3.4 ISSN: 2349-6495(P) | 2456-1908.
[9]. P.John Britto, C.Saravana Murthi and S.R.Kasthuri Raj Dissimilar friction stir welding between AA7075 and AA8011 aluminium alloy using CNC JOURNAL home page: http:// www. aensiweb.com/JASR 2015 November; 11(22): pages 155-157.
[10]. Sharda Pratap Shrivas, G.K. Agrawal, Shubhrata Nagpal, Amit Kumar Vishvakarma, Ashish Kumar Khandelwal Dissimilar aluminum alloy joint strength is effected by heat addition in friction stir welding (FSW) Materials Today: Proceedings 44 (2021) 1472–1477.
[11]. Anitha Lakshmi A, Bandhavi Challa, Sateesh N, Durga Rajesh K V, Revathi G, Khristina Maksudovna Vafaeva & Ankita Joshi, Friction stir welding of aluminum AA6061 & AA8011 using optimization approach based on both Taguchi and grey relational analysis Published by Informa UK Limited, trading as Taylor & Francis Group 24 Aug 2024
[12]. Palani K, Elanchezhian C, Karanam Avinash, Karthik C, Karra Chaitanya, Karthik Sivanur, Yugandhar Reddy K Influence of Friction Stir Processing Parameters on Tensile properties and Microstructure of Dissimilar AA 8011-H24 and AA 6061-T6 aluminum alloy joints in Nugget Zone: Materials Science and Engineering 390 (2018) 012108 doi:10.1088/1757-899X/390/1/012108
[13]. Xavier Sethu E, Sritharan V Optimization of Process Parameters of Friction Stir Welded Dissimilar Aluminium Alloys (AA6061 and AA8011) Using Response Surface Methodology Preprints.org (www.preprints.org) Posted: 15 March 2024 doi:10.20944/preprints 202403.0895.v1