Some investigative studies on dissimilar metals by friction stir welding

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Abstract. The aim of the current work is to develop weldments and to investigate the microstructure and mechanical properties of the aluminium alloy 6061-T6 and magnesium alloy AE42 plates (120x100x3 mm) which are welded through FSW. H13 conical thread tool pin was selected to prepare the welded joints. Two plates that were co-ordinated vertically according to the welding directions were well joined. In this study, two parameters such as weld speed at 60,150 mm / min and tool rotation speed at 800, 1200 RPM are taken into account as defect free. By changing these parameters similar and dissimilar alloys are welded together. Tensile specimens (according to ASTM standards) were developed to estimate mechanical properties including tensile strength, % elongation, yield strength and joint efficiency. It was found that an increase in the tool rotational speed or welding speed of the tool led to an increase in the tensile strength, which reached a maximum value and then decreased. (LOM) Light optical Microscopy research was accustomed examine and study the weld zone properties. Dynamic recrystallization was discovered within the weld region in addition as within the thermo-mechanical heat-affected zone (TMAZ). There’s a transparent reduction within the quantity of precipitate through the TMAZ and from the BM (Base Material) into the weld zone. Observed precipitates from similar and dissimilar welded joints - Mg2Si, Al2O3, SiC, Mg17Al12, Mg2Al3, Al11Ce3 and Al3Ce. Welds are without porosity. XRD with the EDS characterization was executed in the NZ (Nugget Zone) demonstrated the existence of SEM intermetallic phases and their weight in percent. Rapid phase structures of welded joints were detected using X-ray diffraction (XRD), however, the SEM fractograph indicated a flexible ductile fracture mechanism. Vickers micro-hardness test was performed on the thickness of the plate within the weld space to review and perceive the variation of hardness with thickness. An interrelationship between size of precipitate and micro hardness was ascertained. The corrosion behaviour of the base alloy and welded joints was measured in 3.5% NaCl solution using the salt spray test and by investigating the corrosion parameters (corrosion rate, exposure time and weight reduction). Corroded products were analysed and classified using optical microscopy and SEM. The corrosion rate decreases with increasing exposure time, but remains uniform as the corrosion time increases. Finally, a three-dimensional finite element phases was developed for temperature evolution in the friction-stir welded joint plunge depth, dwell, moving phases, and the heat conduction effect is arbitrary in the LAGARAGIAN-EULERIAN formulation in the ABAQUS / EXPLICIT, Johnson-Cook (JC) elastic-plastic model Will be used. The JC model defines the strength of the material as a function of three parameters, i.e. the strength of the material depends on the strain hardening effects, strain rate effects and temperature and verifies the simulated results with the experimental results.
1. Introduction
After two decades of development, Friction Stir Welding (FSW) has become a viable and important manufacturing alternative, especially in the automotive industry (alloy wheels) with aluminium alloys and magnesium alloys. Although FSW was started as an alternative to dissimilar materials, it is now advancing to higher temperature metals, including aluminium alloys and magnesium alloys. Interest has also increased for FSW of dissimilar metals and alloys, especially when welding by conventional welding [1-5] is difficult or impossible.

![Fig 1: A Schematic FSW](image)

1.1 Problems in traditional welding dissimilar metals – Problem Identification
Although magnesium alloys are lightweight and do not have sufficient strength to use in structural material, the combination of aluminium alloy and magnesium alloy is a good construction. However, conventional method on unequal joints is not appropriate because the large coefficient of expansion of the Mg12Al17 intermetallic compound structure is in the stir zone. The use of arc welding is not possible because it produces large HAZ by melting the base metal. It produces error due to high heat input and slow cooling rate and is difficult to joint uneven material due to different chemical composition such as melting point. To overcome the disadvantages, friction stir welding is an alternative method and this process takes place below the melting point of the alloy. The intermetallic compound layer in the stir zone is shorter than the conventional welding process. Improving efficiency by enhancing the intermetallic compound by using filler rod is not required in the FSW. There is a less study in joining asymmetric AE42 magnesium alloy and aluminium AA6061-T6.

| S. No | Author/Year | Process Parameters | Type of Tool Used | Material Used | Remarks |
|-------|-------------|--------------------|-------------------|--------------|---------|
| 1.    | Edward D Nicholas / 1998 | T: 6mm  
T.W.S: 1.2 m/min | AISI H13 tool steel | 7075-T7351 alloy | UTS: increased by 6% to 25% compare to base metal |
| 2.    | K. Colligan / 1999 | T.W.S: 30 mm/min  
T: 6:4 mm | H13 Threaded surface | Al 6061 & 7075 | Aim of this study was to perform tests to reveal the material movement patterns that take place in friction stir welds. |
| 3.    | Joseph R. Pickens / 2000 | T: 3mm | Base metals | A1 alloys 2090 & 8090 | UTS:272 Mpa , Y.S: 137 Mpa, El%:19.6 |
| 4.    | Chao Y.J et al./ 2001 | T: 9mm  
T.S: 113mm/min  
T.R.S: 215 rpm | Steel tool threaded pin | AA2024-T3 and AA7075-T735 | Yield stress and strain rate effects of dissimilar metals. |
| 5.    | Wayne M Thomas / 2002 | T: 6mm  
T.S: 120mm/min | Whorl type probes | 5083-O & 6082-T6 | Lap welds of 190% of the plate thickness, improvement in weld integrity, reduction in upper plate thinning and an increased welding speed. |
| 6.    | Per Bakke /2003 | UTS: 280 Mpa  
% El: 10-12% | Base metals | Mg alloys | Higher RE contents the ductility decreases due to formation of a continuous skeleton of intermetallic decorating the grain borders. |
| 7. | Zhili Feng et al. / 2004 | T: 6mm  
T.R.S: 375,450 rpm.  
T.W.S: 152.4 mm/min. | H13 steel tool | Al319 & Al356 | Comparisons of tensile properties of the base metal and Al319 and Al356 weldments. |
| 8. | W H Jiang et al. / 2004 | T: 6mm  
T.R.S: 914 rpm  
T.W.S: 152.4 mm/min. | H13 steel tool | 6061-T6 & AISI 1018 steel | The tensile failure occurred at the boundary between the NZ and the TMAZ of the base metal has high joining strength. |
| 9. | Erdinc Kaluc, E et al. / 2005 | T: 6.45 mm  
T.R.S: 1600-1650 rpm  
T.W.S: 70 mm/min.  
T.A: 2º | High carbon high chromium steel M5 threaded | 5083 H321-5086 H32 aluminium alloys | It has been observed that friction stir welded joints have so good mechanical properties and metallurgical properties as/ than TIG and/or MIG welded joints. |
| 10. | Cavaliere, P et al. / 2005 | T.R.S: 700 rpm  
T.W.S: 2.67 mm/s  
T.T.A: 3º  
T: 2.5mm | H13 tool | 2024-7075 aluminium alloys | FS weldments decrease in fatigue life respect to the FSW 7075-T6 ones. |
| 11. | Peel, M J et al. / 2006 | T.R.S: 280, 560, 840 rpm  
T.W.S: 100, 200, 300 mm/min.  
Cylindrical pin | AA5083-AA6082 | As a result, such metrics may not be suitable for characterizing the conditions under which welds are produced. |
| 12. | R. Sathish et al. / 2014 | T.R.S: 1000-1250 rpm  
Friction pressure: 18 to 32 MPa | HSS tool | Al 7075-T6 & Al 6061-T6 | U.T.S:81-224 Mpa  
Eln: 13.78% |
| 13. | Vuppula Prasanna et.al /2016 | T: 3mm  
A.F: 4KN  
T.T.A:2º | H13, HSS | Mg alloys | Review paper on Magnesium alloys and tools used for FSW. |
| 14. | Vuppula Prasanna et.al /2016 | T: 5mm  
A.F: 4KN  
T.T.A:2º | H13, HSS | Similar and dissimilar alloy metals | Review paper on FSW and its tools used for FSW. |
| 15. | Vuppula Prasanna et.al /2018 | T: 3mm  
T.R.S : 600-1400 rpm  
T.W.S: 40-120 mm/min  
A.F: 4KN  
T.T.A:2º | H13 tool | Mg alloy Al42 | HV is max at FSZ with 600 rpm and 40mm/min is 68.9 HV.  
Tensile strength is max at 190 Mpa at 1400 rpm. |
| 16. | Gianluca D Urso et al/2017 | T: 4mm  
T.R.S: 1000,1500,2000 rpm  
T.W.S: 10,35,60 mm/min | H13 steel | Al7075, 6060 & 2024 alloys | The best conditions in terms of mechanical strength were obtained using the “intermediate” values of rotational speed, and, in general, when the process parameters result in low values feed rate per unit revolution (F/S), that corresponds to the higher thermal contribution to the joint region |
| 17. | Z. Hou et al. / 2018 | T: 2.5mm  
T.R.S: 600 rpm  
T.W.S: 30 mm/min  
T.T.A: 2º | H13 steel | Al 2024 & Mg alloy A Z31 | Lower residual stresses and better weld quality were obtained with tool offset to the aluminium side |
18. Vuppula Prasanna et.al /2018

T: 3mm
T.R.S : 400,600,800, 1200 rpm
T.W.S:35, 40 80 & 100m/min
A.F: 4KN
T.T.A.2º

H13 tool
Mg alloy AE42
Impact energy value max at FSZ at 34°C is 4 at 1200 RPM with 100mm/min.

19. Vuppula Prasanna et.al /2018

T: 3mm
T.R.S : 400,600,800, 1200 rpm
T.W.S:35, 40 80 & 100m/min
A.F: 4KN
T.T.A.2º

H13 tool
Mg alloy AE42
Corrosion rate of the corroded Magnesium AE42 specimen exposed in 3.5% of NaCl solution for different exposure time of 6.5, 7, 7.5 days for salt spray testing. It was observed that with the increase in exposure time, the corrosion rate decreases.

20. Vuppula Prasanna et.al /2019

T: 3mm
T.R.S : 800, 1200 rpm
T.W.S:40-150m/sec
A.F: 40KN
T.T.A.2º

H13 tool
AA6061-T6 and Mg AE4
UTS is max at 800 rpm, HV is 98Hv at weld zone, Joint Efficiency: 80%

21. Vuppula Prasanna et.al /2020

T: 3mm
T.R.S : 800, 1200 rpm
T.W.S:60 & 150m/min
A.F: 40KN
T.T.A.2º

H13 tool
AA6061-T6
Max HV at 1200 rom is 117 Max UTS is 215 Mpa
J.E= 89.5%.

2. Experimental Setup

Material and Specimen preparations

Mg AE42 is collected in 3mm thick slabs. AA6061-T6 belongs to the heat-treatable 6xxx series, of that aluminium, magnesium and silicon are the main composition. Dimensions for weldments are (120x100x3mm³). Table 1 &2 and Table 3 & 4 shows composition and properties of dissimilar metals.

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Table 2: Chemical Composition of Base metal (Wt. %) of Aluminium alloy AA6061-T6

| 6061-T6 | Cu | Mg | Mn | Fe | Cr | Si | Al |
|---------|----|----|----|----|----|----|----|
| Standard | 0.31 | 0.99 | 0.08 | 0.25 | 0.16 | 0.86 | Balance |
| Observed | 0.30 | 1.00 | 0.06 | 0.19 | 0.13 | 0.67 | Balance |

Table 3: Mechanical properties of Aluminium Base metal AA6061-T6 alloy

| Alloy | 0.2% Yield Strength (MPa) | UTS (MPa) | Elongation (%) | Hardness (VHN) |
|-------|---------------------------|------------|----------------|---------------|
| AA6061-T6 | Standard | 198 | 240 | 26 | 105 |
| Observed | 183 | 236 | 22 | 103 |
Table 6: FS welding Tool Design

| Tool Design | Tool shoulder diameter, D (mm) | Tool shoulder length, L (mm) | Pin diameter, d (mm) | D/d ratio of tool | Pin length, L (mm) | Pitch (mm) of threaded pin |
|-------------|-------------------------------|-------------------------------|---------------------|------------------|-------------------|-------------------------|
| H13         | 12                            | 16                            | 2.5                 | 4.8              | 2.9               | 1                       |

FSW depends on design of tool, process parameters. Design of tool and geometry of it's made. For current research on aluminium alloy AA6061-T6 and magnesium alloy conical tapered threaded tool pin profile is selected. The determined material for high speed steel material is hardened 60HRc [6-8].
Results and Discussions

MICROHARDNESS

Vickers of uneven weldments were measured with the dotted lines shown in Fig.5. Microhardness provides uneven distribution. BM average hardness values of dissimilar metals were 105HV and 75HV. NZ microhardness values supported phase elements and local recrystallization. The higher NZ, values will be high because of the presence of hard and brittle intermetallic compounds [19-26]. NZ grains are recrystallized and smaller when compared to base material. NZ hardness will increase within the FSZ and depends on the strength of the grain size hardening metal alloys. There’s no report on careful analysis of precipitate distribution across the Al / MG weld joint. However, the FSW study on Al-MG-Si compounds are studied [27-29] indicates that the end of sharp needle deposits to a lower hardness within the stir zone.
**X-RAY DIFFRACTION**

Figure 6 contains some of the peaks obtained from the XRD analysis on the specimen. Large peaks of the intermetallic compound Al\textsubscript{12}Mg\textsubscript{17} are found. Al\textsubscript{12}Mg\textsubscript{17} and Al\textsubscript{3}Mg\textsubscript{2} are intermetallic compounds near the intermetallic layer of NZ found by XRD samples. Intermetallic structure of 2 sorts of compounds (Al\textsubscript{12}Mg\textsubscript{17} and Al\textsubscript{3}Mg\textsubscript{2}) has conjointly been recorded in Al-MG welds [30-36]. It is observed, intermetallic compounds like Mg, Al\textsubscript{12}Mg\textsubscript{17}, Al, Al\textsubscript{3}Mg\textsubscript{2} at different diffraction angles with number of peaks of each intermetallic compound are Mg peaks 4 at angles of 42°, 45°, 78°, 108° out of which has maximum intensity at 4000 units at an angle of 45° and minimum intensity at 150 units at an angle of 42°, similarly Al\textsubscript{12}Mg\textsubscript{17} has peaks 3 and angles of 58°, 82°, 118° out of which has maximum intensity at 300 units at an angle of 118° and minimum intensity at 120 units at an angle of 58°. Al has peaks 4 and angles of 38°, 42°, 65°, 113° out of which has maximum intensity at 5800 units at an angle of 38° and minimum intensity at 150 units at an angle of 42°, similarly Al\textsubscript{3}Mg\textsubscript{2} has peaks 2 and angles of 22°, 100° out of which has maximum intensity at 150 units at an angle of 100° and minimum intensity at 120 units at an angle of 22° [37-39].

**MICROSTRUCTURE**

Figure 7: Macrostructure of a FSW joint; cross section showing the HAZ TMAZ and nugget zone

Figure 8: EPMA of dissimilar metals

Detailed examination of the asymmetric microstructure shown in Fig. 7 geometrical section at joint is distinguished in a few different areas. The parent material heat effect zone (HAZ), also known as material deformation, significantly modified the microcirculation and mechanical properties,
modifying the thermo-mechanically affected zone (TMAZ), in which the material was deformed into plastic and also had some thermal inhalation. Finally, welding zone is called the nugget; NZ is a redesigned fine, identical grains containing a few micrometres of original grains and sub-grain borders.

BM contains a larger grains because of more temperature when compared to 1.3 micro meter of base material. The grain size is 25 to 30 micrometre and is stable. Silicon precipitate also can be observed they are 10-15 micrometres long. Thermal and mechanical effect add each other so that the structure is remarkably distorted and the grain starts smashing in TMAZ and the morphology of the grain does not change but the dimension is reduced up to 10 micron. The silicon precipitates rise and are spread in the structure. In addition to recrystallization, both Al-enrichment and β phase dissolve in the interior of α-Mg grains in the nugget area, leading to an increase in Al concentration and corrosion resistance improvement has been noted in the nugget area.

**Fig 9:** Microstructure of FS welded joints on the Mg side nugget zone clockwise from (a) at 800 rpm with 60mm/min and 1200rpm at different magnifications.

**Scanning Electron Microscopy:**

SEM with EDS analysis performed at middle of NZ on weldments. Fig 9 discuss about spot 1, 2 & 3 in different rotational speeds on dissimilar joints. Figure 10 shows images of areas of different patterns with percentage of compositions in tables. Mg (19.26% Mg and 80.74% Al) is abundant in spot 1 and spot 2 has a composition of 91% Mg and 5.58% Al. Similarly Spot 3 contains 2.78% Al and 17.32% Mg and Zone A and Zone B contain 38–54% Al and 46–62% Mg. The Al-Mg binary phase diagram shows two equilibrium intermetallic phases; Phases Mg$_{17}$Al$_{12}$ (39.5–55% Al) and Mg$_2$Al$_3$ (59.7–61.46% Al) [39]. The composition of Zone B on each the Al and Mg aspect intermetallic layer corresponds to the Mg$_{17}$Al$_{12}$ part and therefore the Mg aspect zone A closely corresponds to the Mg$_2$Al$_3$ phase composition vary. Elemental analysis by energy scattering X-ray analysis indicates the presence of semi-quantitative intermetallic compounds. Sensible proof for the existence of intermetallic compounds is shown in figure.
Fig 10: Results of EDS analysis of the dissimilar metal

Tensile Strength

Fig 11: a) Tensile testing specimens

| S. No | Rotational Speed (rpm) | Travel speed (mm/min) | Width (mm) | Thickness (mm) | Sp. Gauge length (mm) | 0.2 Yield Strength (MPa) | Ultimate Tensile Strength (MPa) | Elongation (%) | Efficiency (η) % |
|-------|------------------------|-----------------------|------------|----------------|-----------------------|--------------------------|-------------------------------|---------------|-----------------|
| 1     | 800                    | 150                   | 5          | 3              | 25                    | 140                      | 190                           | 3.0           | 84.4            |
| 2     | 1200                   | 150                   | 5          | 3              | 25                    | 165                      | 187                           | 3.5           | 83.1            |
| 3     | 800                    | 60                    | 5          | 3              | 25                    | 124                      | 167                           | 3.0           | 74.2            |
| 4     | 1200                   | 60                    | 5          | 3              | 25                    | 123                      | 155                           | 3.0           | 68.8            |

Tool rotation speed is enforced to keep up a forced relationship on the joint tension tests. The strength of the bottom metals is 195 MPa. In each joints, 1200 revolutions per minute tool rotation speed, 60 millimetre / min travel speed, 5 KN axial force of 187 MPa with 72% joint. Employing a rotational speed of 1200 revolutions per minute, it’s created to indicate low T.S (Tensile Strength) correlated to the weldment, having joint efficiency of 68% at 800 revolutions per minute discussed in table 7 [40-43].

FRACTOGRAPHY
Fig 12: Effect of tool rotational speed of 1200 rpm on fracture surface morphology

Figure 13 shows the crack surface morphology demonstrating the effect of the rotation speed of the joint. Tension failure of weld joints is caused only by fracture along the central continuous vertical but slightly curved intermetallic metallic (IM) layer. Due to the brittle nature of the joint minimum cross section and IM along the weld center line at the minimum cross section it can be classified that all weld joints failed along the IM layer during tensile testing. Alloy and mg Alloy Cross section of weld joint, tensile fracture pattern. Failure of welded joint specimens is caused by a very narrow IM membrane, leaving IM compounds on the al and mg sides of the fractured surfaces sides of the fracture surfaces [44-45].

Transgranular cracking occurs in the brittle IM phases and the phase-like characteristics similar to cleavage facets. Fig shows SEM fracture morphology from the general direction on the AS to the fracture surface, i.e. towards the AA6061-T6 Al alloy. Cleavage like crack can be observed on the fracture surface, indicating that the asymmetric weld has completely failed through the brittle fracture mode.

CORROSION STUDIES

Table 8 shows the corrosion attack on specimens with a rotational speed of 800 and 1200 rpm. These data show the estimated weight reduction with a solution of NaCl from the salt spray test. The corrosion attack on the magnesium alloy side is much higher compared to the aluminium alloy side. Corrosion testing is performed at 30 h and 90 h intervals. The surface for corrosion evaluation (for salt mist) is mechanically ground with 1200 grit SiC paper, rinsed with distilled water and dried with warm running air [45-48].

Salt spray corrosion testing involves exposing samples in the salt spray as per ASTM B117 standards and methodically evaluating the corrosion-tested sample according to ASTM G1-03. The weight loss is more due to the high rotational speed and high corrosion time as shown in fig 14. The difference in weight loss before and after conducting the experiments are shown in table 8.

Table 8: Results of salt spray test on weight reduction

| S. No | RPM | PD | TS | Corrosion Time (hrs) | Weights (g) Before | Weights (g) After | Change in weights (g) |
|-------|-----|----|----|----------------------|-------------------|------------------|-----------------------|
| 1     | 800 | 3  | 60 | 30                   | 5.15              | 4.87             | 0.28 grams            |
Corrosion morphology

Fig. 15 shows the SEM image of the polished sample after 30 and 70 hours of salt spray corrosion testing. The exposed sample surface was prepared for microscopic examination with a small test. Corrosion test specimens for scratch-free surfaces were polished on a disc-polishing machine. To determine the depth and diameter of the pits, the exposed specimens were cut in the cross-sectional direction, the corrosion products were removed, and then the specimens were covered with hot setting resin and the surface was observed at 200 X magnification. Here, it can be seen that the weld joint is attacked towards the magnesium and the other part of the region is related to the distribution of the $\beta$-phase performance in Fig. 15. The aluminium in the weld joint is not attacked which shows corrosion is higher for aluminium alloys and lower for magnesium alloys [44].

![Fig 14: SEM image of corroded sample at weld nugget](image)

NUMERICAL STUDIES

Numerical simulation of FSW is highly complex due to non-linear contact interactions between tool and work piece.

3.1 Geometry, boundary conditions and the FE mesh

The 3-D numerical model is based on the C3D8RT element type, which is a thermo-mechanically coupled hexahedral element with 8 nodes, each with a trilinear displacement. Plate dimensions 120mmx100mmx3mm in numerical pattern in plunging stage. The mesh contains 23608 nodes and 20972 elements. The numerical pattern of the welding plate, the tool is shown in the figure 6 [40, 41].

3.2 Thermal model

FSW heat generation has two sources: friction heating at the tool work piece interface and plastic energy dissipation due to shear deformation in the nugget zone. When heat is dissipated by circulation into the workpiece, tool and backing plate, and also by convection and radiation from the surfaces. Traditional losses are considered in this model are lower because of lower temperatures. They can be combined with convection from the top surface of the plate by using a slightly higher heat transfer coefficient, the governing equation for heat transfer is

$$\frac{\partial}{\partial x} \left( k \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left( k \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left( k \frac{\partial T}{\partial z} \right) + q_v = \rho c_p \frac{\partial T}{\partial t}$$

Where, $k$ is the materials conductivity W/m K

$q_v$ is the rate at which energy is generated per unit volume of the medium W/m$^3$

$\rho$ is the density kg/m$^3$
$c_p$ is the specific heat capacity J/ (Kg °C)

$$\sigma_f = [A + B \varepsilon^n][1 + C \ln \frac{\varepsilon}{\varepsilon_o}][1 - \left(\frac{T - T_r}{T_m - T_r}\right)^m]$$

![Numerical model of the welding plate, and the tool](image1)

**Fig 15**: Numerical model of the welding plate, and the tool

| Table 10: Mechanical Characteristics of parent material Al alloy 6061-T6 and Mg alloy AE42 |
|---------------------------------------------------------------|------------------------------|-----------------------------|
| Material Properties                                           | Value of Al 6061-T6          | Value of Mg AE42            |
| Young’s Modulus of Elastic (GPa)                              | 198                          | 120                         |
| Poisson’s ratio                                               | 0.33                         | 0.35                        |
| Thermal Conductivity (W/m-K)                                  | 167                          | 139                         |
| Coefficient of Thermal Expansion (°C⁻¹)                       | 23.4x10⁻⁶                    | 26.1x10⁻⁶                   |
| Density (kg/m³)                                               | 2.7                          | 1.8                         |
| Specific Heat Capacity J/(Kg °C))                             | 0.896                        | 1.45                        |
| Latent Heat (J/g)                                             | 400                          | 373                         |
| Temperature of melt (°C)                                      | 412                          | 435                         |

| Table 11: Johnson cook elastic plastic constants for dissimilar metals |
|---------------------------------------------------------------|-------------------------------|
| Dissimilar Metals                                            | A    | B   | n     | m     | Melting temp $T_m$ (°C) | Ambient temp $T_r$ (°C) |
| AA6061-T6                                                    | 285  | 94  | 0.41  | 1.34  | 588                  | 25                   |
| Mg AE42                                                      | 172  | 360.7 | 0.45 | 0.95  | 650                  | 25                   |

![Temperature fields of the tool](image2)

**Fig 16**: Temperature fields of the tool

![Force dependence of the time during the plunge stage](image3)

**Fig 17**: Force dependence of the time during the plunge stage

Study of temperature fields and the plunge force of Al alloy 6061-T6 to magnesium alloy AE42 was developed by coupled thermomechanical model, under different rotating speeds: (800, 1200) rpm with travel speeds of 150mm/min and 60mm/min. Figure 8 shows the coordinates of point T (10, 0, 0) used for measuring the temperature dependence of the time. The heat transfer coefficient through the
welding plate is $687 \text{ W/m}^2 \text{ K}$. A constant coefficient of friction is 0.3 assumed between the tool and the welding with corresponding heat convective coefficients on the surface of the welding plates are $h=15 \text{ W/m}^2\text{ K}$ with the ambient temperature of 210 °C at 30 s. when the plunge speed is 20 mm/min and the rotation speed is 800 mm/min.

CONCLUSION

The temperature fields, plunge force associated plastic deformations of dissimilar weldments completely different rotating speeds throughout the FSW method were analysed employing a couple thermo-mechanical model and therefore the observations associated with an intense plastic deformation influence of the warmth generated because of surface friction plastic deformation. Observations of macrostructure and microstructure shows different zones of weldments. Coarse grains were found to be in HAZ and fine grains within the nugget. Tensile strength of the parent material found was 84%. This behavior is said to the plastic deformation result of warmth generated by surface friction plastic deformation. Maximum temperature made by weldments will vary from 85% - 95% to the melting temperature of the BM. Speed of rotation will increase, the temperature will increase. The temperature field is symmetrical. The contact between the rotating pin and therefore the fastening plate begins to extend, and reaches maximum value at 1200 rev and 800 rev to the fabric malleability and is softened and the plunge force may be reduced. The results show that software ABAQUS is particularly important in simulating mechanical properties in this process. Of the two rotational speeds and welding speeds used to fabricate dissimilar joints, the joint fabricated at a tool rotational speed of 800 rpm and welding speed of 60 mm/min yielded superior tensile properties. The above joint showed a maximum joint efficiency of 76% compared to other joints. During high speeds, the high heat generation causes the grain growth in the stir zone. Moreover, a higher tool rotational speed causes excessive release of stirred materials to the upper surface, leads to voids in the stir zone. On the other side, at lower speeds the area of the stir zone decreases with decreasing and affects the temperature distribution in the stir zone. Macrostructure observations have shown that joints formed at low welding speeds (60 mm / min) have defects such as piping defect in the tile or stair zone and as a result have low tensile properties. Low welding speed (60 mm / min) leads to high temperature and slow cooling rate in the weld zone, leading to high grain growth, which in turn can lead to tensile properties of the joints. The joint made at a welding speed of 150 mm / min exhibited high tensile strength and this may be due to insufficient heat output, which in this condition allows the material to flow plastic with appropriate mechanical work.

Acknowledgments

Thanks to DMRL, Head, Department of Metallurgy, Hyderabad, for permission to use the equipment in connection with this project.

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