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INFLUENCE OF WELD PARAMETERS ON FRICTION STIR WELDING OF AA6061-AZ61

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Abstract

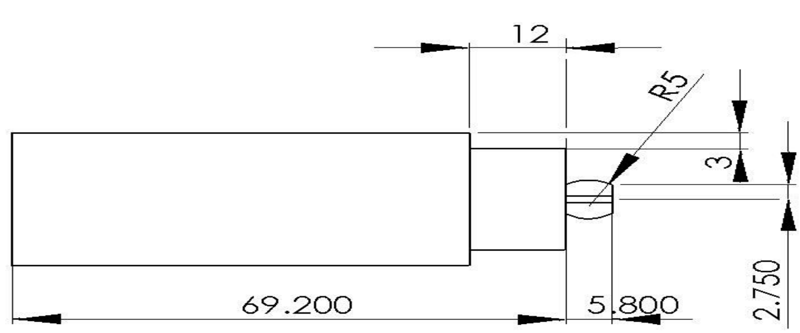
This paper reports the macro and microstructural characteristics of dissimilar friction stir welds of AA6061T6 and AZ61. Dissimilar Friction Stir Welds between AA6061T6 and AZ61 is produced by keeping welding speed as 30 mm/min, axial load as 2.5 KN and varying the rotational speeds between 600 and 900 rpm and the. The welds characterization were analysed with help of Scanning Electron Microscope (SEM), Optical Microscope (OM), and micro harness evaluation. Two different tool profiles (Inverted taper pin and concave slotted pin) are used for this investigation. It is revealed that the good metallurgical bonding is achieved at the joint interfaces of the weld for the higher rotational speed.

Introduction

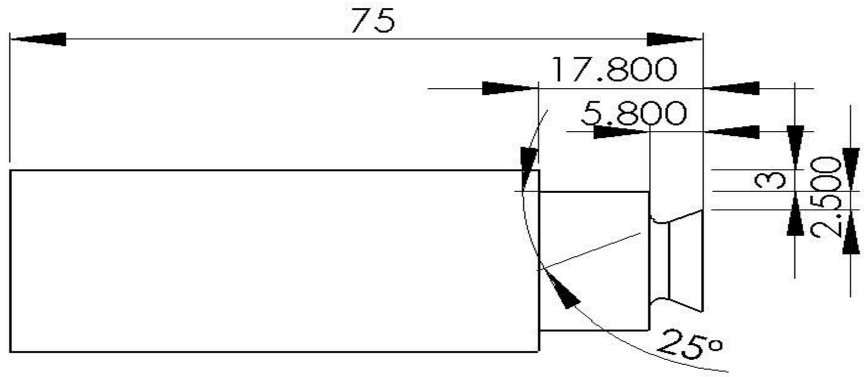
In the early nineties, TWI invented Friction stir welding as a relatively new welding technique that has demonstrated the non weldable by fusion welding or difficult to weld metal like dis-similar combination metal can be welded effectively [1]. Magnesium alloys and Aluminium alloys have found known application in automotive and aerospace sectors due to its weight saving factor. However, the wide- spread application of Mg alloys has been hampered by the poor form-ability inherent to its hexagonal close packed structure. Therefore, it is important to consider the weld properties of Mg alloys, the study of effect of parameters could increase the usage of Mg alloys as complicated parts. Friction stir welding has a lot of merits in joining light metals such as Al and Mg alloys [2–7]. Studies on FSW of Magnesium alloys have been investigated with ternary system of Mg–Al–Mn, Mg–Al–Zn and heat-resistant Magnesium alloys of Mg–Zn–Y–Zr and Mg–Al–Ca [8–17]. In order to increase the industrial applications of magnesium alloys, the development of effective welding techniques are necessary [11]. Friction stir welding (FSW), is better technique which can surpass the issues that exist in the fusion welding process of Magnesium alloys [23,18–21]. It can produce fine-grained structure and porosity free joints a in the stir zone (SZ) that is formed due to dynamic re-crystallization [22]. For ultra fine grained materials, FSW can restrain the grain growth because of the lower heat input during the FSW [24]. Thus, FSW can be a better choice for the welding of fine grained magnesium alloy. For obtaining the high strength Magnesium alloys are required to proceed with combination of Thermal and mechanical processing (TMP) which will also yield a fine-grained micro structure. The conventional AZ (Mg–Al–Zn) series magnesium alloys have poor thermal stability due to the lower dissolution temperature of Mg17Al12 phase. Therefore, the easier grain growth and cavity formation are the major problems during the hot deformation, resulting in decreasing mechanical property. Mg–Zn–Y–Zr alloys containing ternary phases exhibited satisfactory mechanical properties at room temperature as well as at elevated temperature, because ternary phases with high thermal stability pinned the boundaries and inhibited grain growth during the TMP [25]. The literature survey reveals that many researchers are investigated Friction Stir Welding of AZ 31 and other Aluminium designated alloys. Our work is the pioneering effect on investigating the AZ 61 with AA 6061 dissimilar butt joint and studying the mechanical characterization of age hardened Aluminium alloy over Magnesium alloy. The different process parameters are analysed for gaining the desirable properties of the welds obtained for the dissimilar Aluminium - Magnesium alloys.

Experimental Work:

In the present work, 6 mm thick plates of AA 6061-T6 and AZ61 are Friction Stir Butt Welded with two different tool geometries: a inverted taper pin (Tool 1, Fig. 1a) and concave slotted tool (Tool 2, Fig. 1b) with 18 mm shoulder diameter. The welding process are accomplished at four rotational speeds 600, 700, 800 and 900 rpm, keeping axial load and transverse speed as 2.5 kN and 30 mm/min. as constant with tilt angle of 0º.



(a)



(b)

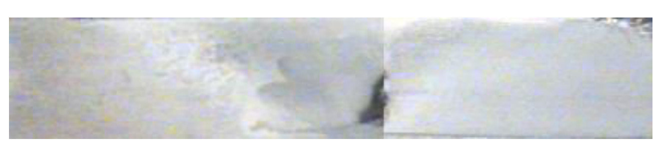
Fig.1.Tool geometries for the current investigation on AA6061-AZ61: (a) Concave slotted tool, (b) Inverted taper tool.

Result and Discussion

Macrostructure examination reveals the weld defects like worm holes and tunnel defects thereby helps to identify the improper combination of weld parameters. Inverted Taper (IT1 to IT4) welds were made with the Inverted Taper Tool. The tool rotation speed alone is varied for the welds IT1 to IT4 by keeping other parameters constant. Weld plates IT1, IT2 and IT3 showed the worm hole defect during visual inspection. However the plate IT4 has less defect.

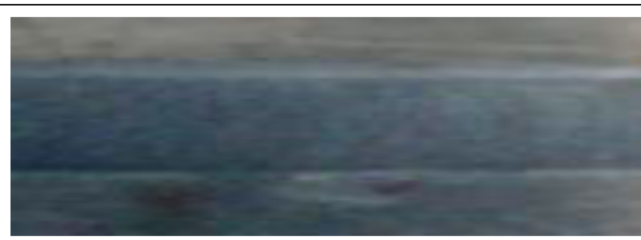
Poor surface quality (like sand paper surface) was observed at all the weldments of the welded plates IT1 to IT4, which is shown in Table 2.

Table-2: **Macro structure of AZ61-AA6061 at different weld parameters with Inverted Taper Tool (IT).**

Code No.	Weld Parameters	Macro structure RS(AZ61) AS(AA6061)
IT1	600 RPM 30 mm\min 2.5 kN	
IT2	700 RPM 30 mm\min 2.5 kN	
IT3	800 RPM 30 mm\min 2.5 kN	
IT4	900 RPM 30 mm\min 2.5 kN	

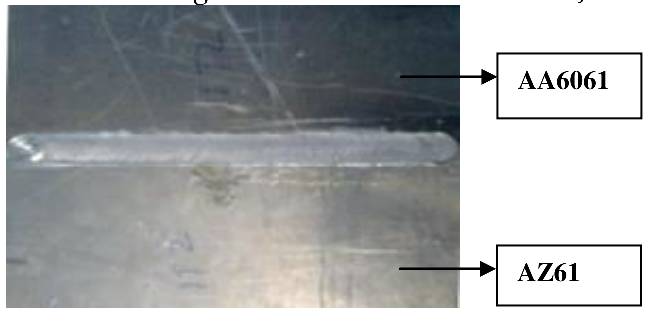
Concave slotted Tool (CT1 to CT4) welds were made with the Concave slotted Tool. For this tool pin profile also tool rotation speed alone varied for the welds CT1 to CT4 and other parameters were kept constant. Weldments of weld plate CT1, CT2 and CT3 showed the less worm whole defect in visual inspection as in Table 3. The weld plate CT4 showed a smooth surface at the weldment as well as no worm whole defect on the weldment. The poor surface quality like sand paper appearance was observed at the weldments of the welded plates IT1 to IT4, this is due to the high temperatures raised during welding; the Aluminium and Magnesium particles tend to attach themselves to the surface of the shoulder of the tool. The surface morphology of the Friction stir welded butt joints of AA 6061-AZ61 alloy plates with Inverted Tool and Concave slotted tool is shown in Figure.2. For different rotational speeds.

Table-3: **Macro structure of AZ61-AA6061 at different weld parameters with Concave slotted Tool (CT).**

Code No.	Weld Parameters	Macro structure RS(AZ61) AS(AA6061)
CT1	600 RPM 30 mm\min 2.5 kN	
CT2	700 RPM 30 mm\min 2.5 kN	
CT3	800 RPM 30 mm\min 2.5 kN	
CT4	900 RPM 30 mm\min 2.5 kN	

The microstructure of the different region of the CT4 welded plate is shown in Figure 3. It shows the microstructure at the weld nugget zone is composed of the fine equiaxed recrystallised grains compared to the microstructure of the base metals.

(a) IT1 Weld Plate



(b) IT 2 Weld Plate

(c) IT 3 Weld Plate

(d) IT 4 Weld Plate

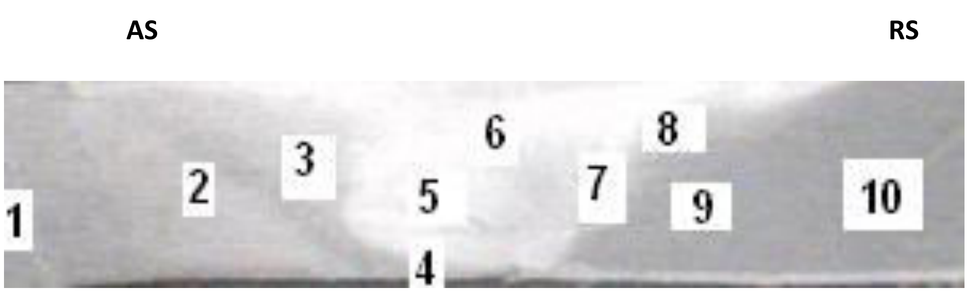
(e) CT1 Weld Plate

(f) CT2 Weld Plate

(g) CT3 Weld Plate

(h) CT4 Weld Plate

Fig.2. Surface morphology of FSW joints of AA 6061-AZ 61 at different rotational speeds
(a) IT1-600 r.p.m. (b) IT2-700 r.p.m.
(c) IT3-800 r.p.m. (d) IT4-900 r.p.m. (e) CT1-600 r.p.m. (f) CT2-700 r.p.m. (g) CT3-800 r.p.m. (h) CT4-900 r.p.m.



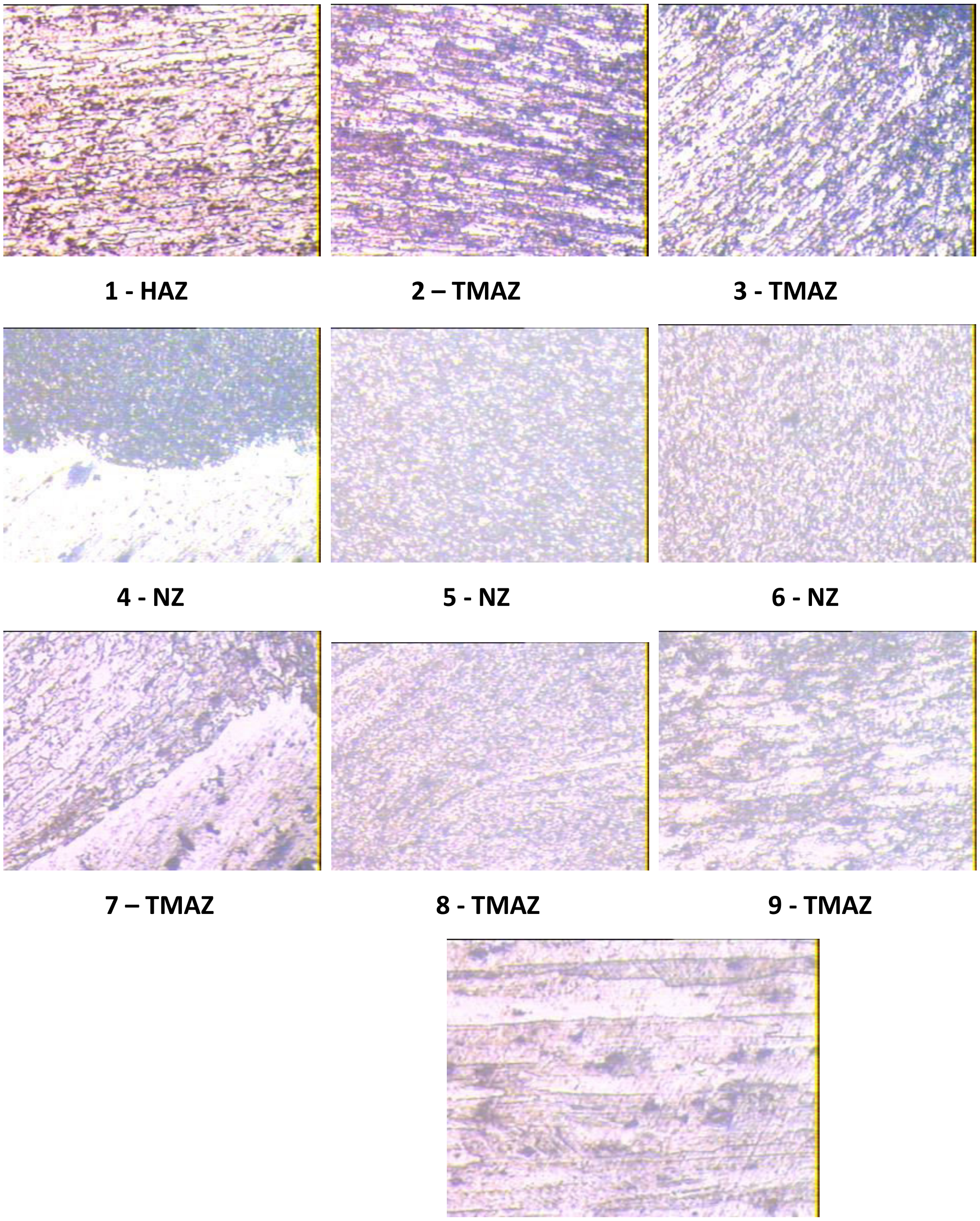
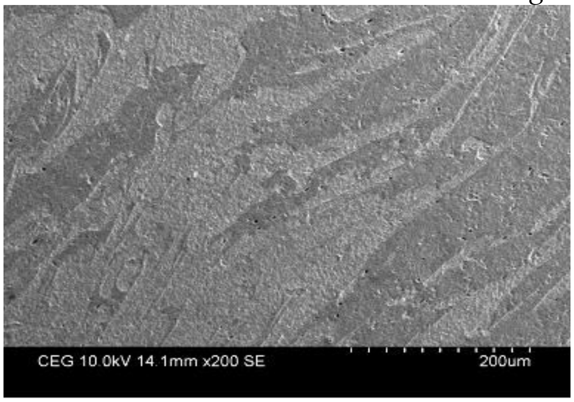
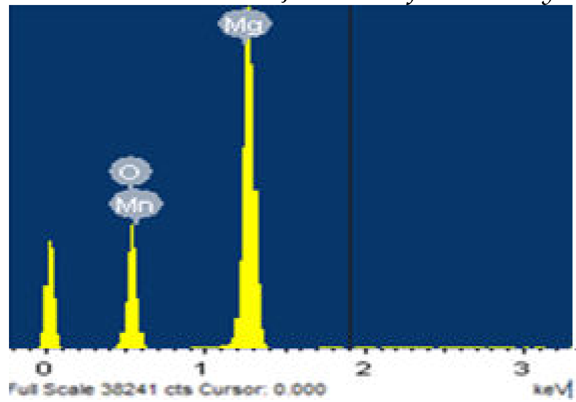


Fig3. Microstructural analysis of different zones of the weld joint for the weldparameter of 900 r.p.m., 30 mm/min. and axial load of 2.5 KN.

The original grain and sub grain boundaries are transformed into nearly fine equiaxed recrystallisation due to high temperature and high rate of deformation in this region. Whereas in thermo mechanically affected zone and heat affected zone microstructure shows larger, elongated grains boundaries in the both advancing and retreating side. The second phase particles of $Al_{12}Mg_{17}$ represents the microstructure of HAZ with slightly darker contrast as shown in Figure. 3 represents the uniformity of intermetallics for the higher rotational speed.





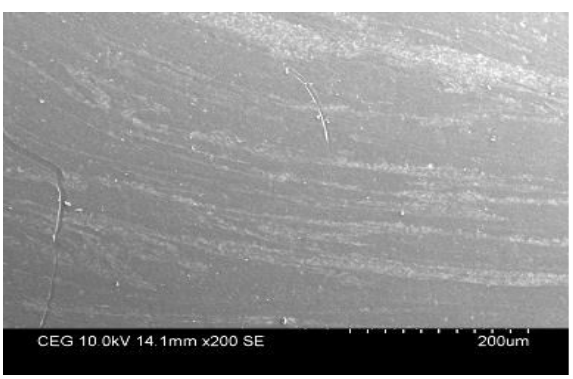
(a) (b)

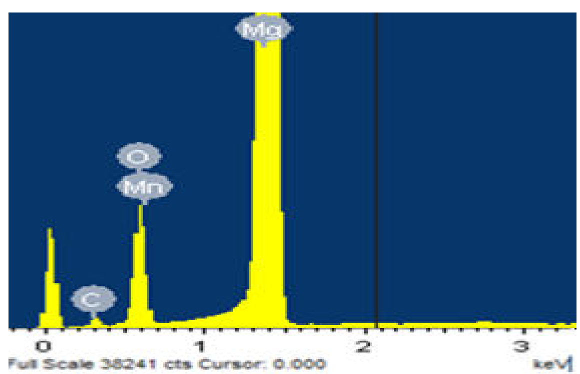
Fig.4. (a) SEM image of nugget zone of AA6061-AZ61 joint by Inverted Taper Tool for the weld parameter of 900 r.p.m., 30 mm/min. and 2.5 KN

(b) EDAX analysis of AA6061-AZ61 joint by Inverted Taper Tool for the weld parameter of 900 r.p.m., 30 mm/min. and 2.5 KN

The SEM image of nugget zone of AA6061 – AZ 61 joint by Inverted Taper tool for the higher rotational speed of 900 r.p.m shows the good fusion of the Aluminium and Magnesium alloys with alternate layers of fine grains as in Figure 4(a). The dark regions are from AA 6061 and the light regions are from AZ 61 alloy. However with respect to the SEM image on Figure 5(a), the joint made with Concave slotted tool geometry reveals the more uniformity of equiaxed grains compared to the SEM image of Inverted Taper tool.

The EDAX analysis of Friction Stir Welded joints of both respective tools on Figure 4(b) reveals the domination of Oxygen and Magnesium such as 55.74% O, 41.76% Mg, 2.40% C, and 0.11% Mn. It is revealed that the compounds formed as black regions in the Mg alloy mainly due the spread of Magnesium oxide. The EDAX analysis of Friction Stir Welded joints of both respective tools on Figure 5(b) reveals the domination of Magnesium such as 25.47% O, 64.26% Mg, 12.05% C, and 0.24% Mn and indicated that magnesium oxide is existing in this area.





(a) (b)

Fig.5. *(a) SEM image of nugget zone of AA6061-AZ61 joint by Concave Slotted Tool for the weld parameter of 900 r.p.m., 30 mm/min. and 2.5 KN*

(b) EDAX analysis of AA6061-AZ61 joint by Concave Slotted Tool for the weld parameter of 900 r.p.m., 30 mm/min. and 2.5 KN

Figure.6 revelas the Micro hardness evaluation of AA6061T6-AZ61 joint for both low rotational and high rotational speed and the maximum micro hardness value is found for the Concave slotted tool pin profile with higher rotational speed.

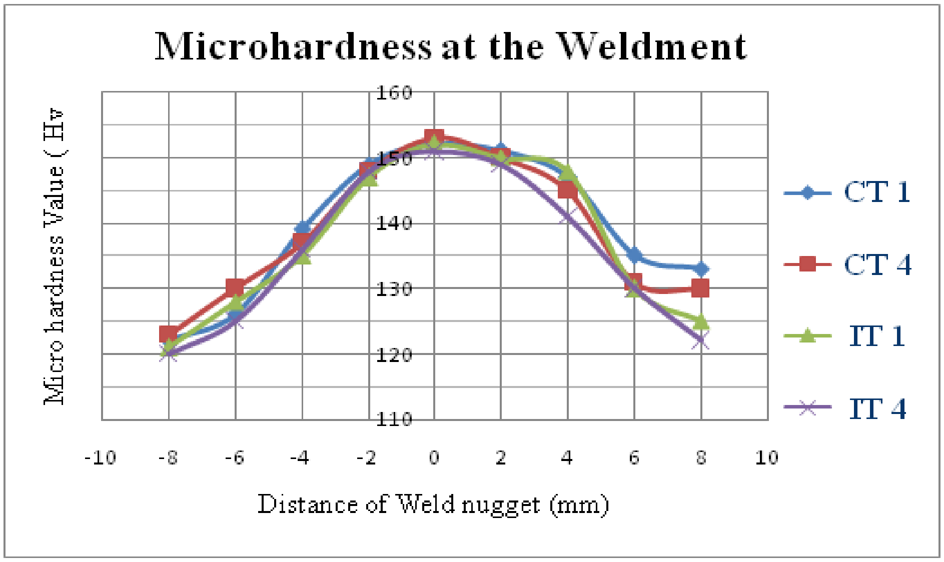


Fig6. Microhardness evaluation of different zones of the weld joint for the weld parameter of 600 r.p.m. and 900 r.p.m., 30 mm/min. and axial load of 2.5 KN for both Inverted tool and Concave slotted Tool.

Conclusion:

At lower rotational speed, the macro structure shows the formation of surface defects such as worm holes and tunnel defects. The micro structure at the higher rotational speed shows the equiaxed fine grained structure. The SEM analysis confirms that the rotational speed alone is not a parameter that is affecting the strength also the tool geometry plays a role. In this current study, the concave tool has the uniformity of grain structure. The EDAX analysis shows the more element of magnesium oxide presence at the joints of higher rotation. It is concluded the joint strength is improved with Concave slotted tool geometry with a rotational speed of 900 r.p.m., weld speed of 30 mm/min. and axial load of 2.5 KN.

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