Pak. J. Biotechnol. Vol. 15 (2) 339-345 (2018) ISSN Print: 1812-1837
www.pjbt.org ISSN Online: 2312-7791

AN EXPERIMENTAL INVESTIGATION ON FRICTION STIR WELDED ALUMINUM ALLOY (AA6063-O) JOINTS USING VERTICAL MILLING MACHINE

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Article received 24.4.2018, Revised 14.6.2018, Accepted 18.6.2018

ABSTRACT

In this work, an experimental investigation and analysis had been made to study the mechanical and micro-structure behaviors of single sided friction stir welded (FSW) aluminum alloy 6063-O joints. Friction stir welding was performed in vertical milling machine using cylindrical profiled AISI H13 Tool steel. The welding had been performed against four input process parameters including Tool Rotational Speed, Weld Traverse Speed, Tool Tilt Angle and Tool Pin Diameter. Taguchi L9 orthogonal array is the technique used to reduce the number of experimental runs to 9. Micro hardness was taken to measure the strength of the weld. The grey relational analysis was performed against micro-hardness to find out the influence of the process parameter. Microstructure was studied using the optical microscopy and Scanning Electron Microscopy separately. The microstructures were taken in both advancing and retreating sides of the weld. From the microstructure analysis, weld zones namely Heat Affected Zone and Thermo-Mechanically Affected Zone and Stir Zone were studied.

Key words: Aluminum, FSW, Taguchi L9 Orthogonal Array, Micro hardness, Microstructure.

1. INTRODUCTION

Friction stir welding (FSW) is a joining process that works on the principle of direct conversion of mechanical energy into thermal energy. In FSW process usage of conventional heat source is avoided. Kumar et al., (2017) discussed the friction welding of two similar AA6063-O flat plates in vertical milling machine using H13 tool steel. The tool hardness was improved from 20 HRC to 45 HRC after nitriding heat treatment. The weld joints were analyzed for defects through visual observation. The present study is the continuation of that work. Bayazid et al., (2015) investigated the effect of FSW parameters such as rotational speed, travel speed and plates position. Using Taguchi analysis, they observed that maximum tensile streength was achieved on rotational and travel speeds of 1600rpm, 120mm/min. Among the process parameters, rotational speed had higher influence on tensile strength. So, tool rotational speed and weld traverse speed are selected as two of the process parameters for our study. Kush and Badheka (2016) studied the effects of different tool pin profiles such as cylindrical, triangular and polygonal pin profiles. They found that irregular and large copper particles were found for triangular pin profile. They also concluded the joints were found to be defect free when cylindrical tool pin profile was used, and it has been selected as the tool profile for the present investigation.

Khan et al., (2015) analyzed the effects of shoulder diameter (D) to pin diameter ratio(d) on the tensile strength. They revealed that maximum and minimum tensile strength had been obtained for the D/d ratio of 2.6 and 2.8 respectively. Banik et al., (2018) studied the mechanical properties of the welds for different tool tilt angles using threaded and taper threaded tool. They observed that forces and torque concerning increases when tilt angle increases. Ravi et al., (2018) employed FSW for joining AA6061 and B_4C metal matrix composites. Weld nuggets had finer grains and B_4C particulates were homogenously found in Al matrix. Vijaya et al., (2018) developed a milling fixture and a clamping setup and performed FSW using milling machine. They tested the performance of the fixture using ANSYS software. Shah et al (2017) used a threaded conical shaped tool pin and inserted an Al foil as a faying surface to enhance the material flow. They compared the impact of 0.2mm tool offset and without offset in material flow. Mahto et al., (2018) performed fractogrophy study on a post friction stir welded AA- 6061 - AISI 304 and observed quasi-cleavage fracture for lower rotational speeds and lower feed rates. Swaminathan et al., (2018) discussed the influence of process parameters during gas metal arc welding of AA7075 and AA6063 using artificial neural network model. Kumar, et al., (2018) developed and designed the automatic head lamp leveling systems and analyzed the quality using welding parameters.

2. EXPERIMENTAL DETAILS

The friction stir welding process was performed on two AA6063 plates of dimensions 150 mm X 100 mm X 6 mm using post nitride H13 tool steel in vertical milling machine and the process was discussed by Kumar et al., (2017). Three levels (L1, L2, L3) of Tool Rotational speeds (560 rpm, 900 rpm, 1400 rpm), Weld traverse speeds (31.5 mm/min, 63 mm/min, 100 mm/min), Tool tilt angle (0^0, $1^{0,}$ 2^0) and tool pin diameter (6 mm, 7 mm, 8 mm) were taken as process parameters for the welding. Post welded specimens were surface grinded and micro hardness values were taken on them in Vicker's micro hardness test machine. The values were taken on Stir zone, Advancing Side, Heat affected zone (AHAZ) and Retreating side Heat affected zone (RHAZ). Three iterations were taken for each value in each zone and the average values are tabulated.

Table I: Micro hardness values of the joints taken at the stir zone.

Weld/ Joint Number	Tool Rotational Speed	Weld Traverse Speeds	Tool Tilt Angle	Tool Pin diameter	Micro hardness (MHV)
1	L1	L1	L1	L1	55
2	L1	L2	L2	L2	71
3	L1	L3	L3	L3	68
4	L2	L1	L2	L3	60
5	L2	L2	L3	L1	65
6	L2	L3	L1	L2	59
7	L3	L1	L3	L2	65
8	L3	L2	L1	L3	76
9	L3	L3	L2	L1	69

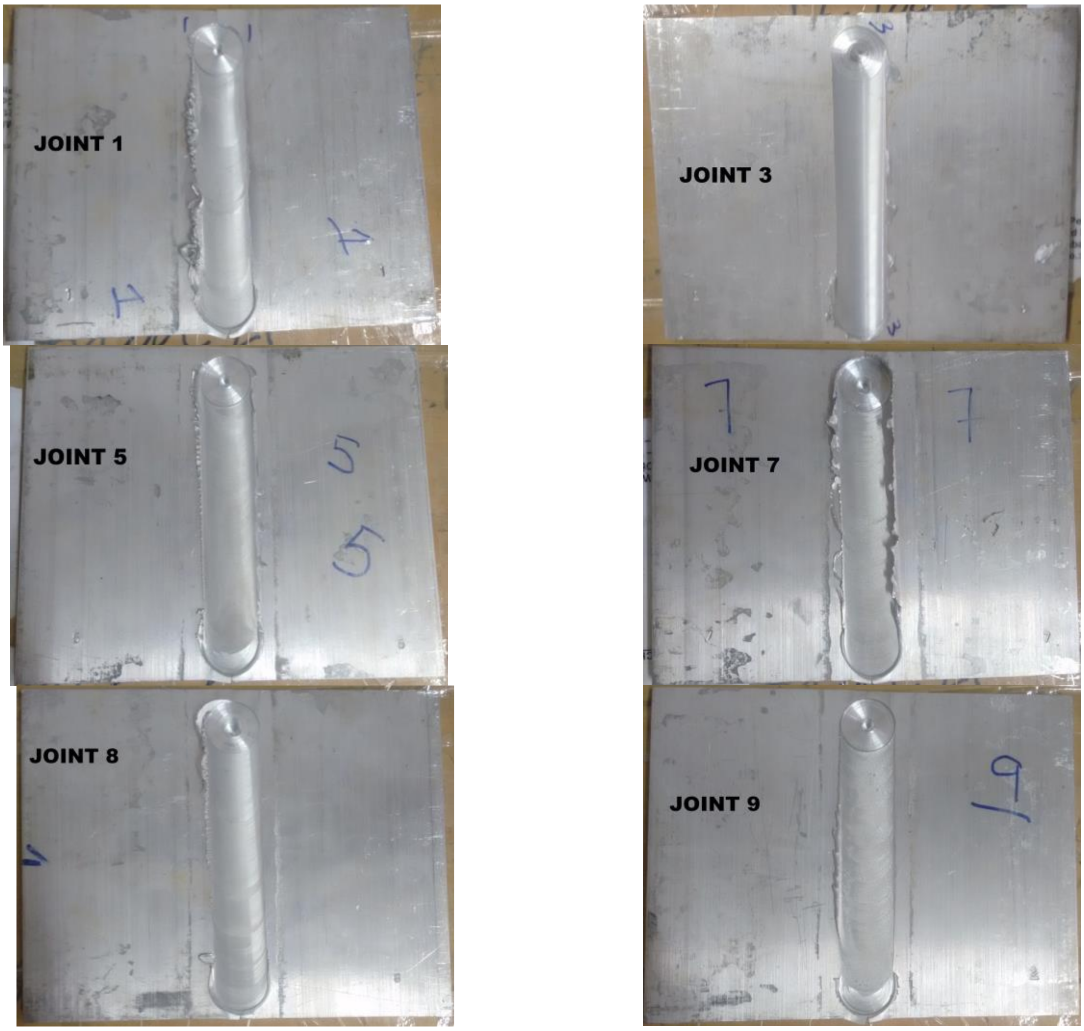


Fig I: Post welded joints 1, 3, 5, 7, 8, 9

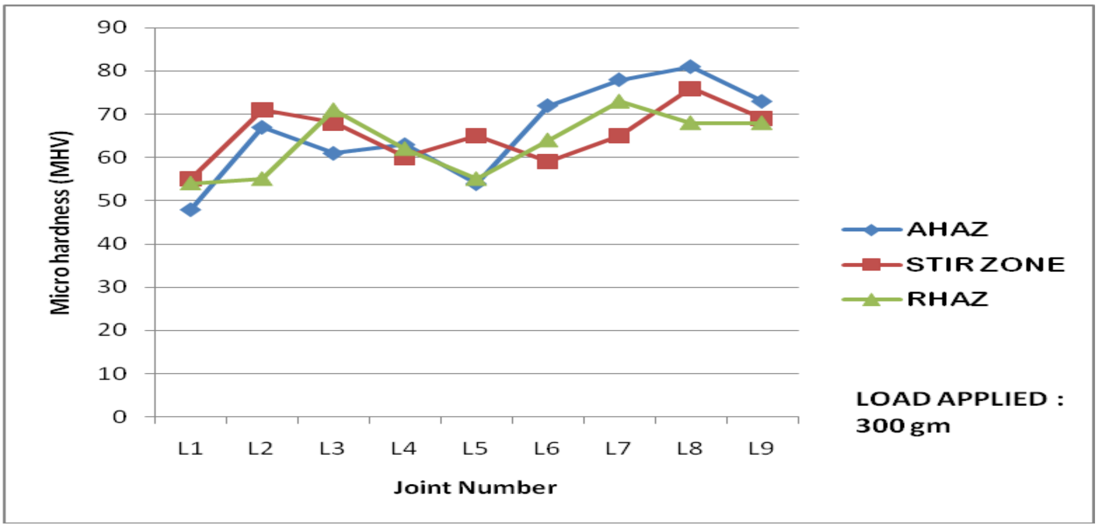
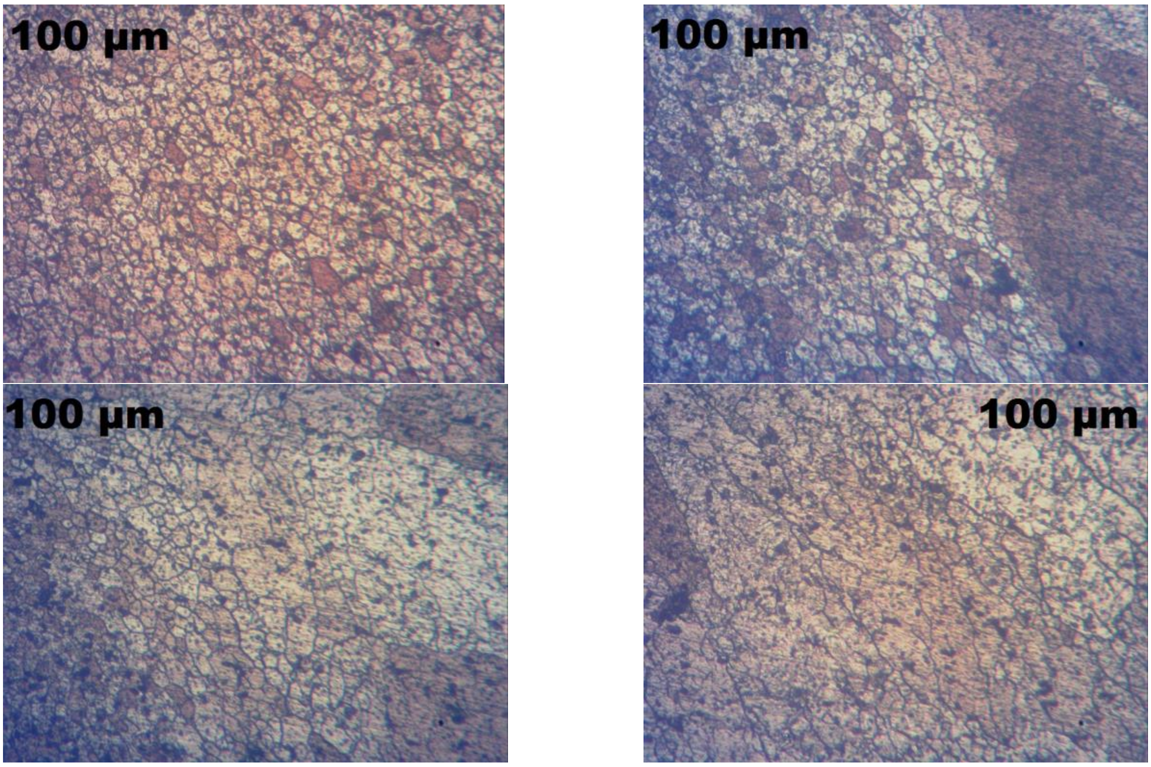


FIG II: Comparison of Micro hardness values taken at AHAZ, Stir Zone, RHAZ

3. RESULTS AND DISCUSSIONS

The post welded samples were cut into the following dimensions 40X10X6 mm. They were manually polished and etched using Keller's reagent. Microstructures were taken on 100x and 200x resolutions. Zones such as Thermomechanically affected zone (Advancing and Retreating Zone), HAZ-advancing side, HAZ- Retreating side, stir zone, Weld zone of FSW samples and work piece were captured and shown in Fig III.



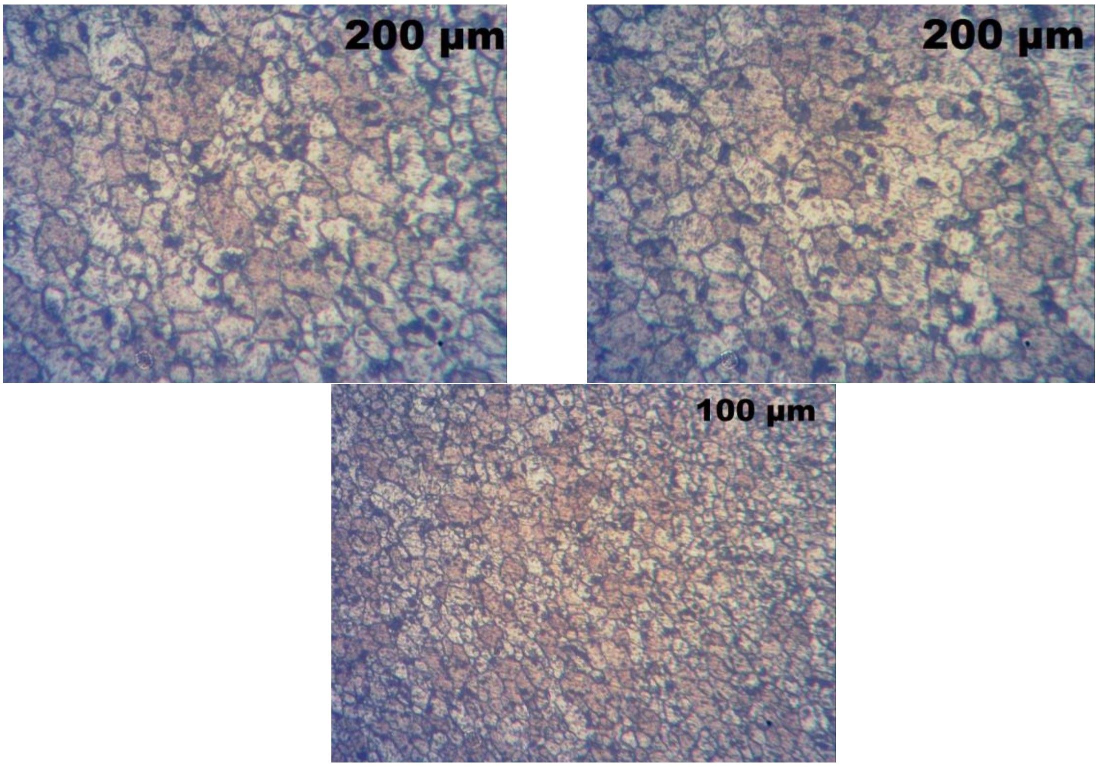


Fig IIIa-g: Optical Microstructures of FSW AA-6063 Joints (a) Base Metal, (b) Stir zone, (c) TMAZ Advancing side, (d) TMAZ Retreating side, (e) HAZ Advancing side, (f) HAZ Retreating side, (g) Weld Nugget.

Heat affected zone is an area on the base metal which is near or at the weld nugget. The metal properties of the zone had been changed due to the heat of the weld. The properties might or might not be beneficial to the welded joint. In FSW, HAZ on both advancing and retreating side is inevitable. Optical microscopy of samples revealed the presence of fine grains and the black dots signifies the presence of secondary components of the base metal.

Stir zone is a region where deformation and mixing of similar or dissimilar metals takes place due to the action of the tool pin rotation at high speeds. When the weld nugget is viewed at cross section, stir zone can be visible. Weld zone has fully recrystallized metal and fine grains.

The weld zone is surrounded by a region that has different microstructure when compared to weld zone is called Thermo mechanically affected zone. The grain size of the parent material is similar to that of TMAZ. Also, TMAZ has partially recrystallized material. The stir zone is surrounded on both the retreating sides and advancing sides by TMAZ.

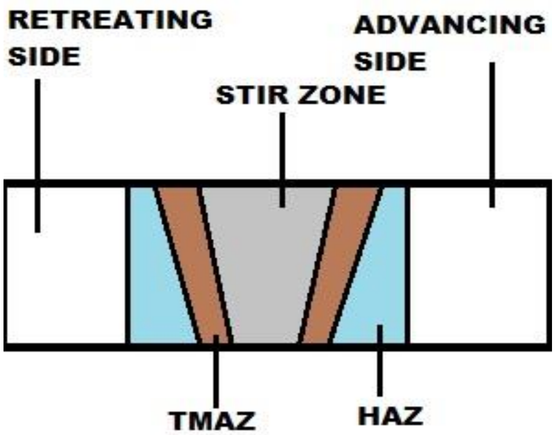


Fig IV: Different weld zones in FSW.

GREY-RELATIONAL ANALYSIS: The overall influence of the process parameters on the performance of the process can be calculated using grey relational analysis. Since there are more than two process parameters, the response is going to be multiple and this approach converts the multiple responses into single response optimization. The single response is then evaluated using Taguchi method. In this study, the response combination is evaluated using Micro hardness values at the weld zone in larger the better system. In Minitab software, the process parameters were given as input response along with micro hardness in Taguchi L9 analysis. Output response is calculated in two forms, one in Signal to noise ratio and other in Means ratio.

The formula for larger the better system for Taguchi L9 method is

$X=10*\log_{10}(\text{sum}\,(1/Y^2)/n)$, Where

X=Value after grey relational analysis.

Y=Value for nth response.

Delta= Highest value – Lowest value.

Table II: Larger the better Response table for Signal to Noise ratios

Level	Tool Rotational Speed (rpm)	Weld Traverse Speed (mm/min)	Tool Tilt Angle (deg)	Tool Pin diameter (mm)
1	36.16	35.54	35.95	35.95
2	35.75	36.97	36.46	36.23
3	36.88	36.28	36.39	36.61
Delta	1.14	1.42	0.51	0.66
Rank	2	1	4	3

Table III: Larger the better Response table for Means

Level	Tool Rotational Speed (rpm)	Weld Traverse Speed (mm/min)	Tool Tilt Angle (deg)	Tool Pin diameter (mm)
1	64.67	60.00	63.33	63.00
2	61.33	70.67	66.67	65.00
3	70.00	65.33	66.00	68.00
Delta	8.67	10.67	3.33	5.00
Rank	2	1	4	3

Table II and III signifies, among the four process parameters, Weld traverse speed had the highest influence on the performance of the weld, next is the tool rotational speed and tool pin diameter and finally tool tilt angle had the least influence.

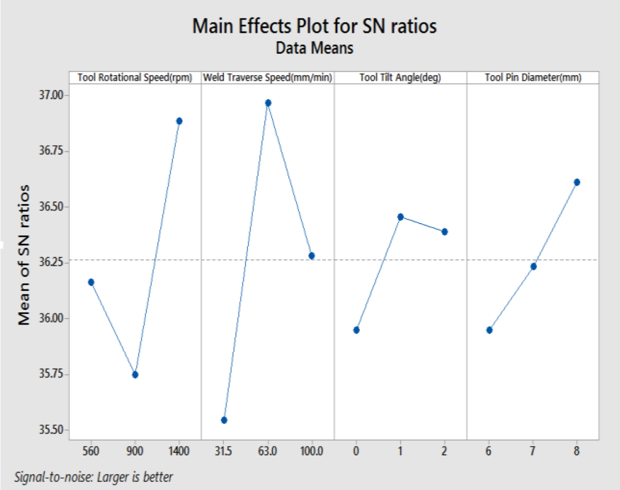


Fig V: Process Parameters (Input Responses) Vs SN Ratio (Output Response) Plot.

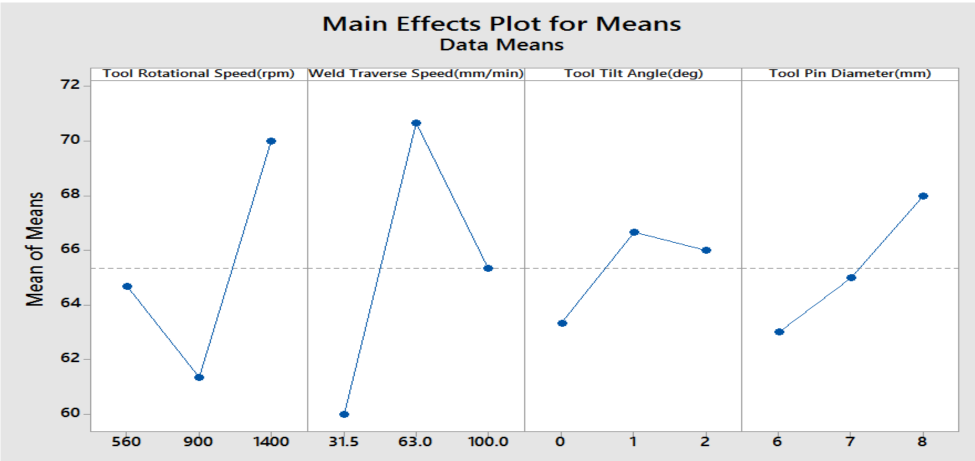
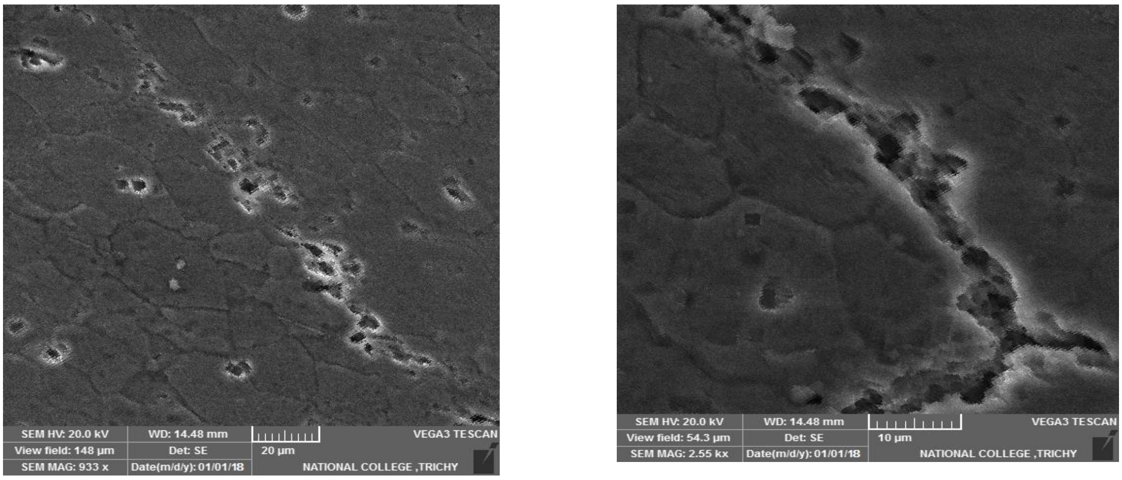


Fig VI: Process Parameters (Input Responses) Vs Mean of Means (Output Response) Plot.

The samples were cut into the following dimensions 10 X 10 X 6mm for Scanning Electron Microscopy analysis. The images in fig VII revealed the presence of voids in the weld nugget. The weld nugget was subjected to deformation and high strain during welding. Voids got created due to change in rate of material transport from advancing to retreating side.



VII: SEM images of post welded FSW samples.

4. CONCLUSION

Friction stir welding of aluminium alloy 6063 plates were successfully performed and post analysis showed the following conclusions.

Micro hardness values taken at the weld nugget revealed that Joint number 8 with Tool rotational speed of 1400rpm, weld traverse speed of 63 mm/min, tool tilt angle of 0^0 and tool pin diameter of 8 mm had the maximum value of 76 MHV. MHV of advancing side HAZ is higher than that of retreating side HAZ. This is due to material diffusion into the advancing side from the retreating side. Taguchi analysis using Minitab affirmed that Tool Rotational speed and weld traverse speed had maximum influence during FSW of AA6063and Tool pin diameter had minimum influence and tool tilt angle had negligible impact. Optical microscopy were carried out on the following zones (i) Base Metal, (ii) Thermo-mechanically affected zone (TMAZ), (iii) Heat affected zone (HAZ) in both advancing (AS) and retreating side (RS). Microstructures of weld nugget had fine and small grains, which signified full recrystallization, even material distribution along the weld zone. Stir zone revealed complete mixing of similar metal alloy and strong bonding.

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