Dissimilar Materials of Friction Stir Welding - Overview

K. Nagendra Kumar[1], P. Ravikanth Raju[2]

[1]Asistance Professor, Department of Mechanical Engineering, Bhaskar Engineering College, Yenkapally, Moinabad (M), R.R.(Dist), Hyderabad-500075, Telangana State, India.
[2]Department of Mechanical Engineering, Anurag Group of Institutions, Venkatapur (V), Ghatkesar (M), R.R. Dist -500088, Telangana State, India

Abstract - *Friction Stir Welding is a joining process which involves the deformation of materials. In this process tool will generate the pressure and temperature and form solid state weld. This process is suitable for joining different materials, different mechanical and chemical properties, and different material structures. Fusion welding processes exhibits poor weldability by Welding of dissimilar aluminium alloys. Because of thin oxide layer formation, oxide layer tends to thicken at higher temperatures on the surface of aluminium alloys. This review addresses the Friction stir welding overview which includes the basic concept of the process, microstructure formation, influencing process parameters, typical defects in FSW process and some recent applications. The paper will also discuss some of the process variants of FSW such as Friction Stir Processing.*

Keywords - *Tool rotational speed, Friction Stir welding, dissimilar aluminium alloy.*

1. INTRODUCTION

FSW was invented in UK in December, 1991 at The Welding Institute (TWI). FSW is a new solid state welding technology that has created a worldwide attraction especially in automobile and aerospace industries as compared to conventional fusion welding techniques for the welding of light weight alloys. For reducing the weight of automobiles the use of lightweight material is most effective. The tool rotation and weld direction are similar on one side called as Advancing Side (AS) and opposite on the other called as Retreating Side (RS).

It is big challenge to weld aluminium alloys with the help of conventional fusion welding processes. Conventional fusion welding techniques are susceptible to various welding defects like cracks, voids, porosity etc. It's a matter of concern, because of thin oxide layer formation, high thermal conductivity, high coefficient of thermal expansion, solidification shrinkage and high solubility of hydrogen and other gases in molten state [14].

Parts made by combining dissimilar materials such as metal-to-metal, polymer- to-polymer, and metal-to-polymer are now days in high demand. The welding of metal-to-polymer is given greater emphasis in this section than metal to- metal and polymer-to-polymer welding, since metal-to-polymer is a novel technique and there are fewer publications in this area [15]. The schematic representation of FSW process is shown in Fig. 1.

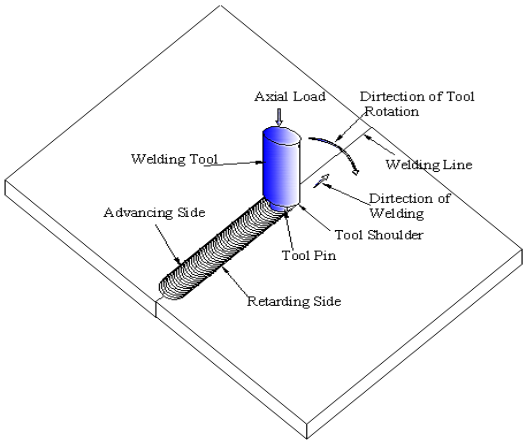

Fig 1: FSW Process [14]

The shoulder is pressed against the surface of the materials being welded, while the probe or pin is forced between the two components by a downward force. The rotation of the tool under this force generates a frictional heat that decreases the resistance to plastic deformation of the material.

1. FSW of AZ31 Mg Alloy to 6061 Al alloys:

Dissimilar friction stir welding between AZ31-O Mg and 6061-T6 Al alloys was investigated using 3 mm thick plates of aluminium and magnesium. Friction stir welding operations were performed at different rotation and travel speeds. The rotation speeds varied from 600 to 1400 r/min, and the travel speed varied from 20 to 60 mm/min. Defect-free weld was obtained with a rotation speed of 1000 r/min and travel speed of 40 mm/min. Tensile test results indicated that the tensile strength of the welded specimen is about 76% of AZ31 Mg alloy and 60% of the 6061 Al alloy in tensile strength [15].

2. The Influences of The Friction Stir Welding on Aluminium 6063 and 7075:

In this research the influence of the friction stir welding on hardness of aluminium 6063 and 7075 was studied. The parameters which influence on welding are rotational speed of 2000 rpm, welding speed of 50-200 mm/min and tilt angle pin tool of 2°. As the result we found maximum tensile strength is105 MPa for welding speeds to 100 mm/min. For the hardness test results showed that the highest measured hardness is 152 HV at weld centre was welding speed 50 mm/min [6].

3. Friction Stir Welded Cast and Wrought Aluminium Alloy Joint:

During the FSW process, the non consumable tool rotates to plunge and travels along the weld line to produce a high quality of joint. FSW process eliminates the fusion welding problems such as crack, porosity and solidification shrinkage. The aim of the work was to evaluate the microstructure and mechanical properties of friction stir welded AA6061 cast and wrought aluminium alloy joint. In FSW, the process parameters such as welding speed of 50 mm/min, rotational speed of 800 rpm and axial force of 8 kN was used to make the joint. Two samples were welded by keeping one sample of wrought alloy as an advancing side and cast alloy in retreating side and another sample of weld is produced by keeping the plate alternatively on both sides. The welded samples were characterized by using metallurgical microscopy and universal tensile testing machine [13]. The microstructures of 6061-T6 cast Al alloy and 6061-T6 wrought Al alloy is shown in Fig. 2.

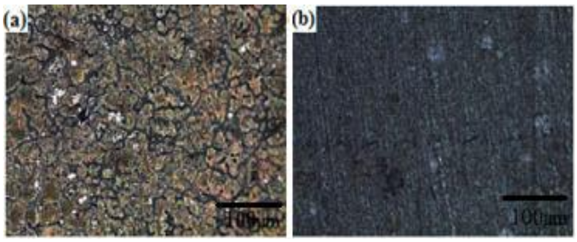

Fig 2: Microstructures of 6061-T6 cast Al alloy (a) and 6061-T6 wrought Al alloy (b).

4. Effect of Heat Input on The Properties of Dissimilar Friction Stir Welds of Aluminium and Copper:

The effect of heat input on the resulting properties of joints between aluminium and copper produced with the friction stir welding process. The welds were produced using three different shoulder diameter tools, viz., 15, 18 and 25 mm by varying the rotational speed between 600 and 1200 rpm and the traverse speed between 50 and 300 mm/min in order to vary the heat input to the welds [10].

5. Friction Stir Welding of Dissimilar Aluminium Alloys (6061&7075) By Using Computerized Numerical Control Machine:

Friction stir welding, a solid state joining technique, is widely being used for joining Al alloys for aerospace, marine automotive and many other applications of commercial importance. FSW trials were carried out using a computerized numerical control machine on (Al 6061 & 7075) alloy. The tool geometry was carefully chosen and fabricated to have a nearly flat welded interface (cylindrical & taper) pin profile. Important process parameters that control the quality of the weld are a) rotation speed (1600&1250rpm) b) traverse speed (120mm/min) and c) tool tilt angle 2 and these process parameters were optimized 0 to obtain defect free welded joints. The main aim in this work was to find the mechanical properties of friction stir welding of dissimilar aluminium alloys (6061&7075) by using CNC vertical milling machine. The limitations of FSW are reduced by intensive research and development. Its cost effectiveness and ability to weld dissimilar metals makes it a commonly used welding process in recent times [16].

6. Friction Stir Welding of Aluminium Alloy to Steel:

Butt-joint welding of an aluminium alloy plate to a steel plate was easily and successfully achieved. The maximum tensile strength of the joint was about 86% of that of the aluminium alloy base metal. Many fragments of the steel were scattered in the aluminium alloy matrix, and fracture tended to occur along the interface between the fragment and the aluminium matrix. A small amount of intermetallic compounds was formed at the upper part of the steel/aluminium interface, while no intermetallic compounds were observed in the middle and bottom regions of the interface. A small amount of intermetallic compound was also often formed at the interface between the steel fragments and the aluminium matrix. The regions where the intermetallic compounds formed seem to be fracture paths in a joint [1].

7. Tool Geometry on Friction Stir Welding of AA 6061 and Az61:

Friction Stir Welding Process (FSW) is a solid state welding method developed by The Welding Institute (TWI). This research work involves the friction stir welding of two dissimilar metals namely AA6061 and AZ61. The geometry of the tool in Friction Stir Welding (FSW) plays a principle role in quality of the weld. In this study several FSW tools have been considered for the fabrication of a number of butt joints. The tool geometry names are as follows: (i) Straight threaded tool, (ii) Taper Threaded tool, (iii) Inverse tapered tool, (iv) Concave shaped fluted tool. These geometries are analysed for the identification of sound weld through ANSYS [11].

8. Optimization of AA6061-AA7075 Dissimilar Friction Stir Welding Using The Taguchi Method:

In this study, the Taguchi method was utilized to determine the optimum process parameters for dissimilar friction stir welding between AA6061 and AA7075 aluminium alloys. The Taguchi L9 orthogonal array and optimization approach was applied on three levels of three critical factors, namely rotational speed, transverse speed and tool tilt angle. The optimum levels of process parameters were determined through the Taguchi parametric design approach. Through the parameter analysis, the predicted value of the dissimilar joint's tensile strength was calculated to be 209.7 MPa, which is in close proximity to the experimental data (219.6 MPa) with 4.5% error. It is concluded from this work that a high tensile value of 219.6 MPa was achieved using 1000 rpm rotational speed, 110 mm/min travel speed and 3˚ tilt angle [21].

9. Dissimilar Friction Stir Welding Between 5052 Aluminium Alloy and AZ31 Magnesium Alloy:

Dissimilar friction stir welding between 5052 Al alloy and AZ31 Mg alloy with the plate thickness of 6 mm was investigated. Sound weld was obtained at rotation speed of 600 r/min and welding speed of 40 mm/min. Compared with the base materials, the microstructure of the stir zone is greatly refined. Complex flow pattern characterized by intercalation lamellae is formed in the stir zone. Micro hardness measurement of the dissimilar welds presents an uneven distribution due to the complicated microstructure of the weld, and the maximum value of micro hardness in the stir zone is twice higher than that of the base materials. The tensile fracture position locates at the advancing side (aluminium side), where the hardness distribution of weld shows a sharp decrease from the stir zone to 5052 base material [5].

10. Friction Stir Welding Parameter on Mechanical Properties in Dissimilar (AA6063-AA8011) Aluminium Alloys:

Friction stir welding (FSW) is a technique in which the work pieces were joined by means of frictional heating and plastic deformation typically at temperatures below the melting temperature of the materials to be joined. The scope of this investigation was to evaluate the effect of joining parameters on the mechanical properties of dissimilar aluminium alloys (AA6063 and AA8011 aluminium alloy) joints produced using friction stir welding. Friction stir weld was performed on the dissimilar aluminium alloys using different rotational speeds and traverse speeds and the influence of these parameters on the mechanical performance of the weld has been investigated in terms of hardness and tensile testing [20].

11. Friction Stir Welding of Dissimilar Joint Between Semi-Solid Metal 356 and AA 6061-T651 by Computerized Numerical Control Machine:

The investigation is on effect of welding parameters on the microstructure and mechanical properties of friction stir welded butt joints of dissimilar aluminium alloy sheets between Semi-Solid Metal (SSM) 356 and AA 6061-T651 by a Computerized Numerical Control (CNC) machine. The base materials of SSM 356 and AA 6061-T651 were located on the advancing side (AS) and on the retreating side (RS), respectively. Friction Stir Welding (FSW) parameters such as tool pin profile, tool rotation speed, welding speed, and tool axial force influenced the mechanical properties of the FS welded joints significantly. For this experiment, the FS welded materials were joined under two different tool rotation speeds (1,750 and 2,000 rpm) and six welding speeds (20, 50, 80, 120, 160, and 200 mm/min), which are the two prime joining parameters in FSW. A cylindrical pin was adopted as the welding tip as its geometry had been proven to yield better weld strengths. From the investigation, the higher tool rotation speed affected the weaker material's (SSM) maximum tensile strength less than that under the lower rotation speed. As for welding speed associated with various tool rotation speeds, an increase in the welding speed affected lesser the base material's tensile strength up to an optimum value; after which its effect increased. Tensile elongation was generally greater at greater tool rotation speed. An averaged maximum tensile strength of 197.1 MPa was derived for a welded specimen produced at the tool rotation speed of 2,000 rpm associated with the welding speed of 80 mm/min. In the weld nugget, higher hardness was observed in the stir zone and the thermo-mechanically affected zone than that in the heat affected zone. Away from the weld nugget, hardness levels increased back to the levels of the base materials. The microstructures of the welding zone in the FS welded dissimilar joint can be characterized both by the recrystallization of SSM 356 grains and AA 6061-T651 grain layers [7].

12. Effect of Friction Stir Welding on Mechanical Properties of Dissimilar Aluminium Aa6061 And Aa2014 Alloy Joints:

In this study, Dissimilar Friction Stir Butt Welds made of 2014 and 6061 Aluminium alloys were performed with various welding parameter. The study involved the influence of square profile pin on friction stir welded joint. FSW parameter such as tool rotational speed, welding speed and axial force plays a significant role in the assessment of mechanical properties. Using ANOVA and signal to noise ratio, influence of FSW process parameters is evaluated and optimum welding condition for maximizing mechanical properties of the joint is determined. An Artificial Neural Network (ANN) model was developed for the analysis and simulation of the correlation between the Friction Stir Welding (FSW) parameters of aluminium (Al) plates and mechanical properties and compared the experimental values with the ANN predicted values [17].

13. Joining of Titanium and Aluminium Dissimilar Alloys by Friction Stir Welding:

Titanium alloy TC1 and Aluminium alloy LF6 were butt jointed and lap jointed by friction stir welding (FSW), and the influence of process parameters on formation of weld surface, cross-section morphology and strength were studied. The results show that, Titanium and Aluminium dissimilar alloy is difficult to be butt joined by FSW, and some defects such as cracks and grooves are easy to occur. When the tool rotation rate is 950 r/min and the welding speed is 118 mm/min, the tensile strength of the butt joint is 131MPa which is the highest□FSW is suitable for lap joining of TC1 Titanium alloy and LF6 Aluminium alloy dissimilar materials, an excellent surface appearance is easy to obtain, but the shear strength of the lap welding joint is not high. At the welding speed of 60 mm/min and the tool rotation rate of 1500 r/min, the lap joint has the largest shear strength of 48 MPa. At the welding speed of 150 mm/min and the tool rotation rate of 1500 r/min, crack like a groove occurs on the interface and the shear strength is zero [8].

14. Dissimilar Metal Joining of 2024 and 7075 Aluminium Alloys to Titanium Alloys by Friction Stir Welding:

The friction stir welding (FSW) process is a solid-state joining process and the joining temperature is lower than that used in the fusion welding processes. Therefore, for dissimilar metal welding, FSW is considered to offer several advantages over fusion welding. The present work investigated the weldability of duralumin and titanium alloys using friction stir welding. The aluminum plates used in this work were 2024- T3 and 7075-T651, and the titanium plates used were pure titanium and Ti-6Al-4V. The average tensile strength of the Ti/2024 FSW joints was 311 MPa, and the tensile strength of the Ti/2024 joint was higher than that of the Ti/7075 FSW joint when the joining conditions were the same. A mixed region of Ti alloy and Al alloy was observed at the joint interface, and the joints mainly fractured at this region, where there was an intermetallic compound layer. In this region, a $TiAl_3$ intermetallic compound was detected by XRD [9].

15. Dissimilar Friction Stir Welded Joints between 2024-T3 Aluminium Alloy and AZ31 Magnesium Alloy:

Dissimilar alloys such as 2024-T3 Al alloy and AZ31 Mg alloy of plates in 3mm thickness has been friction stir butt welded. The welding was carried out at a constant rotation speed of 2500 per min and welding speeds of 200, 300, 400 and 550 mm/min. Effects of welding speeds on microstructures and hardness distributions of the joints were investigated. Distribution of phases in the stir zone (SZ) was analyzed by a scanning electron microscope (SEM) equipped with an energy dispersive X-ray spectroscopy (EDS). Increasing welding speed brought about a redistribution of phases in SZ where the regions occupied by 2024 Al alloy concentrated in the lower portion of SZ while AZ31 Mg alloy concentrated in the upper region beneath the tool shoulder. The laminated structure was formed in the SZ near the boundary between SZ and TMAZ on the advancing side of 2024 Al alloy regardless of the welding speed. The hardness value fluctuates in the SZ due to formation of intermetallic compounds that formed by constitutional liquation during welding [3].

16. On The Friction Stir Welding of Aluminium Alloys EN AW 2024-0 and EN AW 5754-H22:

It was found in this work that the two aluminium alloys can be friction stir welded if the welding parameters are carefully selected. Hardness value in weld area for EN AW 2024-0, there is an increase about 10- 40 Hv. For EN AW 5754-H22 there is a decrease of hardness value because of recrystalization. Welding performance of EN AW 2024-0 is reached to 96.6 %. This value is 57 % for EN AW 5754-H22. It is possible to perform dissimilar welding using different aluminium alloys. Elding performance of dissimilar aluminium alloys EN AW 2024-0 and EN AW 5754-H22 is reached a value of 66.39%. Purpose of the author is to investigate the friction stir welding capability of the EN AW 2024-0 and ENAW 5754-H22 Al alloys are studied, because two aluminium alloys are widely used in the industry and friction stir welding is getting widened to be used to join the aluminium alloys [2].

17. Microstructure and Mechanical Properties of Friction Stir Butt Welded Dissimilar Cu/Cuzn30 Sheets:

The tensile strength of dissimilar Cu/CuZn30 joints was found to be about same and 46% lower than that of Cu parent metal (PM) and CuZn30 PM, respectively. The root and the surface bend strengths of the joints were found to be about 47% higher and 31% lower than that of Cu PM and CuZn30 PM, respectively. The average hardness at the top and bottom lines were found to be about 92 Hv0.1 and

102 Hv0.1, respectively. These hardness values are higher and lower than that of Cu PM and CuZn30 PM, respectively. Different microstructure zones were determined by optical microscopy. It was illustrated that the stirred zone (SZ) exposed to the two main structures: (1) recrystallized grains of CuZn30 and (2) intercalated swirl and vortex-like structure which can be characterized both the recrystallized brass grains and copper layers. In this study, dissimilar Cu and CuZn30 sheets was butt joined by FSW. It has been investigated microstructure properties, micro hardness, tensile and bending tests, in order to evaluate the joint performance and the weld zone characteristics of dissimilar copper/brass (Cu/CuZn30) joints [4].

18. Evaluation of Bending Strength For Dissimilar Friction Stir Welded AA6061T651 - AA7075 T651 Aluminium Alloy Butt Joint:

Aluminium alloys have gathered wide acceptance in the fabrication of light weight structures requiring a high strength-to weight ratio and good corrosion resistance. Modern structural concepts demand reductions in both the weight as well as the cost of the production and fabrication of materials. Compared to the fusion welding processes that are routinely used for joining structural aluminium alloys, friction stir welding (FSW) process is an emerging solid state joining process was invented in 1991 by TWI, in which the material that is being welded does not melt and recast. The major advantage in FSW process is that the maximum temperature reached is less than 80% of the melting temperature (TM), i.e. the joint is performed in the solid-state and excessive micro structural degradation of the weld zone is avoided. This process uses a non consumable tool to generate frictional heat in the abutting surfaces.

The welding parameters such as tool rotational speed, welding speed, axial force etc., and tool pin profile play a major role in deciding the joint strength. This paper focus on Bending Characteristics for friction-stir welded dissimilar precipitation hardenable aluminium alloys between 6xxx (Al-Mg-Si) and 7xxx (Al-Zn-Mg) in varying the process parameters such as rotational speed, welding speed keeping axial force and tilt angle (0º) as constant. Three different tool profiles (taper cylindrical threaded, taper square threaded and Simple Square) are used for this investigation and in that taper cylindrical threaded tool give good result in evaluating bending strength of the above dissimilar butt joints [12].

19. Investigation of Fatigue Behaviour and Fractography of Dissimilar Friction Stir Welded Joints of Aluminum Alloys 7075-T6 and 5052-H34:

The fatigue behavior of friction stir welded joints for dissimilar aluminum alloys 5052-H34 and 7075-T6 was studied. Friction stir welding (FSW) has been done on 4.826mm (0.19) in thick plate by using MTS-5 axis friction stir welder. FSW were carried out under optimum welding parameters with travel speed of 187mm/min (7in/min), rotational speed of 400rpm and forge load of 9KN (2000lbf). Mechanical tests and inspection were performed to characterize the welded joints and determine it to be defect-free. Tension–tension fatigue tests had been done at a frequency of 7Hz with stress ratio R=0.1. Also topography analysis was done using scanning electron microscopy combined with energy dispersive spectroscopy. The fatigue failure has been analyzed [23].

20. Joining of dissimilar aluminium alloys AA2014 T651 and AA6063 T651 by friction stir welding process:

In this work joining of two dissimilar aluminium alloys AA2014 T651 and AA6063 T651 was carried out using friction stir welding. The weld was obtained by varying its tilt angle (2◦-4◦), tool offset (0.5mm towards AS, centre line, 0.5mm towards Rs) and Pin diameter (5mm – 7mm). Tensile strength & %Elongation was carried out to evaluate the strength of the weld. Optical microscope study was carried out to study the uniform stirring of materials. The result shows that better interlocking and bonding of materials occurs at 4 degree tilt angle. The tensile strength is better when the tool is offset towards AA2014 side because of complete fusion of harder material. When, it is offset towards AA6063 side results in insufficient heat generation on advancing side. This leads to incomplete fusion of AA2014. Pin diameter has greatest impact on heat generation. The 6 mm pin diameter, 4 degree tilt angle and 0.5 mm offset towards advancing side give the optimum tensile strength of 371 Mpa [24].

21. Effect of Travel speed on Joint properties of Dissimilar Metal Friction Stir Welds:

The effect of traverse speed on joint properties of dissimilar metal friction stir welds between aluminium and copper sheets was studied. Welds in butt joint configurations were produced between 5754 Aluminium Alloy (AA) and C11000 Copper (Cu). The welds were produced at a constant rotational speed of 950 rpm and the traverse speed was varied between 50 and 300 mm/min while all other parameters were kept constant. Micro structural evaluation of the welds revealed that at a constant rotational speed and varying the traverse speed, better mixing of both metals and metallurgical bonding were improved at the lowest traverse speed. The average Ultimate Tensile Strength of the welds decreased as the welding speed increased. Higher Vickers micro hardness values were measured at the Thermo-Mechanically Affected Zones (TMAZ) and Stir Zones (SZ) of the welds due to dynamic recrystallization and also due to the presence of intermetallic compounds formed in the joint regions. Unlike with similar metal welds which showed a smooth force feedback curve, it was found that a significant variation in force feedback data was obtained for dissimilar metal welds [25].

22. Mechanical Properties of Aluminium-Copper Joints Welded by Friction Stir Welding:

Butt welding aluminium with copper by friction stir welding has been investigated in this study. The rotation direction of the tool and the probe offset with respect to centre of butt line are the main welding parameters affecting the welding quality founded in this study. A sound welding has been obtained when aluminium arranged on advancing side, with sufficient probe offset to aluminium side. Also, defect free Al-Cu welded joint produced when the copper arranged on advancing side with probe offset to aluminium side. So, probe offset play as important factor rather than direction of rotation in welding Al-Cu by friction stir welding [22].

2. CONCLUSIONS

In conclusion, overview of friction stir welding of dissimilar materials focusing on aluminium to other materials has been conducted. The latter focuses on dissimilar aluminium alloys, aluminium to magnesium, aluminium to steel and titanium. Furthermore, this paper review showed that there is a significant progress in FSW of dissimilar materials. Most of the cited research studies are more focused on understanding the microstructure and physical properties of various welds. FSW technology need to be more developed to enable the technique to be employed industrially. The full understanding of the dissimilar FSW process is needed to accommodate the huge demand in the industries including manufacturing and the aerospace industry. Further research is needed on advancing multi-scale finite element modelling techniques to include FSW process defects.

REFERENCES

[1] K. Kimapong And T. Watanabe, “Friction Stir Welding of Aluminum Alloy To Steel”, Welding Journal, pp 277-282, October 2004.

[2] M. Vural, A. Ogur, G. Cam, C. Ozarpa, “On The Friction Stir Welding Of Aluminium Alloys En Aw 2024-0 And En Aw 5754-H22”, Vol. 28 Issue 1, pp 49-54, January 2007.

[3] Saad Ahmed Khodir and Toshiya Shibayanagi, “Dissimilar Friction Stir Welded Joints Between 2024-T3 Aluminum Alloy And Az31 Magnesium Alloy”, Materials Transactions, Vol. 48, No. 9, pp. 2501-2505, 2007.

[4] Z. Barlas, H. Uzun, “Microstructure And Mechanical Properties Of Friction Stir Butt Welded Dissimilar Cu/Cuzn30 Sheets”, Journal Of Achievements In Materials And Manufacturing Engineering, Vol. 30, Issue 2, October 2008.

[5] Yan Yong, Zhang Da-Tong, Qiu Cheng, Zhang Wen, “Dissimilar Friction Stir Welding Between 5052 Aluminium Alloy And Az31 Magnesium Alloy”, Transactions of Nonferrous Metals Society of China, Vol. 20, Supplement 2, pp 619-623, July 2010.

[6] Wichai Pumchan, “The Influences of the Friction Stir Welding on the Microstructure and Hardness of Aluminium 6063 and 7075”, International Conference on Advanced Materials Engineering IPCSIT, Vol.15, IACSIT Press, Singapore, pp 31-35, 2011.

[7] Muhamad Tehyo, Prapas Muangjunburee and Somchai Chuchom1, “Friction Stir Welding Of Dissimilar Joint Between Semi-Solid Metal 356 And AA 6061-T651 By Computerized Numerical Control Machine”, Songklanakarin J. Sci. Technol., Vol. 33, Issue 4, pp 441-448, Jul - Aug. 2011.

[8] Yuhua Chen, Changhua Liu And Geping Liu, “Study On The Joining Of Titanium And Aluminum Dissimilar Alloys By Friction Stir Welding”, The Open Materials Science Journal, Vol. 5, pp 256-261, 2011.

[9] Masayuki Aonuma1 And Kazuhiro Nakata, “Dissimilar Metal Joining Of 2024 And 7075 Aluminium Alloys To Titanium Alloys By Friction Stir Welding”, Materials Transactions, Vol. 52, No. 5, pp. 948-952, 2011.

[10] Esther T. Akinlabi, Stephen A. Akinlabi, “Effect of Heat Input on the Properties of Dissimilar Friction Stir Welds of Aluminium and Copper”, American Journal of Materials Science, Vol.2, Issue 5, pp 147-152, 2012.

[11] D. Raguraman, D. Muruganandam ,L.A.Kumaraswamidhas, “Study Of Tool Geometry On Friction Stir Welding Of AA6061 And Az61”, IOSR Journal Of Mechanical And Civil Engineering (IOSR-JMCE), pp 63-69, January 2013.

[12] S. Ravikumar, V. Seshagiri Rao And Atish Ranjan, “Evaluation Of Bending Strength For Dissimilar Friction Stir Welded Aa6061t651 - Aa7075 T651 Aluminium Alloy Butt Joint”, 2nd International Conference On Trends In Industrial And Mechanical Engineering (Ictime'2013), Sept 17-18, 2013 Hong Kong.

[13] G. Tamizharasi, S. Kathiresan, “Friction Stir Welded Cast and Wrought Aluminium Alloy Joint & Effect of Process Parameters”, International Journal Of Advanced Research In Electrical, Electronics And Instrumentation Engineering, Vol. 2, Issue 8, pp 3682-3689, August 2013.

[14] Paul Kah, Raimo Suoranta, Jukka Martikainen, Carl Magnus, “Techniques For Joining Dissimilar Materials: Metals And Polymers”, Rev. Adv. Mater. Sci., Vol. 36, pp 152-164, 2014.

[15] Alireza Masoudian, Arvin Tahaei, Atefeh Shakiba, Fariborz Sharifianjazi, Jamshid Aghazadeh Mohandesi, “Microstructure and mechanical properties of friction stir weld of dissimilar AZ31-O magnesium alloy to 6061-T6 aluminum alloy”, Trans. Nonferrous Met. Soc. China, Vol. 24, pp 1317−1322, 2014.

[16] R. Hariharan And R.J. Golden Renjith Nimal, “Friction Stir Welding of Dissimilar Aluminium Alloys (6061&7075) By Using Computerized Numerical Control Machine”, Middle-East Journal of Scientific Research, Vol. 20, Issue 5, pp 601-605, 2014.

[17] P. Purushotham, P. Hema, “Effect Of Friction Stir Welding On Mechanical Properties Of Dissimilar Aluminium Aa6061 And Aa2014 Alloy Joints”, International Journal Of Engineering Sciences & Research Technology, pp 7086-7092, April 2014.

[18] Ramaraju Ramgopal Varma, Abdullah Bin Ibrahim, Mohammed, Arifpin Bin Mansor, “Mechanical properties of the friction stir welded Dissimilar aluminium alloy joints”, International Journal of Mechanical And Production Engineering, Volume- 2, Issue- 5, pp 1-5, May-2014.

[19] V. Gokuul, M. Ragavendran, R. Naresh, V. S. Senthil Kumar, “ Effect of tool rotational speed on Friction Stir Welding of AA6061 and AA7075”, International Journal of Chem Tech Research, Vol.6, No.3, pp 1753-1756, May-June 2014.

[20] S.Kailainathan, S.Kalyana Sundaram, K.Nijanthan, “Influence of Friction Stir Welding Parameter on Mechanical Properties in Dissimilar (AA6063-AA8011) Aluminium Alloys”, International Journal Of Innovative Research In Science, Engineering And Technology, Vol. 3, Issue 8, August 2014.

[21] L.H. Shah, N.F. Zainal Ariffin And Akhtar Razul Razali, “Parameter Optimization Of AA6061-AA7075 Dissimilar Friction Stir Welding Using The Taguchi Method”, Journal of Applied Mechanics and Materials, Vol. 695, pp, 20-23, November 2014.

[22] Jawdat A. Al-Jarrah Et Al, “Surface Morphology And Mechanical Properties Of Aluminum-Copper Joints Welded By Friction Stir Welding”, Contemporary Engineering Sciences, Vol. 7, No. 5, pp 219 – 230, November 2014.

[23] Ahmed A. Zainulabdeen And Muna K. Abbass, Ali H. Ataiwi, Sanjeev K. Khanna, Bharat Jashti Aand Christian

Widener, "Investigation Of Fatigue Behaviour And Fractography Of Dissimilar Friction Stir Welded Joints Of Aluminum Alloys 7075-T6 And 5052-H34", International Journal Of Materials Science And Engineering, Vol. 2, No. 2, December 2014.
[24] Ranjith. R, Senthil Kumar. B, "Joining Of Dissimilar Aluminium Alloys Aa2014 T651 And Aa6063 T651 By Friction Stir Welding Process", Wseas Transactions On Applied And Theoretical Mechanics, Vol. 9, 2014.
[25] Esther T. Akinlabi1, Annelize Els-Botes, Patrick J. Mcgrath, "Effect Of Travel Speed On Joint Properties Of Dissimilar Metal Friction Stir Welds", Second International Conference On Advances In Engineering And Technology.pp 155-161, 2015.