PAPER • OPEN ACCESS

A Survey on Friction Stir Welding Of Dissimilar Magnesium Alloys

To cite this article: M A Unnikrishnan and Dhas. J Edwin Raja 2017 IOP Conf. Ser.: Mater. Sci. Eng. 247 012009

View the article online for updates and enhancements.

You may also like

- Optimization and characterization of dissimilar friction stir welded DP600 dual phase steel and AA6082-T6 aluminium alloy sheets using TOPSIS and grey relational analysis
 M D Sameer and Anil Kumar Birru
- <u>Nanoparticles reinforced joints produced</u> <u>using friction stir welding: a review</u> Tanvir Singh
- Effect of Welding Parameters on Mechanical Properties of Friction Stir Welding of Dissimilar Metals- A Review M Sindhuja, S Neelakrishnan and Benjamin Shiloh Davidson





DISCOVER how sustainability intersects with electrochemistry & solid state science research



This content was downloaded from IP address 18.216.254.96 on 13/05/2024 at 23:31

A Survey on Friction Stir Welding Of Dissimilar Magnesium Alloys

Unnikrishnan M A¹ ¹Department of Mechanical Engineering, Noorul Islam University, Thuckalay, 629180 Tamil nadu ,India Email id: unni037@yahoo.com

Edwin Raja Dhas.J² ²Department of Automobile Engineering Noorul Islam University, Thuckalay, 629180 Tamil nadu ,India Email id : edwinrajadhas@rediffmail.com.

IOP Publishing

Abstract -There is a consistent demand for superior materials in every industry. The areas on demand are automobile and aerospace sectors in major.. The most commonly used material in these fields is Aluminium. Though it possess all the properties up to some extent constant demand is pushing for alternate materials. Dissimilar alloys have been a relatively new approach towards these fields. . Friction stir welding dissimilar alloys is a big leap in Automobile sector. In this paper a detailed review of Friction stir welding of Dissimilar Magnesium alloys has been done. This work will serve as a reference to subsequent researchers.

Keywords: Friction stir welding, Magnesium alloy, Process parameter

I. INTRODUCTION

Friction stir welding (FSW) is a solid state welding process in which the rotary motion of a cylindrical tool along the welding line is the prime factor for the weld formation. The simultaneous rotation and translation of the tool induce a strong plastic deformation and promote complex mixing across the joint. The heat generated during the rotation of the tool will cause the materials to get joined without reaching melting point.[1]

II. FRICTION STIR WELDING

Friction Stir Welding (FSW) was first invented by The Welding Institute (TWI), UK in 1991. This technique was developed aiming Aluminium alloys but later it had found profound application in welding of Mg alloys, Cu alloys etc.[2]FSW process consists of a rotating tool with a shoulder and probe arrangement. The heat is developed due to friction between the work piece surface and the tool [2]. The heat thus produced is used to soften the work piece before reaching its melting point. The heat generated during the process is about 80-90% of the melting temperature. With FSW traditional components current and voltage are not present as the heat input is purely mechanical replaced by force, friction etc. The quality of an FSW joint is always better than other fusion welding processes. In this process the FSW material consists of four distinct microstructural zones namely Nugget zone (NZ), Thermo mechanically affected zone(TMAZ), Heat affected zone (HAZ) and Base material (BM). The process parameters chosen during FSW process has great influence on these zones.[3]

III. PROCESS PARAMETERS

The welding parameters are key players during Friction stir welding. Proper selection of welding parameters influences the final weld quality and resulting microstructure[4]. Some of the major process parameters are listed below.

A. Tool rotational speed and Travel speed

This is one of the major process parameters during Friction stir welding and is primarily responsible for the generation of heat. The rotation may be clockwise or counterclockwise accordingly. The rotational motion of the tool generates frictional heat within the work pieces, and the material is brought to plasticized state and due application of pressure will cause the weld to form. The tool travel speed also plays a major role. It depends on several factors, such as alloy type, rotational speed, penetration depth, and joint type.[5]

B. Tool tilt and plunge depth

A suitable tilt angle on the spindle provides an additional benefit for holding the stirred material and also for proper movement of plasticized material. The tilt angle is represented by (θ) . The influence of plunge depth on

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI. Published under licence by IOP Publishing Ltd 1

formation of sound welds are characterized by its influence on temperature distribution and on material mixing. The plunge depth of pin into the work pieces is important for producing sound welds with smooth tool shoulders [5]

C. Tool characteristics

Tool designs have influence on heat generation, plastic flow, the power required, and the uniformity of the welded joint. Tool profile which includes tool shoulder and pin is contributing for almost all factors influencing the weld formation. The variation in pin length and pin profiles has direct impact on material mixing, flow etc. The commonly used pin profiles are cylindrical, conical, threaded, square, octagonal etc.[5] The commonly used tool materials for FSW are Tool steel, carbide tool, High speed steel etc.

IV. WELD QUALITY PARAMETERS AND MEASUREMENT

There are various quality parameters for a welded joint and these parameters are the judging factor for a good weld. Every welded joint must possess these quality parameters. The weld quality parameters are classified as

A. Mechanical properties

The mechanical properties of the weld are playing a crucial in a resultant weld Some of the common mechanical properties that determine the weld quality are Tensile strength, Strength/weight ratio, Elastic properties, Shear strength, hardness which Includes, micro hardness values, Ductility, Impact strength, percentage elongation, Wear, Corrosive behavior, fracture charecteristics, Fatigue etc.

B. Microstructural properties

. Every process parameter selected during welding has significant impact on final microstructure. All these can be found out by some common metallographic analysis techniques. In the case of dissimilar alloys welding one of the major limitation is the formation of intermetallic compounds. All these can be detected through proper microstructural and metallographic techniques. Some of them are Scanning Electron Microscopy(SEM),Surface topography, Dispersive X-ray analysis techniques which includes EDX & XRD,Optical microscopy etc.

C. Thermal properties

Apart from mechanical, microstructural properties on major influential parameter is temperature. The weld temperature varies during FSW owing to change in process parameters, tool pin profile etc. In case of dissimilar alloys the role of temperature is crucial as it determines the formation and thickness of intermetallic compounds. Some of the common thermal analysis methods are Thermo gravimetric analysis, Differential scanning calorimetry, Thermo mechanical analysis etc. All these analysis procedures are necessary for proper evaluation

V. FRICTION STIR WELDING OF DISSIMILAR ALLOYS

Friction stir welding of dissimilar alloys are a growing area of concern. Though there is limitless scope yet there are some limitations also which has to be rectified. Some of the common hurdles during friction stir welding of dissimilar alloys are

A. Heat generation and temperature distribution

The discussion and analytical estimation of heat generation at tool work piece interface in similar welding is relatively easier because of the presence of only one type of material in contact with the tool. However, things become quite complicated when it comes to heat generation and temperature distribution in dissimilar FSW. Two different materials, in general, have different thermal properties, COF, and softening characteristics all these affect heat generation, temperature distribution in the work pieces, and material. The existence of an asymmetric thermal field would cause a sharp temperature gradient as a function of distance in lower thermal diffusivity material. It might result in a lack of bonding between two materials which will lead to defects in the root region of the weld.

B. Formation of intermetallic compounds

The formation of intermetallic phases during dissimilar welding using conventional fusion welding is an issue because it can impair the joint integrity severely depending on the thickness. The formation of intermetallic compounds are greatly influence by welding parameters and the resultant temperature as well. Though the intermetallic formation is not completely avoidable in majority cases its effect, thickness etc can be reduced thus contributing to the final weld quality.

IOP Publishing

VI. REVIEW ON FRICTION STIR WELDING OF DISSIMILAR MAGNESIUM ALLOYS

Shude Ji, Xiangchen Meng[6] researched on the formation of intermetallic compounds during Friction stir welding and its influence on Mechanical properties. The materials chosen were Aluminium alloy 6061-T6 and Magnesium alloy AZ31B plates of 3mm thickness. Tool rotational speed and welding speed were the major process parameters selected which was kept constant at 1200 rpm and 40mm/min.Ultrasonic was included along with the selected parameters. Detailed microstructural analysis were carried out using Scanning Electron Microscopy (SEM) and energy dispersive spectrometer (EDS).X-ray diffraction analysis shows the presence of Al3Mg2 and Al12Mg17 in the nugget zone. Fig 1 shows the microstructure details.



Fig 1. (a) and (b) shows the macrostructures with and without ultrasonic (c) and (d) shows the distribution map of Al/Mg elements with and without ultrasonic(e) and (f) shows the XRD patterns with and without ultrasonic

The average values of toughness for joints with and without ultrasonic are respectively 1.8Jm^{-3} and 0.3Jm^{-3} , which shows the importance of ultrasonic on toughness.

V. Paradiso, F. Rubino[7] analyzed on the variation in mechanical as well as microstructural properties during friction stir welding of dissimilar alloys. The materials chosen for friction stir welding were ZE41A Mg alloy and AA2024-T3 Al alloy. Both the materials were of plate form with 4 mm thickness. Friction stir welding was carried out offsetting the tool of 1 mm towards the magnesium side. The tool was made up of high speed steel consists of a shoulder diameter of 20mm, a conical unthreaded pin of height 3.80 mm, major diameter 6.20 mm, and cone angle 30 deg. The process parameters selected were Tool rotational speed ranging from 1000 to 1400 rpm, feed rate ranging from 20 to 80 mm/min, tilt angle of 2° and shoulder plunge depth of 0.48 mm.



Fig. 2. Microstructural and micro hardness measurements of joint welded at 1200 rpm and 20 mm/min.

Yael Templeman and Guy Ben Hamu[8] studied about the microstructural evolution and corrosion resistance improvement during dissimilar alloys Friction stir welding. The materials chosen were AM50 and AZ31 Magnesium alloys. The process parameters were Tool rotational speed of 2500 rpm and welding speed of 0.1 mm/sec.Two

pin diameters of 6mm and 2.7mm were selected accordingly. Scanning Electron Microscopy, Transmission Electron Microscopy and EDAX Energy Dispersive Spectroscopy (EDS) were employed for microstructural analysis. Phase identification was carried out X ray diffraction (XRD) diffractometer.Recrystallization was occurred during the process in the nugget zone.



The authors quote that in addition to the recrystallization, both Al-enrichment and β phase dissolved into the interior of the α -Mg grains in the nugget area causing an increase in Al concentration and corrosion resistance improvement was noted in the nugget area.

Y. Zhao, L. Huang[9] investigated the effects of Tool travel speed on microstructure and mechanical properties of final weld. The materials chosen were Al 5754/AZ31 Mg alloy plates of 3mm thickness. The tool was made of H13 Tool steel with concave shoulder with diameter of 16 mm and a threaded pin with the length of 2.8 mm. and a constant tile angle of 3.5° was maintained Al alloy was placed on the AS and Mg alloy on the RS as per trials. Three kinds of defects had been detected during the experiment surface peeling, overflow of solidified microstructure and groove like defect are detected due to the variation in selected process parameters.



Fig 4 Microhardness profiles of microstructure from Mg to Al with different locations

SEM & EDS analysis has been carried out to found out the presence of intermetallic compounds, microscopic cracks which leads to a reduction in tensile strength. Also an uneven distribution of hardness values was detected from micro hardness studies. The author finds that defect-free weld joint could be obtained at a travel speed of 100 and 200 mm min–1, the maximum of tensile strength 76.6 MPa was obtained at 200 mm min–1 and it was 35% of AZ31 Mg alloy and A large amount of twins has been observed in the HAZ of the Mg side, and no HAZ was observed in theAl side. And no deformation grains occurred in the TMAZ of the Mg side of all the joints.

C.Luo, X.Li[10] investigated the microstructure and mechanical properties of dissimilar wrought Mg alloys AZ91D/ZG61plates of 6mm thicknesss. An adjustable pin tool made up of H13 Tool steel with a shoulder diameter of 15mm, pin length of 5.9mm with right hand thread was used. The process parameters were Tool rotational speed of 1000 rpm and welding speed ranging from 80mm/min to 240mm/min. Microstructural observation was done using SEM & EDS systems. Material flow analysis was carried out using electron backscatter diffraction (EBSD). The micro hardness of ZG61/AZ91D joints is higher than AZ91D/ZG61 joints. Fine-grain strengthening and texture strengthening are two main observed strengthening mechanisms.



Fig 5. Microhardness profiles of the welds (a) ZG61/AZ91D and (b) AZ91D/ZG61

The author finds that severe deformation and metal flow occurred in the stir zone. During welding base metal is extruded into banded structure and vortex structure. The weld zone was harder than the base material due to smaller grain sizes in the stir zone

Heena K Sharma [11] in their investigation using circular butt joint geometry on AA6061/AZ31 Mg alloys used three different tool geometries along with tool rotational speed & tool travel speed as process parameters. The reasons quoted for not obtaining good quality weld were path of welding, pin geometry, higher values of process parameters. Circular path welding has been found to be inferior to linear path welding.

Fig 6.Circular butt joint welded specimen at a Tool rotational speed of 1200rpm and welding speed of 10mm/min

Five different pin profiles has been chosen namely cylindrical flute pin tool made of HSS tool steel, Threaded pin tool made of HCHCr ,Cylindrical groove pin tool made of H13 Tool steel, Cylindrical threaded pin tool and cylindrical threaded pin tool HCHCr. The tool rotational speed ranged from 800 rpm to 2000 rpm and tool travel speed ranged from 10 mm/min to 40 mm/min.The author finds that a tool rotational speed of 1200 rpm and welding speed of 10mm/min was the most effective set of parameters.

B. Ratna Sunil [12] had done investigations on dissimilar Mg alloys AZ31/AZ91 plates of 3mm thickness. The tool was made of H13 Tool steel with a shoulder diameter of 15mm, tapered pin with 3mm to 1mm diameterand 3mm length. The process parameters selected were tool rotational speeds of 1400rpm, 1600rpm, 1800 rpm and feed rate of 25mm/min, 50mm/min, 100mm/min

Fig 7 (a) Optical microscope images of joint cross section (b) Micro hardness measurements across the weld joint.

The amount of β (Mg17Al12) phase in AZ31 Mg alloy is lower compared with AZ91 Mg alloy. The distribution of β (Mg17Al12) phase was limited to retreating side. Wire cut EDM was used for cutting the specimen after welding. The author states that increased hardness in the nugget zone can be attributed to the grain refinement and the presence of Mg17Al12 particles along with solid solution strengthening.

M. Tabasi [13] had concentrated on the Friction stir welding of dissimilar Al/Mg alloys. The alloys chosen were Al 7075 & AZ31 Mg having 5mm thickness. silicon carbide nanoparticles were introduced into the weldment for the formation of metal matrix composites. Tool rotational speed of 450, 560, 710,900, and 1100 rpm and traverse speed of 11.2, 22.4, 35.5, and 45 mm/min were selected as process parameters. The tool selected for experimentation was of H13 Tool steel material with triangular threaded pin.

Fig 8. Microstructure of FS welded joints on the Mg side stir zone clockwise from (a) at TRS 560rpm and WS 22.4mm/min (b) TRS 710rpm and WS 22.4mm/min (c) TRS 560rpm and WS 35.5mm/min (d) TRS 710rpm and WS 35.5mm/min

Fig 9. FESEM image and map of SiC distribution in the welded sample at (a) and (b) TRS 710 rpm and WS 22.4mm/min (c) and(d) TRS

Optical microscopy and Field Emission Scanning Electron Microscopy (FESEM) were used in order to analyze the microstructure of the stir zone and to study the particle distribution. Furthermore, energy-dispersive X-ray spectroscopy (EDAX) was employed for elemental analysis in stir zone of the specimens. Dynamic recrystallization occurred during the process which leads to nucleation & decrease in grain size.

Hui Shi [14] experimented on the effect of intermetallic compounds in the banded structure zone and its effects on mechanical and microstructural properties during friction stir welding with selected process parameters. The material chosen were Al 6061 & lab prepared Mg alloy. A conical pin profiled tool made up of H13 Tool steel was employed. The shoulder diameter was 12 mm, pin diameter of 4 mm and pin length of 2.5 mm, respectively. The tilt angle of the tool was set 3° forward and the plunge depth was 0.20 ± 0.05 mm during welding.

Fig 10 (a) Transverse cross sections of the welds at different TRS (i) 600 rpm (ii) 700 rpm (iii) 800 rpm and (iv) 900 rpm

(b) XRD spectrum of polished fracture surface at 900 rpm.

Tool rotational speed was varied from 600-1000rpm & tool travel speed was fixed at 100mm/min. Energy Dispersive Spectroscopy (EDS) was utilized for microanalysis of chemical composition. IMCs in the BS were characterized by X-ray diffraction (XRD) method. According to the author BS microstructure should be tailored with the following characters for improving the strength of the BS zone: (i) less IMCparticles in the BS zone; (ii) bands in curved shape rather than straight arrangement; and (iii) bands being relatively short and discontinuous.

A. Dorbane [15] investigated on FS welding of dissimilar Aluminium AA6061-T6/AZ31 Mg alloys. The work concentrated on microstructural and mechanical aspects of weld joint. Optical microscopy and Scanning Electron Microscopy has been employed for microstructure analysis.

Fig 11.Optical microscope observation of the cross section of the welded joint (a) 1600 rpm and 250 mm/min translational speeds (b)to (d) Fixed welding speed of 500 mm/min and TRS of 1600, 1400, 1200rpm

Among the studied weld process parameters, 1400 rpm rotational speed and 500 mm/min translational speed resulted in the optimum joint quality, based on the analysis of the weld integrity and microstructure. The effect of mutual positioning on final weld quality has been found out. Grain refinement occurred and A thin layer of intermetallic compounds (IMC) were seen in the stir zone at the interface between the welded sheets. Microhardness tests and tensile tests had been done for validation. The process parameters chosen were Tool rotational speed (1200, 1400, 1600rpm) and a fixed tool travel speed of 500mm/min

M. Azizieh [16] investigated the effectof process parameters on final weld quality and also on intermetallic formation. The materials chosen were Aluminium AA1100/AZ31 Mg alloys. The tool selected was of H13 tool steel with cylindrical threaded pin. The researcher focused on offsetting the pin position towards Aluminium and Magnesium sides.

Fig 12. Onion ring pattern formation during welding

Fig 13. SEM macrograph and EDS results

The tool had a shoulder diameter of 18mm,threaded pin having a height of 2.7mm and diameter of 5mm.The threaded probes are of 1mm pitch.The pin position of the tool was set at five positions namely at the centerline,1.5mm off the centerline towards AZ31 ,2.5mm off the centerline towards AZ31,1.5mm off the centerline towards AA1100 and 2.5mm off the centerline towards AA1100.The FSW was conducted at several tool rotational speeds of 420, 480, 570, 660, 750, 800 and 1000 rpm and three travel speeds of 15, 20, and 30 mm /min. Optical and scanning electron microscopy (SEM) ,X-ray diffractometer (XRD) were employed for microstructural observation. For mechanical evaluations, transverse tensile and micro hardness tests were conducted.

Yong Zhao [17] researched about the influence of cooling conditions on joint properties and microstructure of Al/Mg dissimilar alloys. The materials chosen were Aluminium AA6013/AZ31 Mg alloys. Underwater friction stir welding and normal friction stir welding in air were conducted to study the influence on microstructure and mechanical properties of the weld joint.

Fig 14. The thermal cycle curves of weld formed in different media. (a) In air (b) Underwater

Weld was made using H13 Tool steel with cylindrical pin profile, a concave 16- mm-diameter shoulder and a 5mm-diameter pin with the length of 2.5 mm. The welding tool rotated counterclockwise and the tilt angle was 2.5° The Tool rotational speed and tool travel speed were fixed at 1200 rpm & 80mm/min.The thermal cycle temperature was measured by two thermocouples fixed on the work pieces. SEM was employed for fracture morphology analysis. The appearance of weld, microstructure and intermetallic details were better in under water FSW than in air.

J. Mohammadi [18] investigated on the microstructural and mechanical properties during FSW of AA6061/AZ31B Mg alloys. Rotation and travel speeds varied between 560-1400 r/min and 16-40 mm/min respectively and the tool was of H13 Tool steel with a threaded tapered pin.X-ray diffraction pattern (XRD), optical microscopy images (OM), electron probe microanalysis (EPMA) and scanning electron microscopy equipped with an energy-dispersive X-ray spectroscopy (SEM-EDS) were used to investigate the microstructures of the joints welded. Micro hardness tests and tensile tests had been performed after welding

H.M. Rao [19] researched on Friction stir spot welding Magnesium alloy AM60B and Aluminum alloy 6022-T4 under various welding conditions. The influences of tool rotation rate and shoulder plunge depth were examined. Welds were made at four different tool rotation rates of 1000, 1500, 2000 and 2500 rpm and various tool shoulder plunge depths from 0 mm to 0.9 mm.

Fig 15 .SEM images of the IMCs on the faying surface in the Friction Stir Linear welding specimen

FSW tool used in this study was made of standard tool steel (H13) and constituted a concave tool shoulder and a triangular pin with threaded groove surface. A continuous layer of IMCs resulted in reduced weld strength while discontinuous IMCs resulted in improved weld strength.

Bang long Fu [20] investigated on the FSW of dissimilar Aluminium AA6061/AZ31B Mg alloys. The tool was made up of H13 Tool steel. The tool shoulder was on concave shape with 10mm diameter and frustum shaped right hand threaded pin. The macro and microstructure were examined using optical microscope, scanning electron microscope (SEM) equipped with EDX capability.

Fig 16.Weld appearance and microstructure of the joint with a tool offset amount of +3mm

A tool rotational speed from 600-800 rpm & tool traverse speed from 30–60 mm/min were chosen. Heat input in Al–Mg dissimilar FSW could be calculated from spindle and x-axis torque. The nugget zone at Mg side was divided into affected zone, banded zone and severe intercalated zone. The heat input shows an increase when the tool was offset towards aluminium side. The heat input during the process and proper intermixing contributed to better weld properties as dissimilar materials owe these two properties in major.

Kwang-Jin Lee [21] researched on the microstructural effects during FSW of dissimilar Al-Mg alloys. The materials chosen were AA6061-T6 and AZ31 alloys. The welding between AA 6061-T6 an AZ31 alloys were done with a tool offset towards AZ31 side . Electron back-scatter diffraction (EBSD) technique was applied to measure texture in the stir zone (SZ). Grain size distribution and misorientation angle distribution were also obtained.

Fig 17. EBSD IPF maps for interface between (a) AA6061 (b) AZ31

Microstructure of the interface consisted of lamellar-like shear bands rich in either Mg or Al. The microstructure shows complex intercalated flow patterns. The tool with concave type shoulder and truncated cone type probe was made of general tool steel of SKD61. Tool rotation speed of 1200 rpm and the tool traveling speed of 10.16 cm/min was selected. The interface region was characterized by lamellar like shear bands.

Alireza Masaudian [22] dissimilar friction stir welding between AZ31-O Mg and 6061-T6 Al alloys was investigated. The rotation speeds varied from 600 to 1400 r/min, and the travel speed varied from 20 to 60 mm/min. An unthreaded cylindrical tool made from H13 tool steel. An unthreaded cylindrical tool made from H13 tool steel with a shoulder of 15 mm in diameter and concaved, a pin of 3 mm in diameter and 2.9 mm in length, and a tilt angle of 2.5° was used for the welding operation.

Fig 18. Transverse cross sectional micrograph of the weld

Al alloys was placed on the AS and Mg alloy on the RS. Elemental analysis of the weld and fracture surface fractography were performed using scanning electron microscopy (SEM)Intercalated microstructure was formed in some regions in the stir zone, and this complex flow pattern may be responsible for the uneven micro hardness distribution in the stir zone.

P. Venkateswaran [23] studied about the various factors that affect the weld quality during friction stir welding of Al/Mg dissimilar alloys. The materials chosen were AA 6063 aluminium and AZ31B Mg alloys. The welding was done using tool made up of H13 Tool steel with a fluted probe. Tool rotational speed from 900-2700rpm,Tool travel speed from 1.69-6.4mm/min and axial force from 14-30KN were selected

AI				
~				
Mg				10 µm
Fig 19.A con	ntinuous intermeta	llic laver alo	ng the w	eld interface

The microhardness distribution of the weld joints is mainly influenced by the local microstructural constituents such as the Al-Mg type intermetallic compounds, strengthening precipitates on the Al sides and grain size on the Mg sides of the weld joints. The elemental analysis of the fracture surfaces was done by energy dispersive spectroscopy (EDS) and microstructural analysis was carried out using Scanning electron microscopy (SEM). Transverse tensile strength of the weld joint is strongly influenced by the interface features.

Pooya Pourahmad [24] investigated about the materials flow and phase transformation in friction stir welding of Al 6013/Mg alloys. The tool material was of H13 Tool steel with a conical pin profile. The process parameters selected were tool rotational speed ranging from 800 to 2000 r/min, traverse speeds from 31 to 75 mm/min and tool tilt angle of 2° and 3° were applied

The author quotes that defect free welds were obtained at a Tool rotational speed of 1600 rpm and welding speed of 35mm/min at a tilt angle of 3°. The microstructure of the dissimilar weld interface was analyzed by scanning electron microscopy (SEM) equipped with an energy-dispersive X-ray spectroscopy (EDS) analysis system. Micrographs of cross section of dissimilar welds revealed three regions. A zigzag interface, interlocking and islanding were observed in some regions . Regions showing extrusion of aluminium into magnesium and vice versa were observed.

W. Woo [25] investigated the influence of friction stir welding on changes in microstructures The process parameters tool travelling speed and rotating speeds were 4.7mm/sec, 1250 rpm (Al FSW) and 0.97 mm/sec, 600 rpm (Mg FSW) respectively. An H-13 steel tool was used for welding.

Fig21. Micro hardness measured on cross-section across weld centerline

The area of research by the author was concentrated on softening behavior and hardness related areas. Severe plastic deformation caused some texture variations which in turn resulted in softening of FSW Mg alloy. It results in a significant reduction in the yield strength and the residual stress in the SZ of the FSW Mg AZ31B alloy.

Yan Yong [26] investigated on the microstructural aspects during friction stir welding of dissimilar alloys. The materials chosen were Aluminium 5052 and AZ31 Magnesium alloys. During FSW process, 5052 aluminum alloy and AZ31 magnesium alloy were placed at the advancing side (AS) and the retreating side (RS) of the tool pin, respectively. A tool with a concaved shoulder of 15 mm in diameter and a cone-threaded pin of 6 mm in diameter and 5 mm in length was used. The tilt angle was 2° from the normal surface of plates

Fig. 22 Microstructures of onion ring in dissimilar weld: (a) Optical microstructure; (b) EDS maps of Mg (c) of Al (d) distribution in onion ring

The author finds that the microstructure of the base metal was replaced by equiaxed and fine grains in stir zone. The tool rotational speed was 600 rom and tool travel speed was 40mm/min. Micro hardness profiles presented uneven distributions and the maximum value of microhardness in the stir zone was twice higher than that of the base materials Microstructure of the weld was observed by optical microscope and scanning electron microscope equipped with an EDX system. The microstructural examination showed an increase in hardness at the stir zone than in the base material.

A. Kostka [27] researched about the microstructural analysis of friction stir welded Al-Mg dissimilar alloys.. The materials chosen were AZ31 magnesium alloy and AA 6040 aluminium alloy.

Fig 23. (a) Secondary electron micrograph of the AA6040 Al alloy and AZ31 Mg alloy interface

(b) TEM micrograph of the interface region showing the intermetallic region

The process parameters were: rotation speed, 1400 rpm, travel speed, 3.75 mm /sec and axial force, of 3.5 kN.Scanning Electron Microscopy (SEM) examination of the interface microstructure revealed that intermetallic compounds occurred along the entire interface between the two alloys. The energy-dispersive X-ray SEM and TEM analysis of the joint were also done. The formation of the intermetallic compounds was studied in detail by TEM.

VII. CONCLUSION

In this work a detailed review on Friction stir welding of dissimilar alloys has been considered. Though there are many the concentration of this work has been limited to dissimilar welding between aluminium and magnesium alloys and magnesium-magnesium alloys. Also the work is concentrated on butt joint Friction stir welding and related works. The influence of various process parameters on final weld quality, formation of intermetallic compounds and its influence on microstructure etc have been quoted. The works of various researchers have been highlighted throughout the paper.

REFERENCES

- [1] R.S.Mishra et.al, Friction stir welding and processing, 2005 Materials Science and Engineering R50 pages 1–78.
- [2] A.Forcellese et.al, Effect of process parameters on vertical forces and temperatures developed during friction stir welding of
- magnesium alloys,2015 ,International journal of Advanced Manufacturing technology, Volume 85, Issue 1, pages 595–604.
 [3] Prakash kumar sahu, Sukhomay pal, Multi response optimization of process parameters in friction stir welded AM20 Mg alloy by taguchi grey relational analysis,2015, Journal of Magnesium and alloys vol 3 pages 36-46.
- [4] Unnikrishnan M A ,Edwin Raja Dhas, j, Friction Stir welding of Magnesium alloys-A review,2015, Advances in Materials Science and Engineering, MSEJ vol 2 no 4.
- [5] Barath Raj singh, A handbook on Friction stir welding Research Gate, 2012, DOI/10.13140/RG.2.1.5088.6244.
- [6] Shude Ji .et.al, Dissimilar friction stir welding of 6061 aluminum alloy and AZ31magnesium alloy assisted with ultrasonic Materials Letters, 2017, DOI/10.1016/j.matlet.2017.05.011.
- [7] V. Paradiso.et.al, Magnesium and Aluminium alloys dissimilar joining by Friction Stir Welding, 2017, Procedia Engineering 183 pages239 – 244.
- [8] Yael Templeman .et.al, Friction stir welded AM50 and AZ31 Mg alloys: Microstructural evolution and improved corrosion resistance, 2017, Materials Characterization, 10.1016/j.matchar.2017.02.018.
- [9] Y. Zhao et.al, Effect of travel speed on the microstructure of Al- to-Mg FSW joints, 2016, Material science and Technology.volume 32 issue 10.
- [10] C. Luo et.al. Microstructure evolution and mechanical properties of friction stir welded dissimilar joints of Mg–Zn–Gd and Mg–Al Zn alloys,2016, Material Science and Engineering, A664(2016)103–113.
- [11] Heena K Sharma et.al, Experimental Analysis of Friction Stir Welding of Dissimilar Alloys AA6061 and Mg AZ31 Using Circular Butt Joint Geometry, 2016 Procedia Technology 23, pp 566 – 572.
- [12] B. Ratna Sunil et.al. Joining of AZ31 and AZ91 Mg alloys by friction stir welding, 2015, Journal of Magnesium and Alloys 3, pp 330–334.
- [13] M. Tabasi et.al. Dissimilar friction stir welding of 7075 aluminum alloy to AZ31 magnesium alloy using SiC nanoparticles, 2015, The International Journal of Advanced Manufacturing Technology, Volume 86, Issue 1, pp 705–715.
- [14] Hui Shi et.al, Intermetallic Compounds in the Banded Structure and their Effect on Mechanical Properties of Al/Mg Dissimilar Friction Stir Welding Joints, 2016, Journal of Materials Science & Technology. Pages 1-8.
- [15] Dorbane et.al, Mechanical, microstructural and fracture properties of dissimilar welds produced by friction stir welding of AZ31B and Al6061,2015, Materials science and Engineering ,DOI/10.1016/j.msea.2015.11.019.
- [16] M.Azizieh et.al, Mechanical properties and microstructural evaluation of AA1100 to AZ31 dissimilar friction stir welds, 2015, Materials Chemistry and Physics ,volume 170,pages 251-260.
- [17] Yong Zhao et.al .Influence of cooling conditions on joint properties and microstructures of aluminum and magnesium dissimilar alloys by friction stir welding,2015,International Journal of Advanced Manufacturing Technology,83: 673-679.

- [18] J. Mohammadi et.al, Friction stir welding joint of dissimilar materials between AZ31B magnesium and 6061 aluminum alloys, 2015, Microstructure studies and mechanical characterizations, DOI/ 10.1016/j.matchar.2015.01.008.
- [19] H.M. Rao et.al, Fatigue and Fracture of Friction Stir Linear Welded Dissimilar Aluminum-to-Magnesium Alloys, 2015, International Journal of fatigue, DOI/10.1016/j.ijfatigue.2015.09.033.
- [20] Bang long Fu et.al, Friction stir welding process of dissimilar metals of 6061-T6aluminum alloy to AZ31B magnesium alloy,2015, Journal of Materials Processing Technology.218:38-47.
- [21] Kwang-Jin Lee, Eui-Pyo Kwon, Microstructure of stir zone in dissimilar friction stir welds of AA6061-T6 and AZ31 alloy sheets, 2014 Transactions of . Nonferrous Metals Society of .China 24: 2374–2379.
- [22] Alireza Masoudian et.al., Microstructure and mechanical properties of friction stir weld of dissimilar AZ31-O magnesium alloy to 6061-T6 aluminum alloy, 2014, Transactions of . Nonferrous Metals Society of .China 2424: 1317–1322.
- [23] P. Venkateswaran et.al. Factors affecting the properties of Friction Stir Welds between aluminum and magnesium alloys, 2012, Materials Science and Engineering A.545:26-37.
- [24] Pooya Pourahmed et.al ,Materials flow and phase transformation in friction stir welding of Al 6013/Mg,2013, Transactions of . Nonferrous Metals Society of .China 2423:1253–1261.
- [25] W. Woo et.al ,Softening behavior of friction stir welded Al 6061-T6 and Mg AZ31B alloys,2011, Science and Technology of Welding and Joining 2011 vol 16 no 3.
- [26] Yan Yong et.al, Dissimilar friction stir welding between 5052 aluminum alloy and AZ31 magnesium alloy,2010,Transaction of nonferrous metals society of china 20: s619-s623.
- [27] A. Kostka et.al, Microstructure of friction stir welding of aluminium alloy to magnesium alloy, 2009, Scripta Materialia 60: 953-956.
- [28] Rajiv Mishra.et.al, A Framework for Friction Stir Welding of Dissimilar Alloys and Materials, 2015, ISBN: 9780128026212.
- [29] Wei Guo et.al, Microstructure and mechanical properties of dissimilar inertia friction welding of 7A04 aluminum alloy to AZ31 magnesium alloy,2017, Journal of alloys and compounds, volume 695, pages 3267-3277.
- [30] JFC Moraes et.al, Effect of overlap orientation on fatigue behavior in friction stir linear welds of magnesium alloy sheets, 2017, International Journal of Fatigue volume 100, pages 1-11.
- [31] Richard Johnson et.al, Friction Stir Welding of Magnesium Alloys, 2016, Essential readings in Magnesium technology, part 8, pages 487-492.
- [32] S.D.Ji et.al, Investigation of Ultrasonic Assisted Friction Stir Spot Welding of Magnesium Alloy to Aluminum Alloy,2016,volume 48,issue1,pages 2-7.
- [33] B.Mansoor et.al., Friction Stir Welding of AZ31B Magnesium Alloy with 6061-T6 Aluminum Alloy: Influence of Processing Parameters on Microstructure and Mechanical Properties, 2016, Friction stir welding and processing, pages 259-266.
- [34] Todd.R.Curtis et.al, Joining Al 6061 to ZE41A Mg Alloy by Friction Stir Welding Using a Cold Spray Transition Joint, 2016, Friction stir welding and processing ix, part vi pages 221-236.
- [35] Zhida Liang et.al, Continuous drive friction welding of 5A33 Al alloy to AZ31B Mg alloy, 2017, Journal of Manufacturing processes, volume 25, pages 153-162.
- [36] Uceu Suhuddin,et.al, Microstructure in Dissimilar Friction Spot Weld of Al to Mg Alloys Observed by Stop-Action Technique,2016,Friction stir welding and processing vii,pages 263-270.
- [37] Zeina G. El Chlouk.et.al, The Effect of Tool Geometry on Material Mixing during Friction Stir Welding of Magnesium AZ31B Welds, 2015, proceedings of MEMA'15, pages 235-242.
- [38] Zhe Liu .et.al, Textural variation in triple junction region of friction stir welded Mg alloys and its influence on twinning and fracture, 2016, Material science and Engineering, volume 658, pages 185-191.
- [39] A.Macwan.et.al, Similar and Dissimilar Ultrasonic Spot Welding of a Rare-Earth Containing ZEK100 Magnesium Alloy,2016,Magnesium Technology, pages 109-113.
- [40] S.M.Manladan.et.al. A review on resistance spot welding of magnesium alloys,2016, The International Journal of Manufacturing Technology, Volume 86, Issue 5, pages 1805–1825.