International Journal of Research in Engineering and Innovation
(IJREI)
journal home page: http://www.ijrei.com
ISSN (Online): 2456-6934

ORIGNAL ARTICLE

Investigation of microstructure and mechanical properties of friction stir welded joint of AA2024 and AA5052

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Article Information

Received: 12 October 2020
Revised: 26 November 2020
Accepted: 02 December 2020
Available online: 05 December 2020

Keywords:

Tensile strength;
Microhardness;
Microstructure;
Friction stir welding;

Abstract

In this work, the analysis of friction stir welding on dissimilar aluminum alloys of AA2024 and AA5052 have been successfully fabricated. The mechanical characterization of FSW welded joints were investigated using experimental methodology by adjusting processing parameters. The confidence interval has shown that tensile strength and hardness increased with increasing tool rotation. The maximum tensile strength, and micro-hardness at nugget zone are 235 MPa, and 109 HV at tool rotation 1200 rpm, traverse speed 40 mm/min and tilt angle 2^0. The effect of tool rotation on FSW welded joint also improve the ductility of the welded joints, FSW welded joint with tool rotation 1200 rpm were more ductile than the FSW welded joint due to fine grain structure. When the tool rotational speed increases from 1200 rpm may produce an excessive release of stirred welded material on the top surfaces of the base plate, obtained micro void into the stirred zone. The grains size in the nugget zone at higher tool rotation (1200 rpm)was observed much finer (5.4 µm) than the lower tool rotation (800 rpm). The FSW welded portion at 800 rpm shows the large and deep dimples whereas welded portion at tool rotational speed of 1200 rpm shows fine and shallow dimples.

1. Introduction

Friction stir welding (FSW) is a solid state welding process and it was invented in 1991 by the Welding Institute (TWI), Cambridge, UK [1]. This process joins two different metals by fusing them from the heat produced by a rotating tool. FSW has many advantages over conventional processes and it has also replaced the fastened joints, due to its significant weight and cost reductions. The tensile strength is directly proportional to traverse speed (TS). Softening of the material was observed in the weld region and mostly evident in the heat-affected zone (HAZ) on the advancing side of the welds and corresponded to the failure location in tensile tests. The reason for this phenomenon is due to the kinetic and thermal asymmetry of the FSW process [2]. The New welding approach has been introduced to improve the welding quality of TIG welded joint, the influence of friction stir processing on TIG welded joint have been analyzed and they observed mechanical properties and heat transfer of TIG+FSP welded joint. The mechanical properties of TIG+FSP welded joint were observed better than TIG welded joints. [3-9]. The maximum failure load of joints reached 62% of Al-Si alloy base metal with the joints fractured at the interface. The transient phase TiAl forms at the joining interface by Al-Ti diffusion reaction. The formation of $TiAl_3$ is strongly dependent on welding speeds during friction stir welding and thus affects the mechanical properties of joints [10]. Stress levels observed are higher on the retreating side and Grain growth is observed with an increase in the processing parameters that promote heat

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https://doi.org/10.36037/IJREI.2021.5105

generation. The grain size evolution is consistent with the models developed, taking into account the strain rate and the processing temperature [11]. An Al-rich layer was formed at the joint interface. Increasing the aluminum content of the Mg–Al–Zn alloy, Ti–Al intermetallic compound layer was observed clearly on the joint interface. The joint fractured in the intermetallic compound layer in the tensile test. The intermetallic compound plays an important role in making a Ti/Mg joint, but the increased thickness of this compound tends to reduce the tensile strength [12]. the maximum temperature gradients resulting from the friction of shoulder and pin and the workpiece was reported in the center of the pin. The difference between the two tests can be minimized by optimizing in the boundary conditions [13]. The ultrafine grained microstructure with the mean grain size of ~0.7 μm is obtained in the weld nugget by using water cooling. However, The FSW joint exhibits softening compared with the ultrafine grained based material and the heat affected zone (HAZ) has the lowest hardness owing to the coarsening of the strengthening precipitates [14].
The objective of the present work is to investigate mechanical properties of welded joint of AA2024 and AA5052 by friction stir welding and analyzed the microstructure of welded joint by SEM testing machine.

2. Materials and method

The work-pieces to be joined by FSW process are machined to the required dimensions. The required dimensions of the plates are prepared based on the bed length and width of the milling machine, length of the backing plate, and the design of the clamping system, so that the arrangements do not allow the distortion of the plates due to forces induced by the rotating tool. However, the aluminum-alloys are designed to be around 300 mm long and 80 mm wide sheet metal cut into the specified dimensions by a shear cutting technique. The final dimensions of the work pieces are 150 mm x 40 mm x 6.2 mm. The aluminum plates were to be machined at the sides in order to make them flat to ensure accurate face-to-face contact at weld joint. This was accomplished by using the shaping machine and a vice for holding the plates firmly. The chemical composition of base material and processing parameters are shown in table 1 and 2. The tensile stress of friction stir welded joints were measured under uniaxial tensile stress with the help of universal testing machine as per ASTM E8 standard as shown in fig. 1.

Table 1: Chemical composition of base material

Material	Si	Cu	Fe	Zn	Mg	Mn	Cr	Al
AA2024	0.21	0.12	0.35	0.12	2.4	0.12	0.25	Bal.
AA5052	0.5	3.9	0.4	0.25	1.5	0.6	0.1	Bal.

Table 2: Processing parameter for friction stir welding

Sample No	Welding Speed (mm/min)	Tool rotational speed (rpm)	Max. Force (N)
1	40	800	454
2		900	424
3		1000	398
4		1100	357
5		1200	339

Figure 1: Dimension of tensile test specimen

3. Results and Discussion

3.1 Tensile strength

A universal testing machine was used to perform the tensile test at room temperature. Three tensile test specimens for each processing parameters are used to evaluate the tensile strength of the FSW welded joint of dissimilar aluminum alloy AA 2024 and AA5052 and average value have been taken as shown in table 4. The transverse direction is perpendicular to the welding direction. The tensile sub test specimens were cut with the help of milling machine according to the ASTM E8 sub test specimen. The results show that the tensile strength of the welded joint of AA2024 and AA5052 are significantly varied when the tool rotational speed varies from 800 to 1200 rpm. A higher tensile strength of 234.60 MPa was observed in the joint made by the threaded pin profile at tool rotational speed 1200 rpm, traverse speed 40 mm/min with tilt angle 2°, whereas lower tensile strength of 177.78 MPa was observed at tool rotational speed of 800 rpm with same traverse speed and tilt angle as shown in fig. 3. The tensile strength at 1200 rpm was31.96% higher than the tool rotational speed of 800 rpm because a lower tool rotational speed i.e. 800 rpm produced a lower heating condition along with poor stirring action by the tool pin and improper consolidation of FSW welded material by the tool shoulder [15], hence the lower tensile strength was obtained.
When the rotational speed increased, the heat input per unit length of the welded joint also increased which caused a fine uniform grain refinement was obtained to improve the tensile strength. When the tool rotational speed increases from 1200 rpm may produce an excessive release of stirred welded material on the top surfaces of the base plate, obtained micro void into the stirred zone. The increase in temperature as well as coarsening of grains and cooling rate at more than desired temperature may reduce the tensile strength of the welded joint of at high rotational speed. Some defects were observed when the material flow around the advancing side (A.S) of the weldment, because there is no force promoting its movement back into the volume stirred by the moving tool [16]. The percentage elongation of welded joint at 800 rpm was lower than 1200 rpm. The tensile stress strain diagram of welded joint with different processing parameters were shown in fig.2.

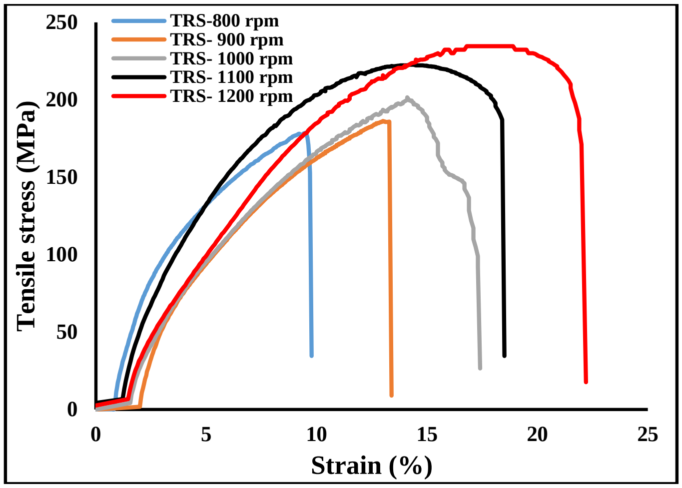


Figure 2: Comparison of stress strain diagram of FSW welded joint of AA 2024 and AA5052 with different rotational speed

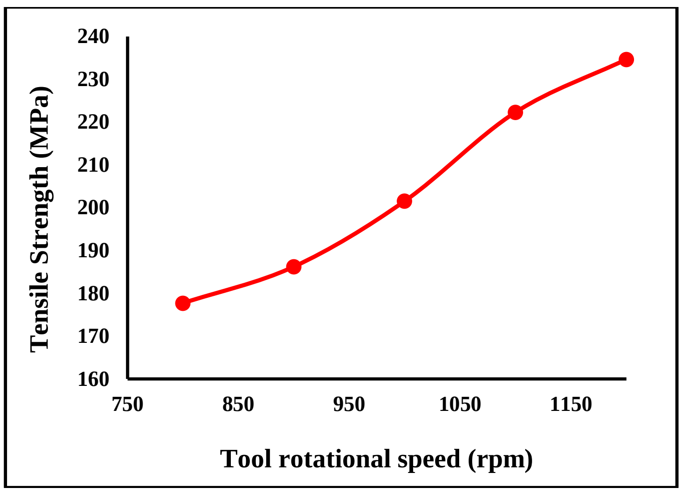


Figure 3: Variation of tensile strength and tool rotational speed of FSW welded joint

Processing parameters of friction stir welding are the main factor affecting the welded joint. If the rotating speed of FSW tool is too low, then the frictional heat will not have generated enough to induce plasticized flow which lead to defect in the weldment. The other important factor is welding speed. When welding speed is too low then the frictional heat makes the temperature too high then there is the possibility of excess heat flow in the welded joint, whereas when the weld speed increases the material just below the tool softens to such a degree that it acts as a lubricant, lowering the friction and reduce the temperature.

3.2 Micro-hardness

The hardness test was performed at seven different places namely parent metal-1 (AA 2024), advancing side, heat affected zone (HAZ), Thermo-mechanically affected zone (TMAZ), nugget zone and parent metal retreating side. At each places three different reading were taken and mean values was opt. The hardness in the nugget zone was slightly higher as compare to TMAZ and heat affected zone which was attributed to small grain size. Decreasing trend of micro-hardness in TMAZ is due to dissolution of precipitates and lower hardness was pronounced in the HAZ due to coarsening of precipitates [17].

Fig. 4 demonstrates the variation of micro-hardness from heat affected zone (HAZ) to thermo-mechanically affected zone (TMAZ) of the FSW welded joint of AA2024 and AA5052 at different value of tool rotational speed. From the figure, it was seen that the hardness value at nugget zone increases when the tool rotational speed increased. Moreover, increase of tool rotational speed caused increment of hardness due to fine microstructure and low heat concentration [18].

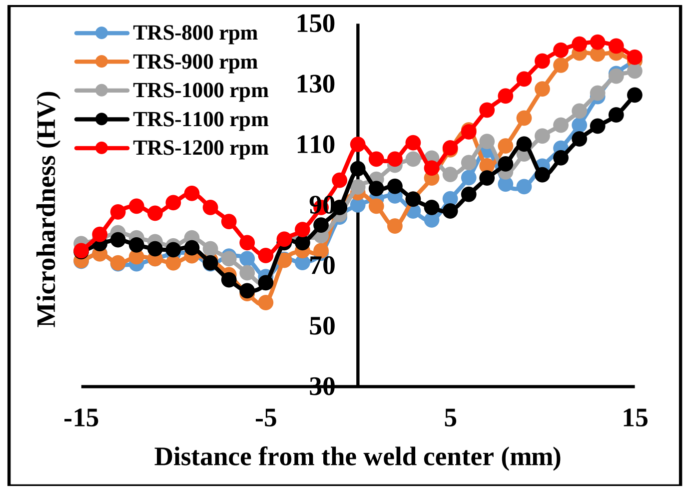


Figure 4: Distribution of micro-hardness of FSW welded joint of AA 2024 and AA5052 with different rotational speed

The micro hardness directly affects by the phase dispersion microstructure and dislocation density. In conventional friction stir welding process, inducing high heat input and thermal cycle cause grain growth and roughen the microstructure of the weld nugget zone.

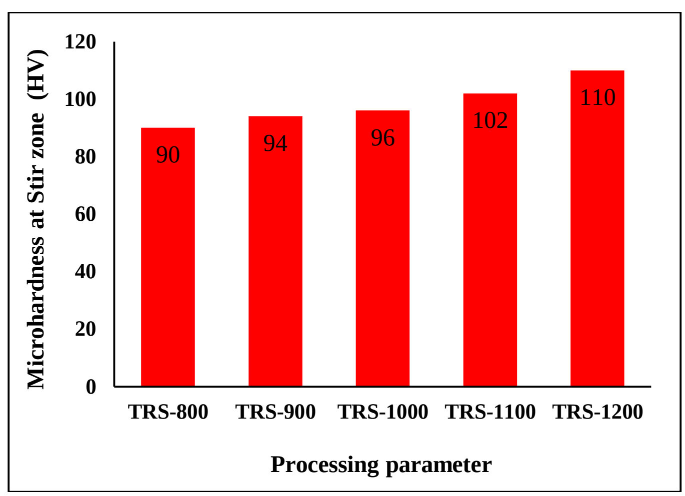
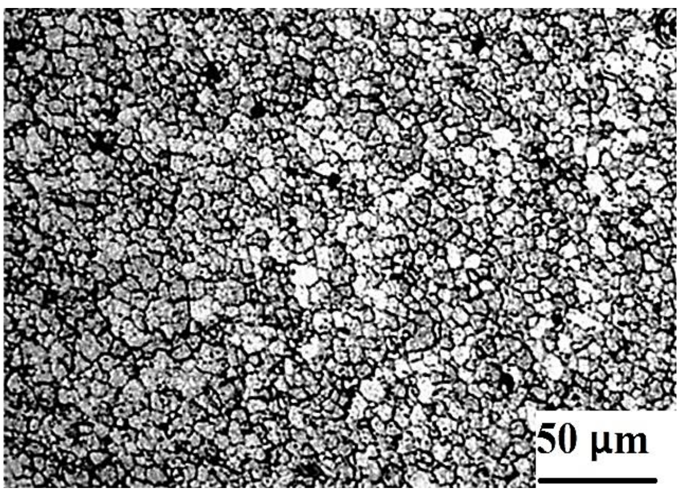


Figure 5: Comparison of micro-hardness of FSW welded joint at nugget zone of AA 2024 and AA5052 with different rotational speed

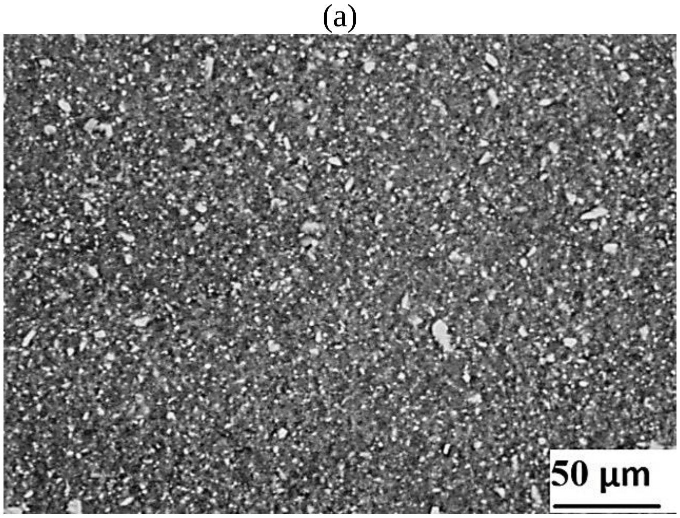
The microhardness values are less momentous in affecting the mechanical properties of the welded joint, because processing parameter (tool rotation speed, current, feed rate etc.) have more influencing factor over the hardness value [9]. The micro hardness values at the middle and bottom of the welded joint detected the major effect, because the grain size and microhardness number were changed due to solidification sequence and cooling rate of the weldment. The microhardness number also play a very important role to recognizing the metallurgical phase. In fig.5, it is shown that by increasing the tool rotational speed, the hardness at the nugget zone increases and reaches to a maximum value at their intermediate level. The maximum hardness (110 HV) was observed at tool rotational speed of 1200 rpm, whereas minimum hardness (90 HV) was obtained at tool rotational speed of 800 rpm.

3.3 Microstructure analysis

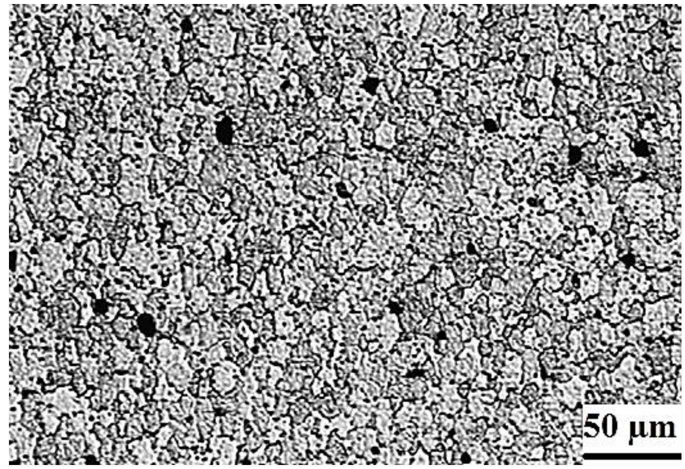
Fig. 6 shows the effect of tool rotational speed (800-1200 rpm) on the microstructure of the nugget zone of the friction stir welded joint of AA 2024 and AA5052.The temperatures at the weld nugget zone for dissimilar aluminum alloy reached 400-480°C. It is reasonable to predict that the temperature in the weld nugget zone was higher than the adjacent region (i.e. HAZ and TMAZ).



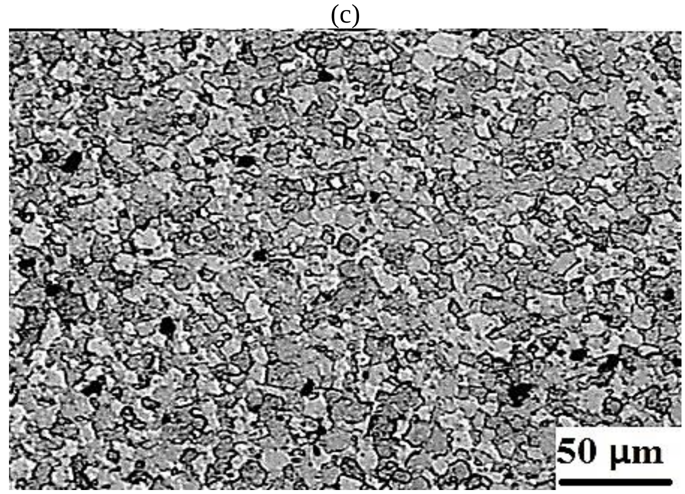
(a)



(b)



(c)



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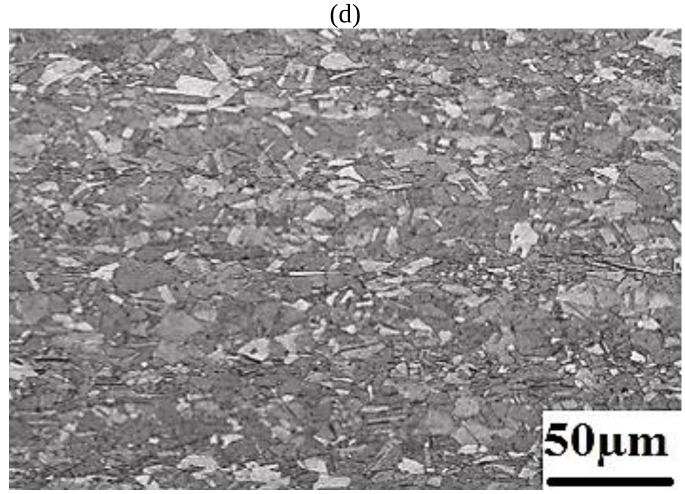


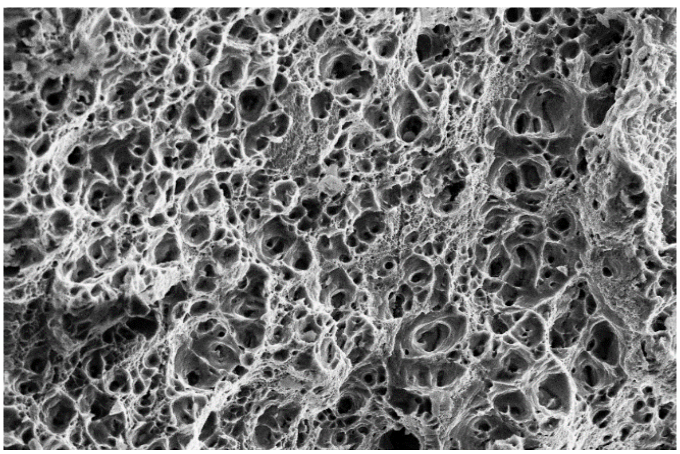
(e)

Figure 6: SEM images of friction stir welded joint of AA 2024 and AA5052, (a) 800 rpm, (b) 900 rpm, (c) 1000 rpm, (d) 1100 rpm, (e) 1200 rpm

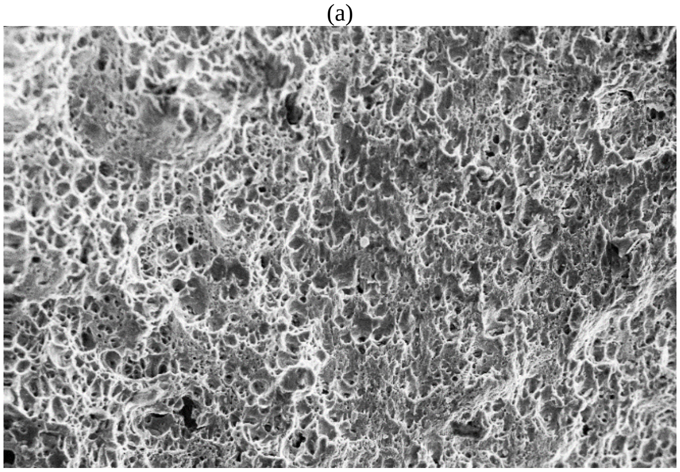
The extensive plastic deformation and the frictional heating generate fine recrystallized equiaxed grains in the weld nugget zone [19]. Dynamic recrystallization of the nugget zone resulted in the formation of fine and equiaxed grains in the weld nugget zone. The grain size was observed fine when the tool rotational speed increases from 800 rpm to 1200 rpm. The grain size in the nugget zone at tool rotational speed of 1200 rpm was finer than that of tool rotational speed of 800 rpm. The average grain of the nugget zone was observed 5.4 µm at 1200 rpm, whereas 12.4 µm grain size was observed at 800 rpm. This may be attributed to the lower temperature in the retreating side [20], lower deformation resistance of AA2024 than AA5052, during increased in temperature and smaller initial grains size of AA 2024 than AA5052.

3.4 Fractured surface analysis

The fractured tensile test specimens at high magnifications were investigated as shown in fig.7. When the tensile force was applied to the friction stir welded joint of AA2024 and AA5052, the tensile stress and strain concentration takes place in the lower strength region or part of the welded joint, and consequently, the welded joint was fractured in this region [21]. If the FSW welded joint were free of defects, then the joints were fractured on the advancing side (A.S) instead of retreating side (R.S) that means retreating side is greater than advancing side [22].



(a)



(b)

Figure 7: SEM images of tensile fractured specimen, (a) 800 rpm, (b) 1200 rpm

The fracture morphology between the high tool rotational speed and low tool rotational speed shows the clear difference that the FSW welded portion at 800 rpm shows the large and deep dimples whereas welded portion at tool rotational speed of 1200 rpm shows fine and shallow dimples. This was the evidence of crack nucleation and growth 4mm away from the weld line. The fine dimples were found in the high tool rotational speed whereas large dimples were found in low tool rotational speed. There were some characteristics in the fractured surface of FSW welded specimens, which illustrated both the cleavage and ductile fracture mechanisms. The quasi cleavage has explained this type of fracture mechanism and was regularly separated characteristic on the fracture surface that reveals features of both plastic deformation and cleavage [23].

4. Conclusions

The analysis of friction stir welding on dissimilar aluminum alloys of AA2024 and AA5052 have been successfully fabricated. The mechanical characterization of FSW welded joints were investigated using experimental methodology by adjusting processing parameters. The following conclusions have been made from the experimental work.

- The confidence interval has shown that tensile strength and hardness increased with increasing tool rotation.
- The maximum tensile strength, and micro-hardness at nugget zone are 235 MPa, and 109 HV at tool rotation 1200 rpm, traverse speed 40 mm/min and tilt angle 2^0.
- The effect of tool rotation on FSW welded joint also improve the ductility of the welded joints, FSW welded joint with tool rotation 1200 rpm were more ductile than the FSW welded joint due to fine grain structure.
- When the tool rotational speed increases from 1200 rpm may produce an excessive release of stirred welded material on the top surfaces of the base plate, obtained micro void into the stirred zone.
- The grains size in the nugget zone at higher tool rotation (1200 rpm)was observed much finer (5.4 µm) than the lower tool rotation (800 rpm).
- The FSW welded portion at 800 rpm shows the large and deep dimples whereas welded portion at tool rotational speed of 1200 rpm shows fine and shallow dimples.

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Cite this article as: Basit Hassan Hakeem, Amit gupta, Vikas Nandal, Investigation of microstructure and mechanical properties of friction stir welded joint of AA2024 and AA5052, International journal of research in engineering and innovation (IJREI), vol 5, issue 1 (2020), 42-47. *https://doi.org/10.36037/IJREI.2021.5105*.