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Tool Rotational and Tool Travel Parameters Influence on Friction Stir Welded Dissimilar Joints Properties

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Abstract

Present work is to examine the effects of tool rotational and tool travel parameters on Friction Stir Welded (FSW) dissimilar joints mechanical and microstructural characteristics for 3 mm thick pure copper and 6061 aluminium alloy plates. Welds were made with a cylindrical tapered pin to achieve this goal. The tool rotational speed and tool travel speed are the primary FSW factors considered in this study. Copper plates were kept on the joint's advancing side. Tensile and bending tests are carried out to assess the tensile and bending strength of weld joints in accordance with ASTM standards. Vicker's microhardness tests were carried out in the transverse direction of the weld to check the hardness distribution in weld nuggets. An experimental analysis shows that the best tensile strength 98 MPa and bending stress 16.6 MPa are achieved at tool rotating speeds of 1000 rpm and 62 mm/min, correspondingly. The larger concentration of copper particles in the aluminium region is mostly to blame for this. For 1400 rpm and 62 mm/min, a nugget zone hardness of 190 HV is attained. The presence of more Cu particles on the Al side is evident in SEM pictures, and the higher tensile and bending strength is mostly attributable to the Cu particles covering the Al material in the weld zone. According to X-ray analysis, the synthesis of intermetallic complexes such Al4Cu9, Al2Cu, AlCu, and AlCu4 explains the chemical reaction and phase transformation at the interfaces. The maximum strength values improved because of these intermetallic compounds' proper metallurgical bonding and thinnest thickness. According to fracture analysis, joints with higher strengths have intergranular fracture, while joints with lower strengths experience brittle fracture on both aluminium and copper joints.

Keywords: *Fractography, FSW, Dissimilar Welding, XRD*

1.0 Introduction

During the Friction Stir Welding (FSW) process, the kinetic energy generated by sliding two bodies against one another is transformed into heat. When the heat is contained in a small area and the rate of movement is high, welding takes place. It involves inserting a rotating, non-consumable tool with a probe into the workpieces mating edges. Concentrated heating causes the material near the probe to soften, and the tool rotation and translating coupled cause material to travel from the front to the back of the pin. This procedure results in the production of a solid-state joint[1]. Due to their technical and financial benefits, dissimilar welded materials are frequently used in a variety of industrial fields, including nuclear, aerospace, chemical, electrical, and electronics[2].

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Due to contrasts in smelting temperatures the variations could result in residual stresses, cracking, and the buildup of numerous intermetallic compounds in the weld[3]. Joining unrelated blends of Aluminium and Copper by fusion welding is typically challenging, the FSW of Aluminium and Copper has been restricted. Precisely various discrete physical, chemical, and mechanical characteristics as well as their propensity to form brittle intermetallic compounds (IMCs), this is the case[4]. However, there is a big variance amongst melting points of two materials (nearly 400 °C). If copper and aluminium are joined, this could result in a substantial difference in the microstructure and functionality of Cu-Al joints. Additionally, at high temperatures, Al was easily oxidized, and brazed or fusion-welded joints were susceptible to welding cracks. Therefore, it was challenging to produce a high-quality Cu/Al weld joint using traditional welding techniques. It is very challenging to avoid the Cu-Al intermetallic through union welding or pressure welding which led to decreased mechanical properties of joints[5]. Tool pin profile plays a major role when it comes to mechanical and microstructural properties of aluminium and copper joints. A cylindrical tool pin profile allowed for defect-free unlike friction stir welding and on the other hand, it was discovered that taper tool pin profile was ineffective for friction stir welding between dissimilar metals[6]. Commercial pure copper friction stir welding joint efficiency was 94.03% when compared to base material in terms of microstructure, microhardness, and tensile properties[7]. FSW welded aluminium and copper interfacial region shows mixed layers of two materials and presence of intermetallic compounds was detected using energy dispersive spectroscopy and higher feed rate and smaller shoulder diameter can be regarded for highest tensile strength[8]. The nugget zones extensive deformation as well as the microstructure evolving characteristics have a significant impact on the joint's hardness and corrosion resistance during FSW[9-10].

Divergent amalgamation of Al and Cu by FSW expertise has been an exciting topic of examine over the past few years[3,4,11-14]. The goal of the current research is to examine the impact of tool rotational speed and tool travel speed using tool design that makes use of cylindrical taper tool pin profiles on dissimilar AA6061-Cu FSW joints for mechanical and microstructural properties.

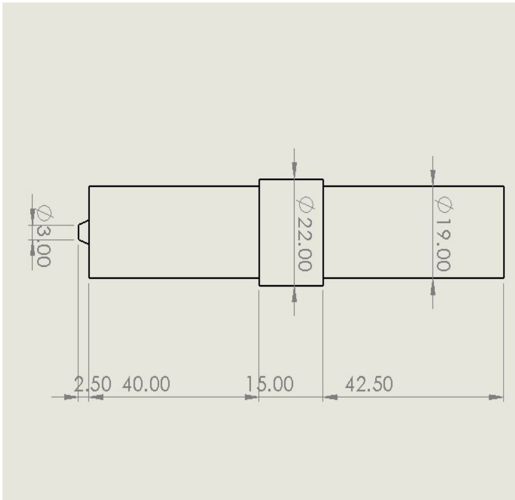
2.0 Experimental Work

Using a vertical milling machine, friction stir welding was done on pieces of pure copper and 6061 aluminium alloy that were 100x50x3 mm in size. The samples were cleaned with emery paper of various grades before being acetone degreased. In this study, friction whip welds of aluminium and copper were created applying a HcHcr tool with a cylindrical taper unthreaded pin that had a major diameter of 5 mm, a minor diameter of 3 mm, and a shoulder diameter of 22 mm by fluctuating the

(a)

(b)

Figure 1. Vertical Milling Machine and Position of workpieces on fixture.



(a)

(b)

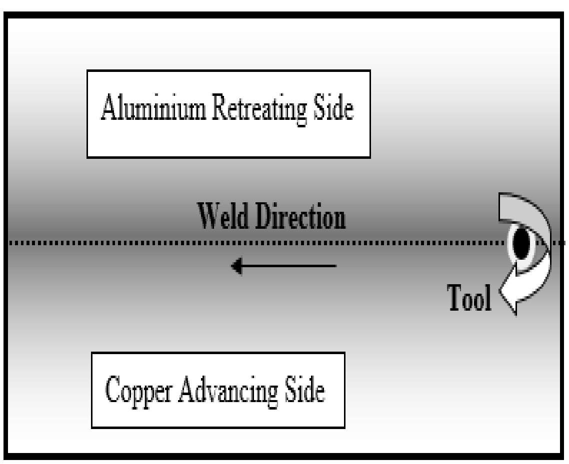
Figure 2. (a) Dimensions of the tool and (b) Finished tool.

tool's gyratory speed and feed rate while maintaining additional constraints. Figures 1 and 2 depict a graphic of the upright milling and the tool that was used.

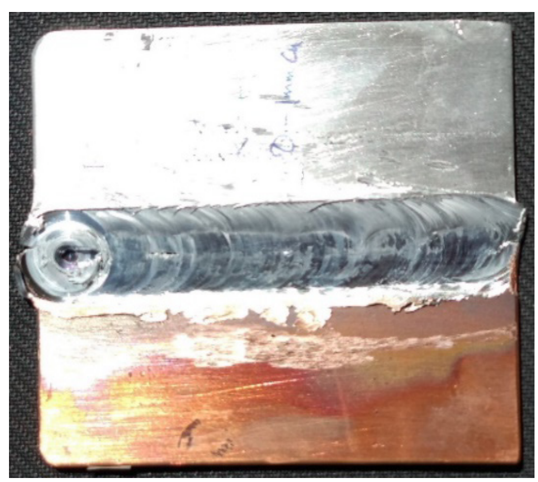
To achieve good properties of welded parts, experiments were conducted using various agrees of rotational and traverse speeds. These tests the tool pin was positioned for zero offset. Copper was placed on the progressing crosswise and aluminium was placed on retrieving side. The positions of the workpieces are shown in Figure 3. The welding parameters considered for this study are disclosed in the Table 1.

Table 1. Parameters Used for Preparing the joints.

S/No	Tool Rotational Speed (rpm)	Tool Travel Speed (mm/min)
1	1000	50
2	1000	62
3	1400	50
4	1400	62
5	2000	50
6	2000	62

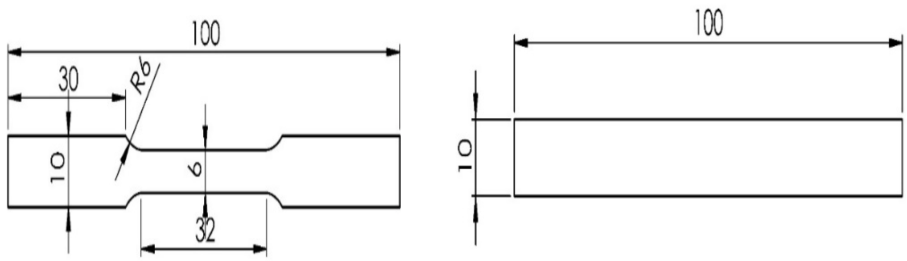


(a)

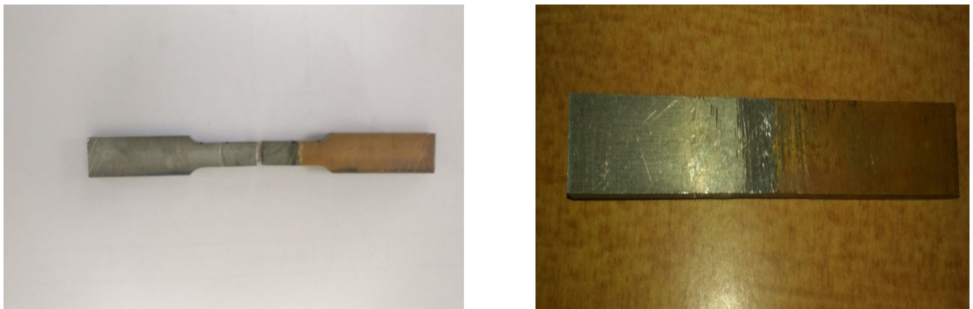


(b)

Figure 3. (a) Tool Movement direction and (b) Welded Sample.



(a)



(b)

Figure 4. (a) ASTM standard dimensions of the specimens and (b) Prepared specimens for tensile and bending test.

Figure 5. Sample of Specimen prepared for microstructural analysis.

According to ASTM E384-17, the microhardness test was carried out utilizing a Vicker HWMMTX7 microhardness tester with a diamond indenter. Using a universal testing equipment, the tensile characteristics and bending strength of the welded junction were assessed in accordance with ASTM E8-16a and ASTMD790. In Figure 4, ASTM standard dimensions of the specimens and prepared specimens for tensile and bending are displayed. In order to conduct the microscopy analysis specimens were cut using wire EDM machine and polishing was done using Emery paper in the 1000, 1200, and 1400 grit grades. The twin disc polishing equipment was used to polish the surface until a mirror finish was achieved. The specimen prepared for microstructural analysis is shown Figure 5.

3.0 Results and Discussion

3.1 Tensile Strength

Tensile strength obtained for the prepared joints are tabulated in the following Table 2. Tensile strength of disparate joints Al & Cu were found highest of 94.14 MPa for tool revolving speed of 1000 rpm and tool traverse speed of 62 mm/min. On other hand, the least tensile strength of 44.37 MPa was attained for tool speed of 2000 rpm and tool track speed of 50 mm/min.

The tensile strength of the chosen parameters has a certain trend. The tensile strength steadily decreases as tool revolving speed is raised from 1000 rpm to 2000 rpm. Absence of homogeneous mixture development and insufficient heat input through weld nugget precinct are blamed for the lowest tensile strength at higher tool spinning speeds. On the other hand, the production of

Table 2. Tensile strength obtained for all the parameters.

S/No	Rotational Speed (rpm)	Traverse Speed (mm/min)	Tensile Strength (MPa)
1	1000	50	77.70
2	1000	62	94.14
3	1400	50	52.29
4	1400	62	51.74
5	2000	50	44.37
6	2000	62	45.54

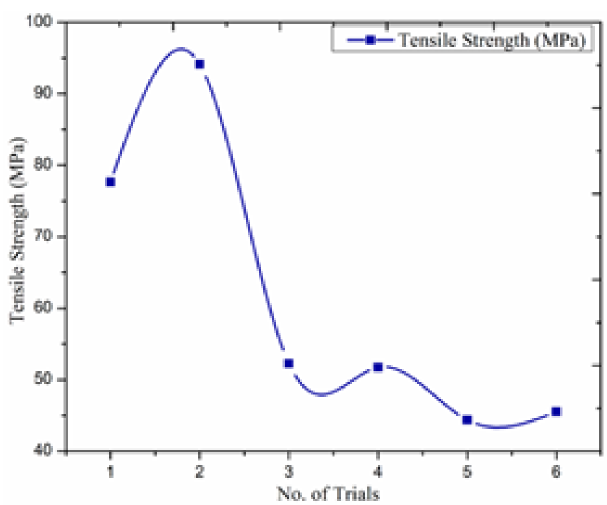


Figure 6. Tensile Strength Variation for Trials conducted.

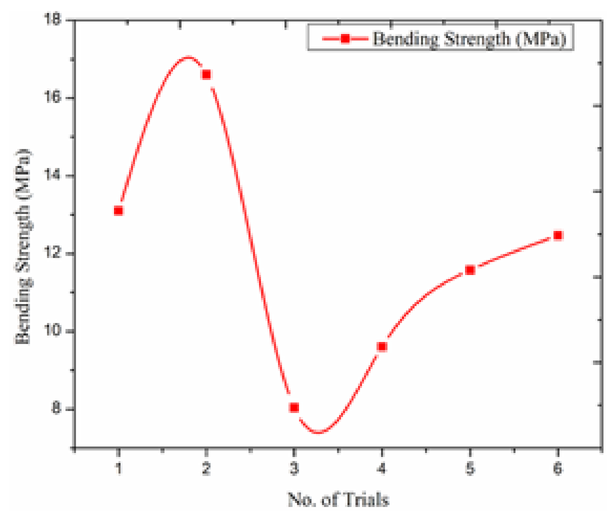


Figure 7. Bending Strength Variation for Trials conducted.

thick intermetallic phase is liable for the highest tensile strength due to a larger heat input for the tool's speed of 1000 rpm and tool traversal speed of 62 mm/min[15].

3.2 Bending Strength

Samples were sliced with wire EDM after welded connections in 10×100 mm measurements, three-point bending tests are performed. The loaded welded specimens continue to be encumbered till U-shape or a breakdown is noticed. However, failures and fractures are more common in HAZ and welded zones.

Table 3. Bending strength obtained for all the parameters.

S/No	Rotational Speed (rpm)	Traverse Speed (mm/min)	Bending Strength (MPa)
1	1000	50	13.1
2	1000	62	16.6
3	1400	50	8.04
4	1400	62	9.61
5	2000	50	11.58
6	2000	62	12.47

Table 3 contains the findings of the bending strength test. The strongest bending is seen at 1000 rpm and 62 mm/min, while the joint's bending strength at 2000 rpm and 62 mm/min also exhibits a substantial amount of strength. The weakest bending strength was achieved at 1400 rpm, 50 mm/min. Additionally, there is no discernible trend in the bending strength.

3.3 Micro Hardness

The Microhardness results obtained are listed in the following Table 4 for selected parameters. This Hardness testing is performed to perceive the material's capability to endure plastic distortion from a accepted source. Tool creates indentations on nugget zone of the specimen and the Vickers Hardness Number (VHN) values are thus obtained.

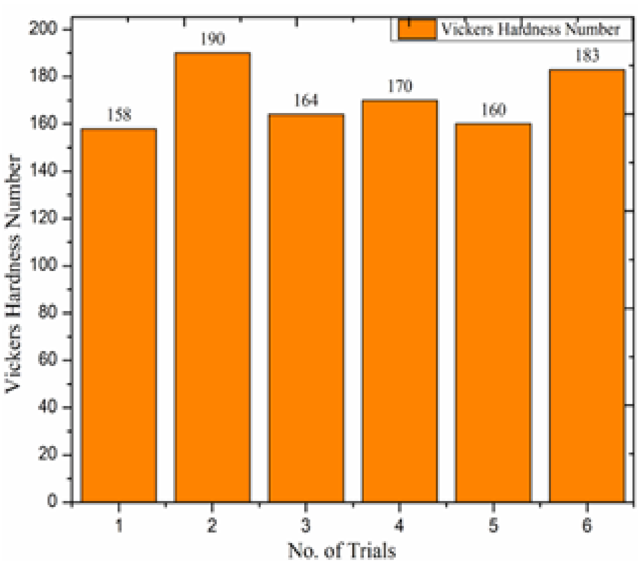


Figure 8. Hardness Numbers on nugget zone for Trials conducted.

The joint obtained at 1000 rpm and 62 mm/min have the highest Vickers Hardness number. Also joints at 2000 rpm and 50 mm/min and 62 mm/min have a considerably good Hardness number. There is no trend observed that the hardness number increases or decreases with varying rotational speed or travel speed.

The hardness of copper and aluminum is generally noted to be higher in the weld zone than in the heat-affected zone. Recrystallization of grains in the weld area may be the cause of this. The real value of hardness at the interface is determined by the sum of all friction welding parameters[16].

3.4 Microstructure Analysis

It's noteworthy that both the interior and microstructure of the weld are considered when evaluating the attribute of Al-Cu dissimilar connections. The SEM micrograph of the Al6061/Cu welded connection achieved with various parameters are shown in Figure 9a to 9f. For highest tensile strength parameter, rotation speed of 1000 rpm, traverse speed of 62 mm/min is shown in Figure 9b. The SEM image of the stir zone revealed that copper particles were finely dispersed throughout the Al6061 matrix. Along with the tiny copper pieces, larger particles with a flake-like shape were also observed. Both types of copper fragments were distributed in a homogeneous manner that resembled that of a particle-reinforced composite structure. Good mechanical qualities result from proper

Table 4. Microhardness test results of various parameters

S/No	Rotational Speed (rpm)	Traverse Speed (mm/min)	Vickers Hardness (HV) (At nugget zone)
1	1000	50	158
2	1000	62	190
3	1400	50	164
4	1400	62	170
5	2000	50	160
6	2000	62	183

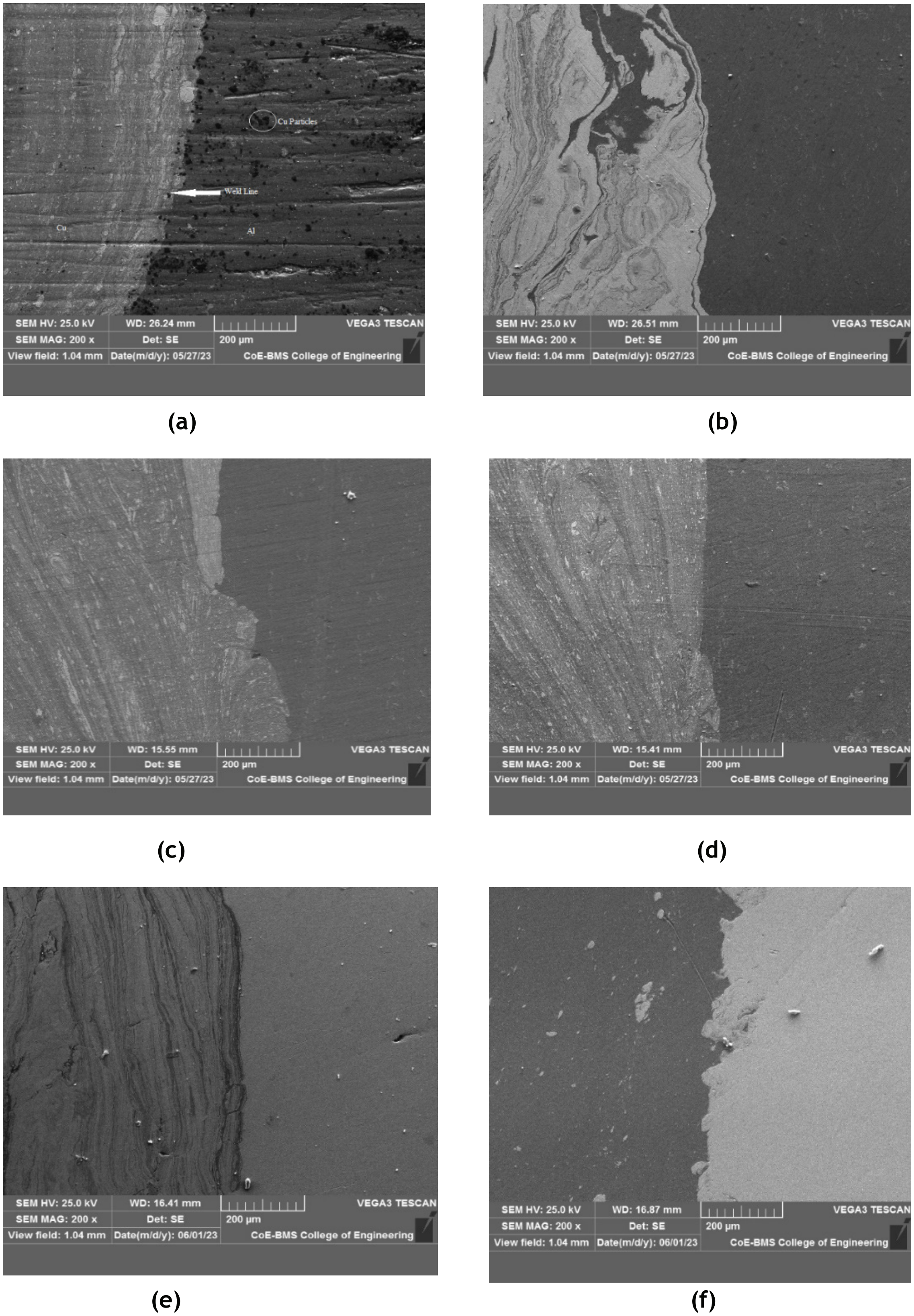
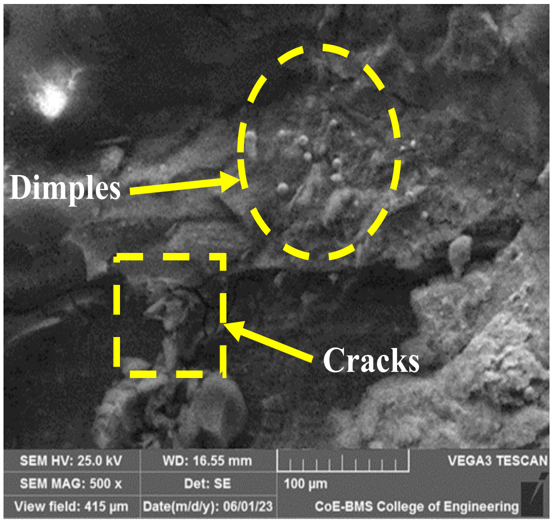


Figure 9. SEM micrograph of all the trials.



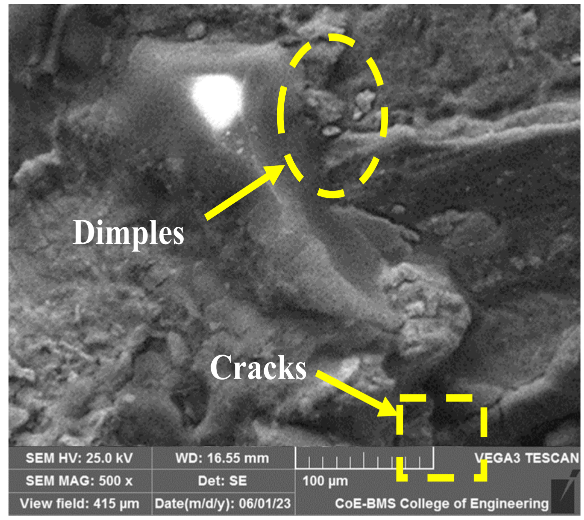


Figure 10. Fractographs for (a) Maximum and (b) Minimum tensile strength.

mixing of the two materials and consistent, flawless dispersion of copper particles in the Al6061 matrix[17].

Figure 9(e) shows the SEM image of lowest tensile strength property for rotational speed of 2000 rpm and travel speed of 50 mm/min. It can be observerd that, the material flow in the weld zone affects microstructure advancement & mechanical characteristics of weld seams in the FSW route. Lack of stirring was caused by a higher heat scenario[18].

3.5 Fractography Analysis

Fractography is a methodology that studies the fracture surfaces of materials by carefully examining the morphology and topography of the fracture specimen under a microscope. It is used to identify the factors that lead to material failure as well as to examine the fracture surfaces of the materials.

The microstructure development and mechanical properties of the weld seams in the FSW manner are influenced by the material flow in the weld area. Examination of unilaterally damaged fracture surfaces showed that the microstructural characteristics had an impact on the breaking strain and rupture characteristics of the produced Al-Cu materials. Figure 10(a) for parameters 1000 rpm and 62 mm/min exhibited several cleavage planes and intergranular fracture patterns close to the copper side[19]. Large amounts of dimples and cleavage planes on the fracture surface indicated ductile failure at the Al alloy side. Figure 10(b) for parameters 2000 rpm and 50 mm/min demonstrates signs of mix modal fracture dominated by brittleness; however, the dominance of brittleness because, intermetallic compounds do not link well, leaving weak spots at their interfaces. This weak zone experiences crack initiation with loading, resulting in intergranular fracture[20].

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