Microstructure Characterization and Testing of Aluminum 7075 and Magnesium AZ31B FSW Butt Joint

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Abstract –- D**issimilar friction stir welding of Al 7075 and Mg AZ31 are performed in a view to develop a defect free weld. The paper deals with generating sound weld by avoiding formation of intermetallic compounds (IMC) voids, tunnel defect, improper mixing of metals which detoriates the weld intergrity.In this paper, variation of two process parameters such as tool rotation speed (rpm) and tool traverse (mm/min) are carried out.Out of these parameters, a unique combination was evaluated for better mechanical properties.Study further involves designing of truncated conical tools with threads and designing of jigs and fixtures to carry out welding process.To verify quality of welds different mechanical properties such as tensile strength, hardness, percentage elongation are observed by performing different test on welded specimen Moreover, microstructure of the welded portion is characterized on SEM to have uniform voids free and fine grained microstructure.A trade of between tensile strength and ductility can be gained by forming a fine grain structure.**

***Keywords*--- Friction Stir Welding, Microstructure characteristics, Tunnel Defect, AZ31B, Al7075.**

I. INTRODUCTION

FSW is relatively new method in metal joining because today many industries prefer using material which can offer excellent mechanical properties, light weight characteristics with optimized structure. Aluminium and magnesium offer such abilities and find applications in many industrial sectors like aerospace, marine industry, automobile mainly for their strength to weight ratio. High strength aluminium alloys have been increasingly employed in welding of fuel tanks of launch vehicles, space shuttles and ships. In practical application welded zone experience large amount of forces which are most critical area for failure to sustain these sound weld need to be produced. But when joining of aluminium and magnesium by conventional method such as TIG, EBW, MIG, laser beam welding leads to liquation induced cracking and porosity as well as formation of intermetallic compounds. This results in poor weld joints. To overcome these a solid state welding technique called FSW can be employed.

Friction stir welding is a solid state welding process of its solid state nature (no melting happens at joining) and has some advantages over other fusion welding methods. FSW is a method of joining two similar or dissimilar workpieces, wherein the tool rotating at a certain speed plunges at a certain depth in the workpiece interface called as plunge phase, initiating the weld. Once the sufficient heat is provided the tool is further provided with transverse feed, plasticizing the material called as main phase. The last phase called termination phase, where the tool is withdrawn from the workpiece. These are the three phases explaining the FSW mechanism.

Akash Gupta et al. [5] studied that the defects produced with truncated conical tool were lesser than the cylindrical tool. Paper also indicates that negligible defect was found during FSW with the truncated conical tool at the rotational speed of 2000 rpm and welding speed of 40mm/min.Mastanaiah et al.[] proposed that tool should be positioned towards softer aluminium alloy side to improve fatigue and tensile properties of weld joint. Also, Intimate mixing of dissimilar alloys was observed at higher tool rotation speeds and lower tool traverse speeds.

Mr. P. H. Shah et al.[7] experimented and concluded that the appropriate temperature for a defect free friction stir welding can be within the range of 375-420 degree Celsius. Also, the joints fabricated with 20mm shoulder diameter yield maximum joint efficiency.

Pavankumar Thimmoraju et al.[1] studied effects of different tool profiles on friction stir welding of different aluminium alloys. Tensile tests were performed on the welded specimens as per ASTM standards. The recorded tensile properties showed that the highest tensile strength of 116.749 Mpa was measured for weld joint made with hexagonal tool profile. A lower tensile strength of 72.731 Mpa and 75.588 Mpa was recorded for triangle and square tool profile respectively.

E G Cole et al.[2] work considers the butt-weld configuration of dissimilar aluminium alloys, where for a particular set of alloys and tool design, the practitioner must determine which alloy will be located on the advancing side of the tool as well as the tool's offset from the joint. It was concluded that not only should the material with the lowest solidus temperature should be on the 'cold' side of the weld (retracting side) but also the material most susceptible to weakening at elevated temperatures should experience the least amount of power input achievable during the weld process. Regarding tool alignment, offsets should be implemented as a method of increasing or decreasing the amount of heat input, or temperature exposure, experienced by the butted alloys.

Piyush Gulati et al.[6] in his paper concluded that increasing the shoulder diameter of the tool, peak temperature are higher and the material deforming state changes from high flow stress to low flow stress. The author also found that the square pin gives maximum strength to the joint.

Better weld characteristics are well defined by the shoulder diameter of tool. To study the shoulder diameter effect S. R. Babu et. al. [10] carried experiments by varying the shoulder diameter and stated that for range of 18 mm and 24 mm shoulder diameter defect free FSP was performed on AZ31 alloy of 6mm plate thickness. The paper also explains for shoulder diameter less than 18 mm set of FSP defects like voids, tunnels, holes in weld area.

For uniformity of weld joints P. Sevelet. al. [9]emphasis on process parameters and its role on microstructural characteristics and mechanical attributes. To develop proper material flow during operation taper cylindrical pin profile was used. With this profile, high mechanical properties of weld were obtain at 750 rev/min and 75 mm/min ratio of rotational speed to feed rate.

Because of wide range of experimental data it makes difficult and time consuming for researcher to develop a set of parameters which can offer high joint properties. For this D. Devaiah et. al [8] used Taguchi approach and gave optimal process parameters values as rotational speed 1120rev/min, feed rate 70 mm/min and tool tilt angle s2 degrees for FSW of AA5053 and AA6061 with high weld strength.

The literature survey reflects almost scarce work of FSW on AA7075 and magnesium AZ31B. Hence, the study focus on developing defect free joints with optimal parameters with characterization.

II.EXPERIMENTAL PROCEDURE

The Al 7075 and Mg AZ31B were procured from commercial supplier from Mumbai of dimensions 2×3 feet of 4 mm thickness with chemical composition as shown in Table 1. The 4 mm thick sheets of AZ31B and AA7075 were cut into 18 specimens of length 300 mm and width 100 mm. The sheets were machined by using turning operation to develop fine edges. This helped to remove any inhomogeneity across the edges to develop smooth joint. In the present work, the FSW operation was carried out using VMC Machine. Two carbide tools were used to join Al/Mg had a tool shoulder diameter of 16 mm with a tapered cylindrical pin of length 2.5 mm. Taper cylindrical and square shaped tool profiles were used.

TABLE I

CHEMICAL COMPOSITION OF AA7075 AND AZ31B

Alloys	**Chemical Composition**									**Mechanical Properties**		
	Al	Mg	Fe	Zn	Mn	Si	Cr	Cu	Ni	Tensile Strength (Mpa)	Elongation (%)	Hardness (HV)
Al 7075	Bal.	2.49	0.24	5.72	0.3	0.42	0.21	1.64	-	280	9	150
Mg AZ31B	2.99	Bal.	0.0021	1.00	0.35	0.0086	-	0.0091	0.00072	255	12	55

Fig. 1 Clamping of plates on VMC

Fig. 2 FSW tool

Prior to the microstructural examination on the base material and welded joint specimens the mounted specimens were grounded and polished up to 1200 grit followed by 1 µm diamond slurry and 0.04 µm colloidal silica. To observe the microstructural features, the Mg and the Al parts of the weld were etched using standard acetic picral solution (4.2 g picric acid, 10 ml acetic acid, 70 ml ethanol and 10 ml distilled water) and Weck's reagent (4% $KMnO4$ and 1% NaOH diluted in distilled water), respectively.

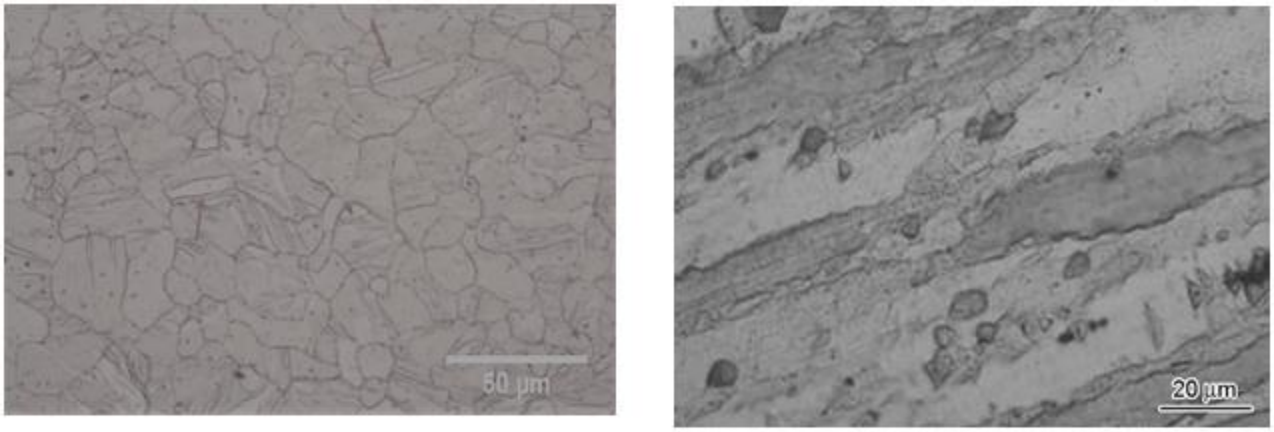
An optical (light) microscope and a scanning electron microscope (SEM) were used to observe microstructure, intermetallics and different zones formed after the weld. The welded specimens were evaluated for Vickers micro hardness using parameters of 100 gf and dwell time of 15 s.

The microhardness measurements were performed at 2 mm from the top of the weld in the thickness plane (normal direction transverse direction (ND-TD) plane, perpendicular to the welding direction). The hardness values were also measured at three different distances from the top of the weld to study the variation of the hardness in the welded joint. ASTM E8/E8M-15 (ASTM International, PA, 5,USA) tensile test specimen geometry was used for the tensile experiments.

TABLE I

FSW PARAMETERS

(Rotational speed, traverse speed)	25	45	65
800	S1	S2	S3
1000	S4	S5	S6
1200	S7	S8	S9



(a) (b)

Fig 3. Microstructure of base material (a) AZ31B (b) Al7075

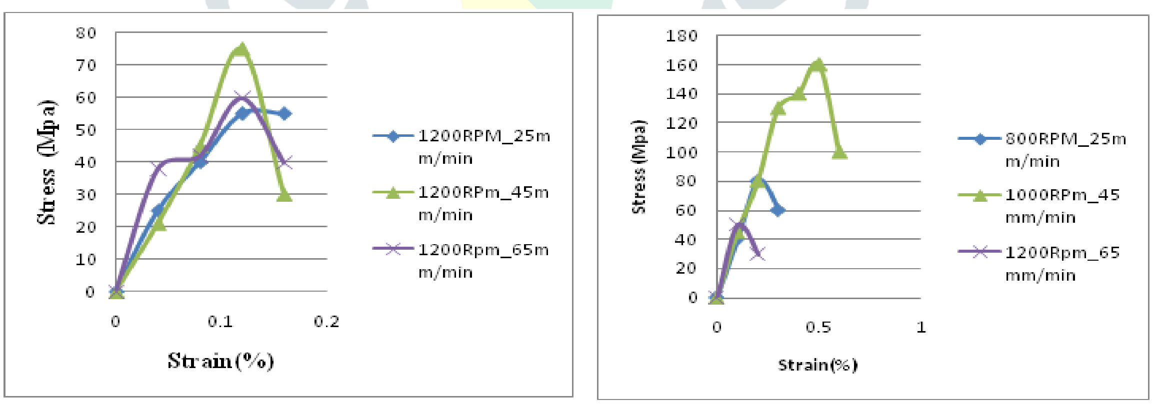
III.RESULTS AND DISCUSSION

Uniaxial tensile testing

In the purpose of studying the joint efficiency of different weld parameters, to account for potential ranges of operation conditions and finally to study the failure mechanisms; the mechanical response of tensile tests conducted at room temperature and strain rate of10-3 s-1 are presented in Figure 4.

Room temperature

The engineering stress-strain tensile response of dissimilar FSW of Al (on AS) and Mg using constant tool rotation speed of 1200 rpm, and tool translation speeds of 25, 45 and 65 mm/min are presented in Figure 4(a). From this figure it could be observed that decreasing the translation speed resulted in higher strain to failure but lower strength. This observation can be explained by the fact that reducing the tool translation speed leads to an increase in the heat input, which consequently increase the average grain size resulting in higher strain to failure and lower strength.The stress-strain response of the joint obtained using 65 mm/min as translation speed presented the lowest strain to failure, which can be the consequence of the less heat input that results into smaller grain size.



(a) (b)

Fig 4.Engineering stress – strain curves of uniaxial tensile tested welds at room temperature and 10-3 s-1 with (a) constant tool rotation speed, (b) constant tool translation speed.

The mechanical response of joints obtained by fixing the tool translational speed at 45 mm/min, and varying the tool rotational speeds between 800 rpm to 1200 rpm (with Al on AS) are plotted in Figure 4(b) From this figure, it can be observed that the joint obtained with 1200 rpm tool rotation speed presented the lowest strain to failure and strength compared to the other welding parameters. It was also observed that the joints obtained using 1000 rpm tool rotation speed showed the highest strain to failure. Those observations can be explained by the fact that using 45 mm/min and 1000 rpm as weld parameters produced the optimum heat generation and strain rate which resulted in defect-free joint and higher mechanical properties The stress-strain response of the studied dissimilar Al/Mg welds exhibited a brittle behavior.

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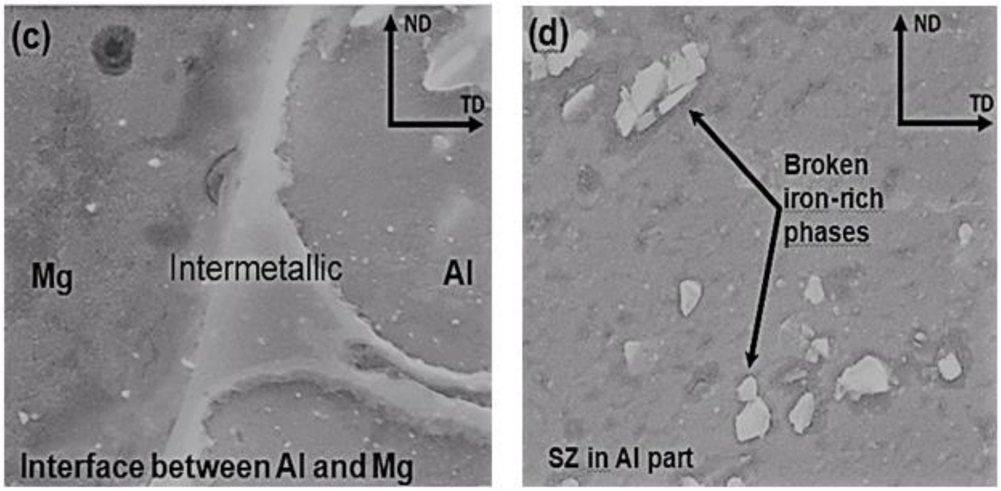
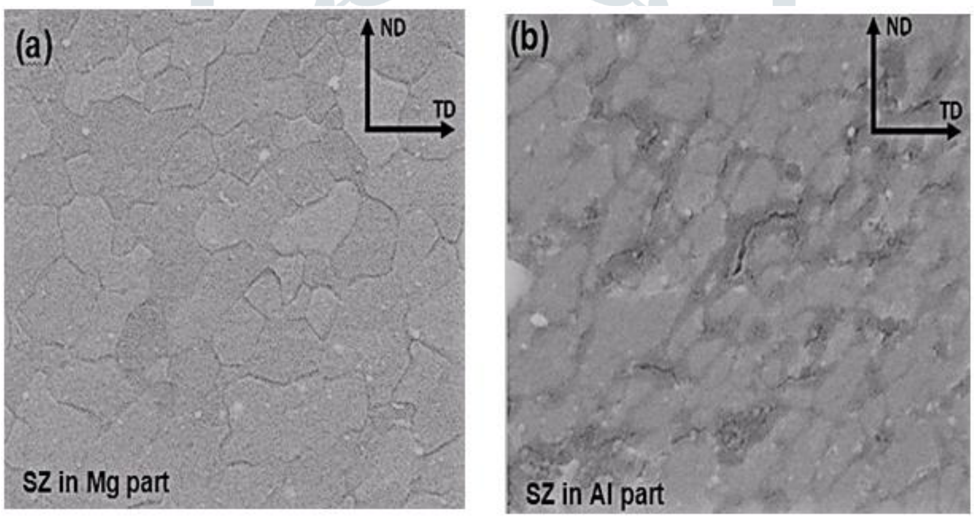


(a) (b)



(c) (d)

Fig. 5 SEM analysis of the SZ in the joint prepared using 1400 rpm and 500 mm/min. (a) magnesium stir zone, (b) aluminum stir zone, (c) Intermetallic in the Al/Mg interface and (d) aluminum stir zone showing broken precipitates

Scanning electron microscopy observations

Figure 5 shows SEM micrographs observation of the SZ of Al/Mg dissimilar welded sheet joined using 1000 rpm and 45 mm/min weld parameters placing aluminum on the AS. Figure 5(a) and 5(b) reveal an equiaxed microstructure of the SZ in Mg and Al sides, respectively. The microstructure of the SZ seems to be the consequence of a completely recrystallization that resulted in a very fine grains structure. It can be assumed that the observed microstructure resulted from a severe deformation with not enough heat input to induce a sizeable grain growth. Fig 5(c) shows the interface between Mg and Al separated by a thin layer of IMC. Friction stir welding of aluminum and magnesium results in the formation of brittle IMCs such as Mg_2Al_3 and $Mg_{17}Al_{12}$. The formation of IMC was reported to occur in localized fusion zones, which is strongly dependent on the heat input resulting from the weld parameters. Therefore, the IMCs are most likely to form in weld zone that encountered the highest temperature, more precisely at the interface between aluminum and magnesium and in some localized areas of the SZ.

A higher percent of IMCs has been reported in the SZ compared to the BMs. Figure 5(d) shows broken precipitates present in the Al part of the stirred zone, probably induced by the severe deformation encountered by the material during FSW. The SEM images present a defect-free interface between the FS welded Al7075 and AZ31B alloys. The microstructure and the weld integrity analysis demonstrated that 1000 rpm rotational speed and 45 mm/min translational speed can be used as the optimum welding parameters in the present study. The optimum parameters observed in the study are based on the tool geometry used. The analysis of the microstructure revealed a defect free weld with the presence of brittle IMCs in the SZ. Observable IMC layer at the interface between magnesium and aluminum suggested that the interface reached a high temperature close to melting during the FSW process. Also, the presence of IMCs at the interface suggests that the most probable zone of crack initiation during mechanical loading will be the interface between the magnesium and aluminum.

Microhardeness

The magnesium crystalline structure is a hexagonal-closed pack (HCP), the crystal unit cell of aluminum is face-centered cubic (FCC), Mg17Al12 has a body-centered cubic (BCC) crystal structure and finally the Mg2Al3 intermetallic phase In order to detect the difference in the mechanical and microstructural properties of the different zones of the weld and in the purpose of identifying the zones of the welds where fracture is most probable to occur micro-hardness testing was conducted.

The peak in the hardness values between the aluminum and the magnesium can be related to an abrupt change in the microstructure, more precisely the grain size and also to the presence of the IMCs. Therefore, the process of crack initiation will be further accelerated when the weld is subjected to tensile loading conditions owing to his higher density of dislocations.

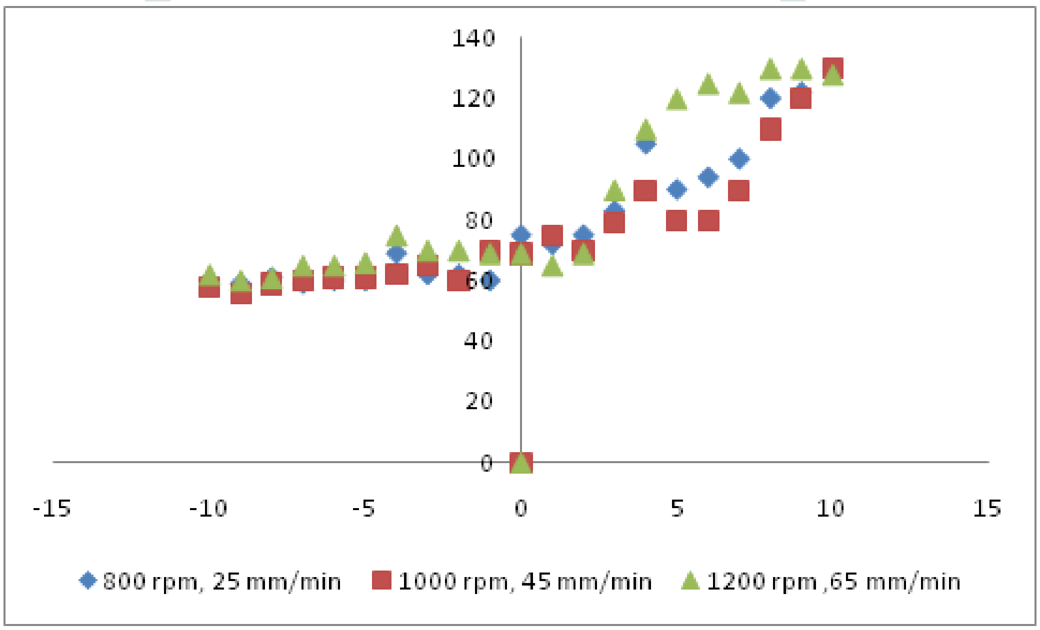


Fig. 6 Micro-hardness values(hardness vs distance from weld)

V.CONCLUSION

The following conclusions can be made based on the present study on friction stir welding on dissimilar metals – aluminum and magnesium:

1. AZ31B magnesium alloy was successfully FS welded with 7075 aluminum alloy with different parameters and material configurations.
2. The examination of the FS welded joints cross section area, having aluminum on advancing side of the FSW resulted in better welds with fewer defects in the stir zone.
3. Among the studied weld process parameters 1200 rpm rotational speed and 45 mm/min translational speed resulted in the optimum joint quality, based on the analysis of the weld integrity and microstructure.
4. The optimum parameters obtained in the study were found for the taper cylindrical tool geometry used in the present work.

ACKNOWLEDGEMENT

A special thanks to Prof. H. A. Deore and Prof. S. C. Shinde for their intellectual and practical support during the project work.

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