# Effect of Tool Rotational Speeds on Friction Stir Welded AA6082-T6 Aluminium Alloy Joints

**Sameer MD, Aruri Devaraju, Saikumar Gadakary, Srinu G**

***Abstract*: In the current work, an attempt has been made to investigate the effect of tool rotational speed on microstructural and mechanical properties of friction stir welded AA6082-T6 aluminium alloy. Four different tool rotational speeds such as 500, 700, 900 and 1100 rpm were used to produce the joints while keeping the other process parameters constant. The tool used to fabricate the welded samples was tungsten carbide with straight cylindrical pin profile. The microstructural properties were examined using an optical and scanning electron microscope and found that the 700 rpm produced joint showed equiaxed grain structure with 14.3 µm average grain size. The mechanical characteristics such as tensile strength, impact strength and microhardness were evaluated and found the highest tensile strength of 265 MPa, impact energy of 10 J and micro hardness of 76 HV in the weld zone for the sample prepared with 700 rpm tool rotational speed. The fractographic studies were also carried out to study the mode of failure.***

***Keywords: Friction stir welding, mechanical properties, microstructure.***

## I. INTRODUCTION

Friction stir welding (FSW) is a solid-state welding process came into the existence in the year 1991 at The Welding Institute (TWI) in the United Kingdom [1]. The process is most suitable for joining long flat panels without fusion or filler metal. The maximum temperatures involved are about 80% of the melting temperatures of the welded plates. The joining is based upon the combined action of the frictional heat generated and mechanical deformation due to the rotating tool. The geometry of a tool is such that it consists of shoulder and pin, generally, the shoulder is cylindrical in size and pin with different profiles is inserted into the faying surfaces [2]. The principle behind the heat generation during the process is due to friction between the rotating-traversing tool and workpiece and shoulder abrading the material being joined. The plates are strongly clamped with a backing plate below the weld line. The advantages of FSW over other fusion welding are high-quality weld can be achieved, the absence of solidification cracking, porosity (gas entrapment), oxidation (no requirement of shielding) and other defects. Several Studies have made on the different aluminium alloys using different tool materials. Elongovan et al. [3] conducted friction stir welding on AA6061 aluminium alloy using different tool pins and tool rotational speeds. They have used high carbon steel as the tool to fabricate the joints. Daniolos et al. [4] studied the joining of dissimilar aluminium alloy of grades AA6082-T6 and AA7075-T651. They concluded that the weld fractured at the HAZ was a good quality joint. The authors have studied friction stir welding of many similar and dissimilar metals [5-8]. They found that the weld parameters such as tool rotational speed, tool traverse speed, and tool tilt angle plays an important role for the superior weld joint properties. Heidarzadeh et al. [9] did study of tensile behaviour of 6061 Al alloy. They reported that bigger and fewer precipitates result in easier dislocation movement than smaller and more precipitates during the tensile test. Balasubramaniam et al. [10] conducted experiments on post-weld heat treated AA6061 Al alloy joints. They found that most of the strengthening precipitates dissolved during the FSW process results in fewer density precipitates. Bozkurt et al. [11] employed different tool materials to join 2124 Al alloy via FSW. They have observed that good welded joint was obtained when the tool was coated with AlTiN. Moreira et al. [12] conducted experiments on 6061 and 6082 and analysed the different tool rotating speeds and advancing speeds. There has been considerable work on 6082-T6 Al alloy Friction Stir welding and the effect of various parameters has been studied and documented. However there is limited work on isolated factor of tool rotational speed. In the present study, an effort has been attempted to investigate the response of different tool rotational speeds using WC tool material to fabricate the joints and significant effects on the behavioural trends.

## II. MATERIALS AND METHODS

Alloy 6082 is a versatile heat treatable structural alloy with application ranging from medium to high strength. It has tremendous corrosion resistance to seawater and easily welded. The mechanical properties of as-received AA6082-T6 material are the ultimate tensile strength (UTS): 280 MPa, yield strength (YS): 220, elongation: 24 and hardness:65. The chemical composition of the parent metal is in the Wt% of proportions Mg: 1.1, Zn: 0.20, Cr: 0.25, Si: 0.90, Mn: 0.70, Fe: 0.50, Cu: 0.05, Ag: 0.05 and remaining is Al. The 5-axis friction stir welding machine of BiSS-ITW make was used to fabricate welded joints of 2 mm thick

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sheets. The scheme of welding is illustrated in figure 1(a) and photographic image of the FSW machine is shown in 1(b). photographic view along with the dimensions are shown in figure 2.

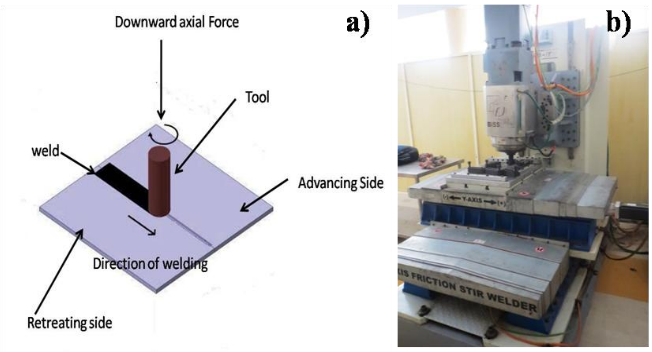


**Figure 1 a) Schematic of friction stir welding process b) FSW machine**

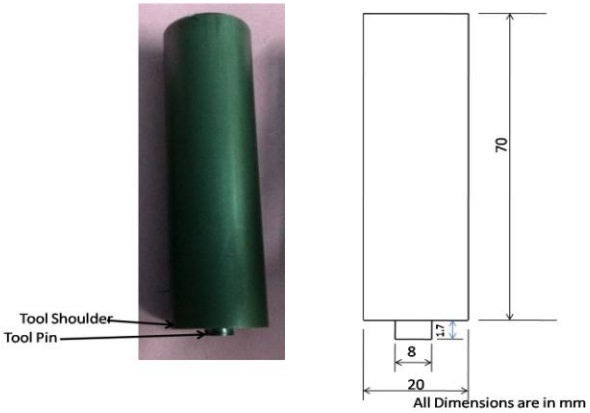


**Figure 2. Photographic view and the dimensions of the WC tool used**

To study the different mechanical and microstructural properties of different welded joints, samples were prepared from the fabricated sheets using wire-cut EDM. An optical microscope was used to observe the microstructures, Vickers microhardness tester for microhardness, universal testing machine for tensile tests and Charpy's V-notch impact tests were conducted using standard guidelines. Scanning electron microscopy (SEM) was used to examine fractured surfaces. The parameters employed to conduct the experiments are given table 1,

**Table 1. Process Parameters**

| S.No | Tool rotational speed (rpm) | Traverse Speed(mm/min) | Tilt angle 0° Plunge depth 0.2 mm are constant |
|---|---|---|---|
| 1 | 500 | 40 | |
| 2 | 700 | | |
| 3 | 900 | | |
| 4 | 1100 | | |

## III. RESULTS AND DISCUSSION

### Macrostructure

The tool material used was tungsten carbide (WC). The

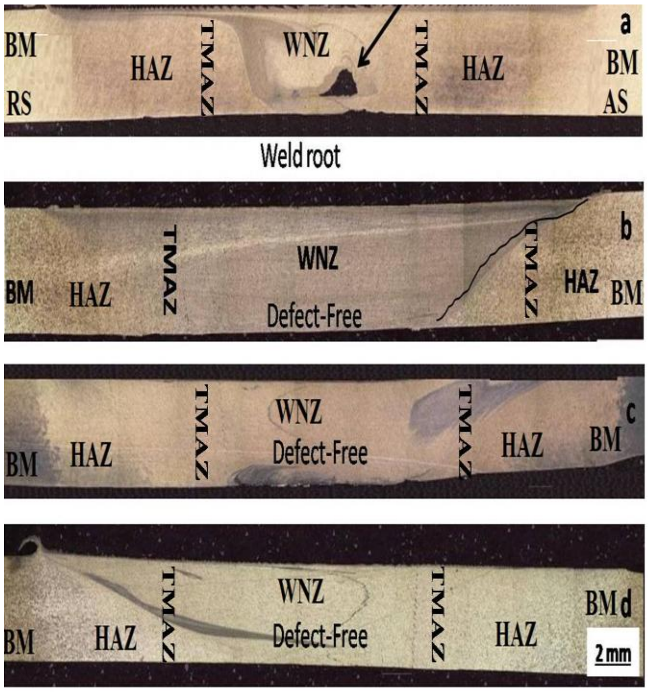


**Figure 3. Macrostructures of friction stir welded joints of AA6082-T6 a) 500 b) 700 c) 900 d) 1100 rpm**

Figure 3 shows different macrostructures of welded joints produced at various spindle speeds. The joints made with 700 to 1100 rpm showed defect-free joints whereas the joint manufactured using 500 rpm showed a defect in the weld region. From the macrostructure examination, it can be observed that tool rotational speed contributes a significant role in producing a defect-free joint. When the tool rotational speed is higher it caused the release of excessive stirred material resulting in defect-free joints. On the other hand, lower rotational speed could not stir enough material and lower heat input caused the flow to leave a tunnel defect in the stir zone.

### Microstructure

Figure 4 represents the macroscopic and microscopic images of the weld sample prepared with 700 rpm rotational speed. The joint microstructure is evaluated among the prepared samples due to its superior mechanical properties compared to other samples. From figure 4 region 1 gives the weld centre zone. This region has a banded structure due to the stirring tool pin. The pin causes extrusion and stacking of material when rotated [13]. Figure 4(a) shows the stir zone region and figure 4(b) shows the high magnification image of the weld nugget zone (WNZ)/stir zone (SZ) with dynamically recrystallized equiaxed grains with a visible amount of MgSi precipitates. Figure 4(c) shows the three zones of the weld joint towards the advancing side (AS). The grains were highly deformed in the thermo-mechanically affected zone (TMAZ), as the distance further increased from stir zone the grain size has increased.

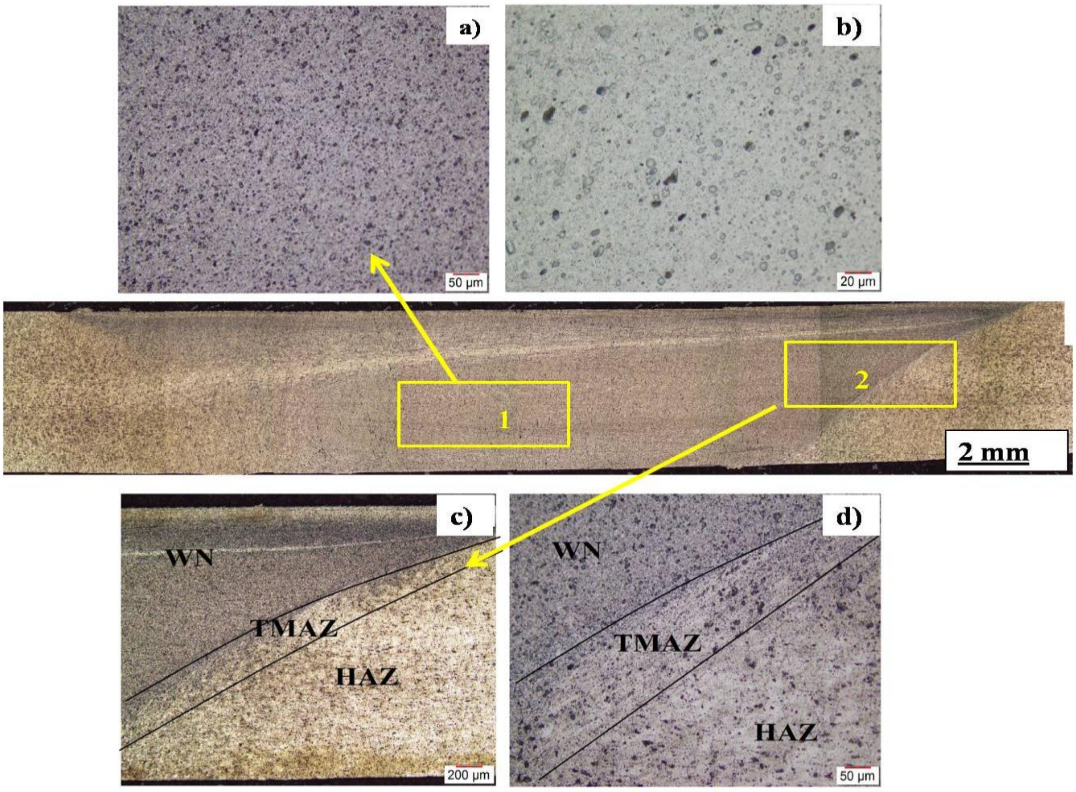


**Figure 4. Optical micrographs of 700 rpm joint a) weld nugget zone b) High magnification of Stir zone c) different zones towards AS d) High magnification of different zones towards AS**

Figure 5 demonstrates the stir zones of all the joints fabricated with various spindle speeds for the correlation of grain sizes. The difference in the grain structure can be observed and dispersal of precipitates which strengthens the materials was also observed in all the images of the optical microscope. FSW process is highly influenced by rotating speed, very high rotating velocities tend to uplift strain rate, in turn, affects the recrystallisation process. Higher temperatures are caused due to higher rotating speed which leads to a slower rate of cooling [14]. Figure 5(b) shows the optical micrograph of the stir zone fabricated by using 700 rpm rotating speed with smaller equiaxed grain size of 14.3 µm compared to other samples. The sample fabricated with 1100 rpm has coarser grain size among the fabricated joints. It is obvious that as the rotating speed raises consequently heat input raises, hence the coarser grain structure is formed. Therefore, the optimisation of tool rotational speed has to be done to achieve the homogeneous distribution of equiaxed grains in the friction stir processed region.

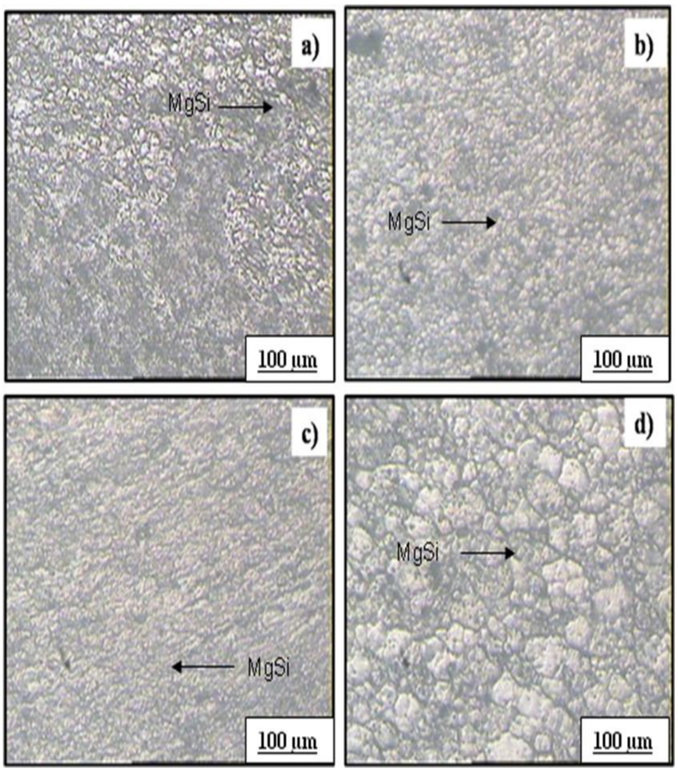


**Figure 5. Optical micrpgraphs of different stir zones a) 500 rpm b) 700 rpm c) 900 and d) 1100**

**Tensile properties**

The tensile test specimens were prepared according to ASTM standard procedures are shown in figure 6.

**Figure 6 Tensile test specimens before test**

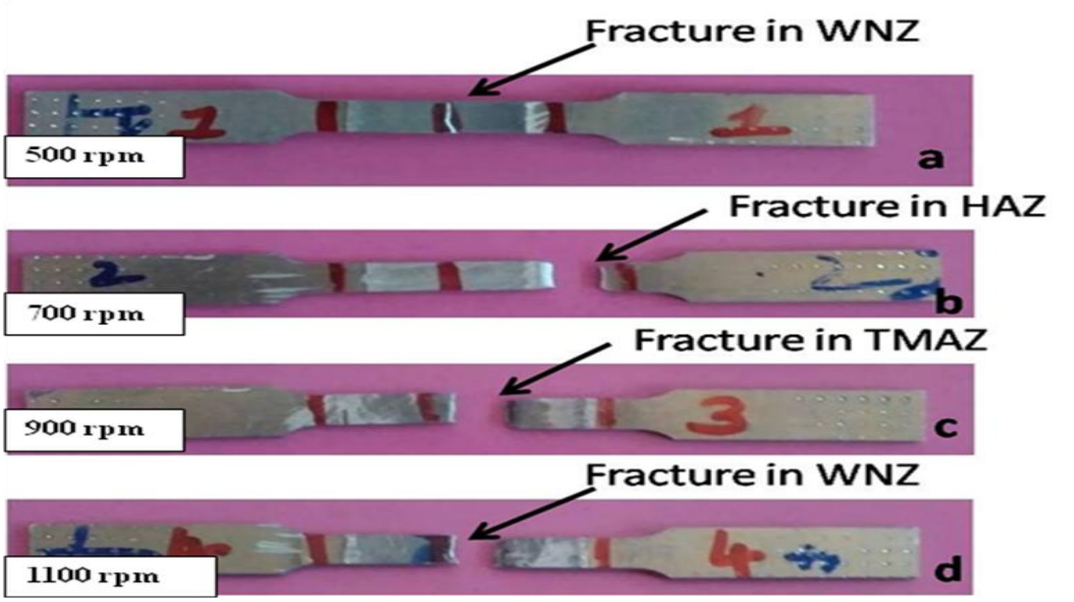


**Figure 7 Fracture locations of the different joints after tensile testing**

Figure 7 shows the tensile specimens after the tensile test for different weld conditions. It can be observed from the figure 7(a) the fracture location for the sample prepared with 500 rpm was identified in the weld nugget zone. Whereas for the sample 2 shown in figure 7(b) the joint has fractured in heat affected zone which indicated defect-free joint with good bonding in the joint interface. The tensile test sample prepared with 900 rpm as shown in figure 7(c) was fractured in TMAZ and for the sample 1100 rpm, the fracture location was observed in WNZ. The tensile test results of all the welded samples are tabulated in Table 4.

From Table 4 it can be seen that the specimen produced from the lowest spindle speed has least tensile strength and highest elongation percentage. As the spindle speed was raised the UTS has enhanced and ductility decreased, however, further increment in the spindle speeds lowered the UTS and increased elongation percentage, it is obvious that when the material has highest tensile strength its elongation is lowest [4]. The reason for the variations in the strength and ductility can be attributed to following two factors; i) at low rotational speeds, coarse secondary phase particles increase and ii) at higher speeds the strengthening precipitates have suffered dissolution in the HAZ region. Figure 8 shows the response of rotating tool speeds on UTS

**Table 4. Mechanical properties of different weld conditions**

| S.NO. | Tool rotational speed (rpm) | Tool Traverse speed (mm/min) | Tensile strength (MPa) | Elongation (%) | Impact Energy(J) |
|---|---|---|---|---|---|
| 1 | 500 | 40 | 182 | 11 | 5 |
| 2 | 700 | 40 | 265 | 7 | 10 |
| 3 | 900 | 40 | 226 | 8 | 7 |
| 4 | 1100 | 40 | 193 | 10 | 6 |

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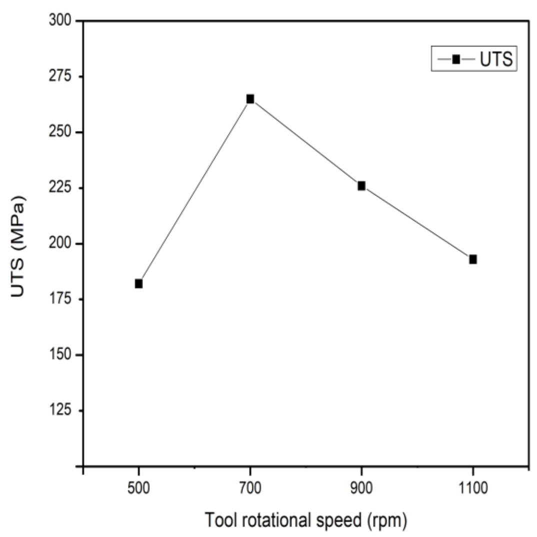


**Figure 8. Response of UTS for various tool rotational speeds**

**Impact Strength**

**Figure 9. Impact test specimen after test**

Charpy impact test was conducted to evaluate the joints sudden load strength. Figure 9 shows the impact test specimen after the tests and figure 10 shows the response of tool rotational speed on impact strength. The lowest impact strength was observed for the joint prepared with 500 rpm this can be attributed to low rotational speed which could not provide required frictional heat and time required for material mixing. The low rotational speed does not provide sufficient frictional pressure and friction time. As the rotational speed increases the impact strength also increases, however with further increment in the rotational speed the impact strength decreases this may be attributed to the grain coarsening.

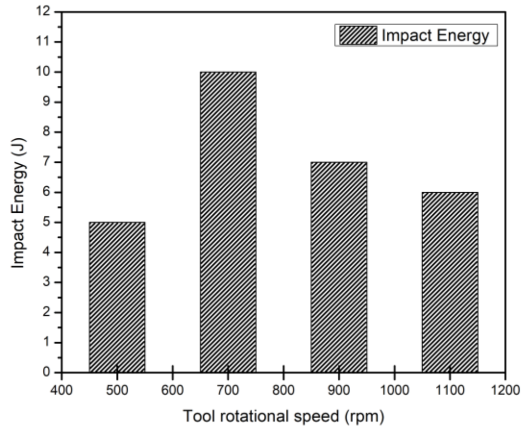


**Figure 10. Impact strength of different joint processed at various rotational speeds**

**Fractography**

The fractographic features of the samples 1100 rpm and 700 rpm were depicted in figure 11. The fracture surface of the joint prepared with 1100 rpm showed few dimples indicating brittle failure. The joint fabricated with 700 rpm showed dimples of different size and shape indicates ductile failure. The 700 rpm produced joint fracture at HAZ towards AS during tensile test reveals that the strength is less towards AS than RS. The stir zone has good bonding between the material and enough heat generation and strain rate; hence the fracture occurs out of the stir zone. Generally, small equiaxed dimples indicate the recrystallisation of grain structure. The 700 rpm sample exhibit a dense group of small dimples surrounding the big dimples due to high plastic deformation. In figure 11 b) the fracture of strengthening precipitates were observed, it indicates that hard and brittle precipitates triggered the formation of microvoids. Therefore, these smaller voids transform into the large crack during tensile test leading to final fracture [15].

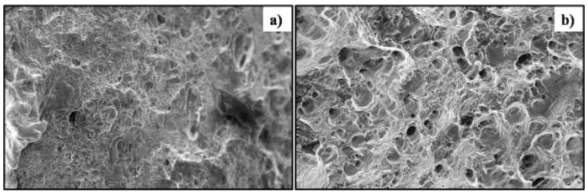


**Figure 11. Fractographic images of the specimens a) 1100 rpm and b) 700 rpm**

**Microhardness**

The microhardness profiles of the joints welded at 710 rpm and 1100 rpm were presented in figure 12. It was observed from the distributions that welds exhibited a typical W-shaped curve. The average hardness of the joints appeared to be less than the hardness of the base metal (100HV). Both the joints demonstrated their minimum hardness in the HAZ due to dissolution of strengthening MgSi precipitates during welding [16]. The microhardness in the stir zone of 700 rpm (76 HV) appeared to be higher than microhardness in the stir zone of the 1100 rpm produced joint. This could be attributed to the equiaxed grain size of 700 rpm joint is smaller than the grain size of 1100 rpm joint, consequently, the increase in hardness would occur according to Hall-Petch relation.

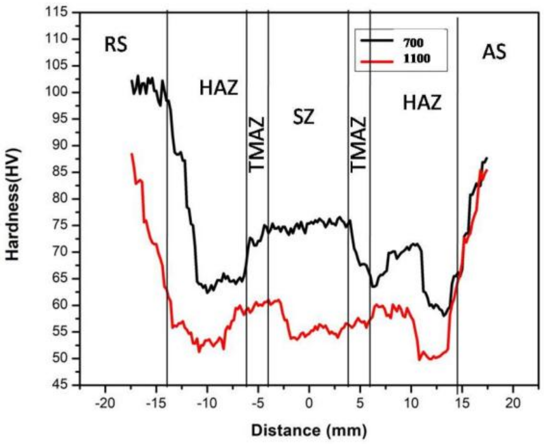


**Figure 12. Microhardness profile of the joints 700 rpm and 1100 rpm**

## IV. CONCLUSION

After experimental investigations on AA6082-T6 thin 2 mm Aluminium alloy friction stir welded with a tungsten carbide tool following conclusions were derived.

1. The tensile strength increased from 182 MPa to maximum of 265 MPa when the tool rotational speed was raised from 500 to 700 rpm.
2. The microstructure of joint produced with 700 rpm exhibited small equiaxed grain size with 14.3µm.
3. Lowest impact strength of 5 J was observed for 500 rpm and when the rotational speed was increased the impact also increased to 10 J.
4. The brittle nature of failure was noticed for the 1100 rpm whereas the ductile nature of fracture was noticed for 700 rpm with equiaxed dimples.
5. The lowest microhardness region was found in HAZ. The highest microhardness of 76 HV was found for 700 rpm produced joints due to the Hall-Petch effect.

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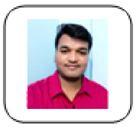

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