Available online at www.sciencedirect.com

ScienceDirect

Procedia Technology 23 (2016) 566 – 572

Procedia Technology

3rd International Conference on Innovations in Automation and Mechatronics Engineering, ICIAME 2016

Experimental Analysis of Friction Stir Welding of Dissimilar Alloys AA6061 and Mg AZ31 Using Circular Butt Joint Geometry

Heena K Sharma[a], Kamlesh Bhatt[b],Krunal Shah[c] Unnati Joshi[d]

[a]*Research Scholar, Mechanical Engineering Department, A D Patel Insitute Of Technology, New V V Nagar-388121, India*
[b]*Associate Professor, Production Engineering Department, BVM Engineering collage, V V Nagar-388120,India*
[c]*Assistant Professor, Mechnical Engineering Department, A D Patel Insitute Of Technology, New V V Nagar-388121, India*
[d]*Associate Professor, Mechnical Engineering Department, A D Patel Insitute Of Technology, New V V Nagar-388121, India*

Abstract

The Aluminium alloy 6061 and Magnesium alloy AZ31 plates of 6 mm thickness are welded in circular butt joint geometry by friction stir welding (FSW) process, using CNC vertical milling machine. Process parameters such as welding speed and tool rotational speed play an important role to obtain a better weld joint for dissimilar metals/materials. The friction stir welding tool is one of the critical components to the success of this process. It consists of a cylindrical shoulder and a pin with different geometry. In the experimental work, the said tool has been designed with cylindrical pin having four different geometries for friction stir welding of the dissimilar circular metal plates. Friction stir welding has been carried out at welding speed varying from 10 to 40 mm/min and tool rotational speed from 800 to 2000 rpm. Effects of process parameters on butt welded circular joint were investigated for weld strength. In this research work, it is found that welded joint between dissimilar metals alloys Al 6061 and Mg AZ31 can be formed using friction stir welding by selecting proper tool pin profile and welding parameters. It is suggested that friction stir welding of Aluminium alloy and Magnesium alloy with circular butt joint geometry would be useful in the future for automobile applications by getting the benefits from each material in a functional way.

Peer-review under responsibility of the organizing committee of ICIAME 2016
Keyword: Friction Stir Welding (FSW), Circular Butt Joint Geometry, Dissimilar Alloys, 6061 Aluminium Alloy & AZ31 Magnesium Alloy, Weld Strength

1. Introduction

Friction Stir Welding is a solid-state process in which the metal parts are joined without reaching melting point. Friction Stir Welding (FSW) was invented by Wayne Thomas at TWI (The Welding Institute), and the first patent applications were filed in the UK in December 1991[1]. A non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of sheets or plates (rectangular or circular) to be joined and traversed along the line (arc in case of circular joint) of joint. The tool serves two primary functions: (a) heating of workpieces (plates), and (b) movement of material between two materials in a mushy state to produce a joint. The fundamental difference between conventional fusion welding techniques and the solid-state friction stir welding (FSW) technique is that no heat is added to the 'system' in the later; instead heat is generated internally by means of friction at the tool-material interface resulting in the plastic deformation of the material around the stir zone[1]. The heating is accomplished by friction between the tool and the workpiece surfaces and resulting plastic deformation of workpieces leads to a union past the tool. The localized heating softens the material around the pin and combination of tool rotation and translation leads to movement of material from the front of the pin to the back of the pin. As a result of this process, a joint is produced in 'solid state'. Because of various geometrical features of the tool [1], the material movement around the pin can be quite complex [7] During FSW process, the material undergoes intense plastic deformation at elevated temperature, resulting in generation of fine equiaxed crystal grains. Equiaxed grains can, in some cases, be an indication for recrystallization and it can be achieved by heat generated due to friction between edges of the joint [7]. The fine microstructure in friction stir weld joint produces good mechanical properties [7]. A schematic of the process is presented in Fig. 1.

Corresponding author
*E-mail address:*hksharma911@gmail.com

2212-0173 © 2016 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license
(http://creativecommons.org/licenses/by-nc-nd/4.0/).
Peer-review under responsibility of the organizing committee of ICIAME 2016
doi:10.1016/j.protcy.2016.03.064

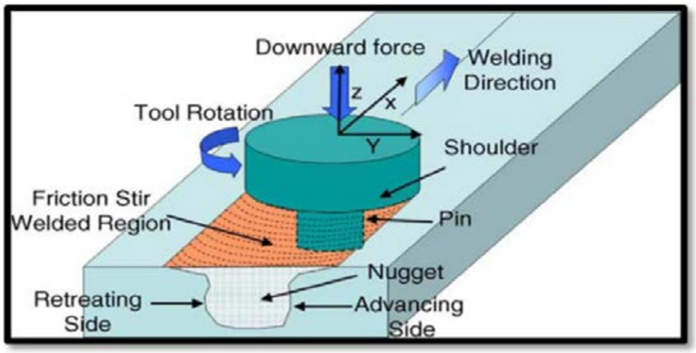


Fig. 1 Schematic diagram of FSW [1]

Friction Stir Welding (FSW) can be considered as a green technology [1] because no gases are evolved during the process. Also, there are no toxic fumes or smoke produced during or after the welding process. The process is energy efficient and environmentally friendly [1]. Normally metals and alloys are joined by fusion welding process; particularly welded joints of materials having low weldability may be found with welding defects. Some Al, Cu and Mg alloy series are not at all fusion weldable, and therefore, friction stir welding is useful to join such metallic materials [2].

1.1 FSW of dissimilar materials

Research studies on dissimilar metal friction stir welds are hereby highlighted and presented in this section. A joining criterion for lap welding of dissimilar Aluminium and stainless steel has been achieved [6]. Successful welds of Aluminium and Copper with good joint integrities have also been reported [8]. Also, good weld joint efficiency in dissimilar joints between Mild steel and AA6082 Aluminium alloy has been achieved [9]. Other successful dissimilar material welded joints using the FSW process include Aluminium & Magnesium [3] and Steel & Titanium alloy [4], Aluminium & Titanium [13], Mild Steel and Copper Bronze [14]. These review (Referring to Table 1) reveals that a lot of potential exists to successfully join dissimilar materials using the FSW process .

Table 1. FSW of dissimilar materials

Materials	Plate thickness (mm)	Rotational speed (rpm)	Welding speed (mm/min)	Tool Geometry	Welding Joint Geometry	References
AA6061 Al and Mg AZ31 Alloys	1.6	1400 & 800	38	Threaded pin tool	Butt Joint Lap Joint	V. Firouzdor et al[3]
2024-T3 Al alloy and AZ31 Mg alloy	3	2500	200 & 300, 400 & 550	Threaded pin tool	Butt Joint	Saad Ahmed Khodir et al [5]
SS400 Steel and A5083 Aluminium alloy	2	100 to 1250	25	Threaded pin tool	Butt Joint	K. Kimapong et al[6]
AA 5083/Copper and AA6082/Copper	1 (Cu) & 6 (Al)	750 & 1000	160	Conical and Scrolled Shoulder	Butt & Lap welds	I. Galvão et al [8]
Al 6082 with Mild Steel	6	200,600 & 800	10 – 80	Cylindrical pin tool	Butt Weld	Sajin G. Sajan, et al[9]
AA 6061 Al and AZ31 Mg Alloy	4 Thick	800	35	SKD-51 tool steel pin tool	Hybrid Butt Welding	Woong-Seong Chang, et al[11]

1.2 Methodology of Experimental Process

Since most of the experimental work in the field of friction stir welding of dissimilar metals or alloys has been carried out by making straight butt joints between flat plates using different tool pin profiles by different researchers. It is observed that circular butt joint between dissimilar metals or alloys is rarely performed using friction stir welding. Therefor the present work has been carried out for friction stir welding of Aluminium alloy 6061 and Magnesium alloy AZ31 for creating circular butt joint using the welding parameters as shown in table 5 using different tool pin profiles.

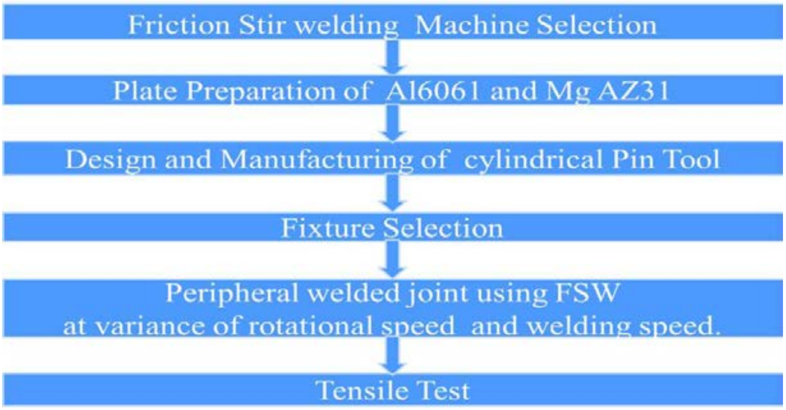


Fig. 2 Methodology of Experimental Process

2. Experimental Process

Circularly or peripherally welded joint of dissimilar alloys such as AA6061 Al alloy and AZ31 Mg alloy using friction stir welding using vertical milling machine have been produced. The Aluminium AA6061 alloy plate of 200 mm outer diameter x 95 mm inner diameter x 6 mm thick was welded to the Magnesium AZ31 alloy plate of size 95 mm diameter x 6 mm thick (Fig. 3). The actual set up with VMC, alloy plates, fixture, etc. is shown in the figure 4.

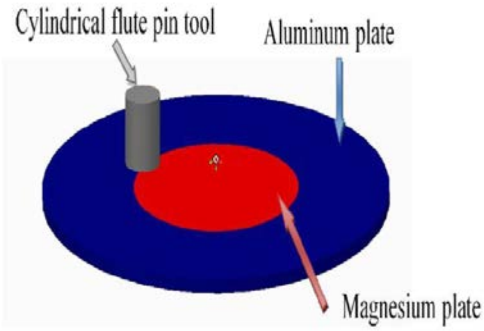


Fig. 3 Virtual Experimental setup

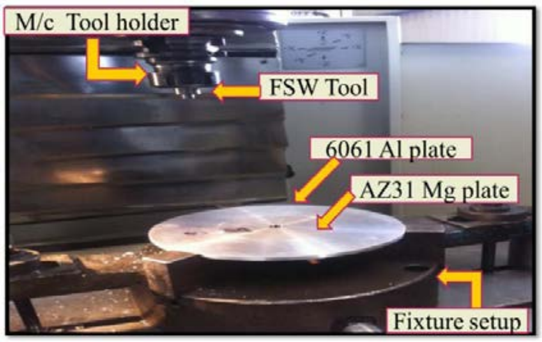


Fig. 4 Actual Experimental setup on VMC machine

2.1 FSW Machine Selection

The Vertical Milling M/c. has been used for friction stir welding. Two dissimilar plates of the said alloys arranged on the machine bed using fixture support as shown in figure 5 were welded with different tools having various tool pin geometries (Fig. 6) and material types. The machine specifications are shown in Table 2.

Fig. 5 CNC Vertical milling machine

Table 2. CNC Vertical Milling Machine Specification

Parameter	Unit	Specifications
Table		
Table size (clamping area)	mm x mm	315 x 1,060
Traverse		
X-axis x Y- axis x Z-axis	Mm	800 x 350 x380
Spindle		
Power(cont./15min. rating) Fanuc	kW	3.7/ 5.5
Power(cont./15min. rating) Siemens	kW	3.7/ 5.25
Speed	Rpm	6,000
Tool holder taper	BT 40	
Machine Size		
Width x Depth x Height	Mm	2,450 x 2,100 x
Installation Data		
Machine weight	Kg	2,500
Power supply	415 V, 50 Hz, 3 Phase	
Total connected load	kVA	
CNC System	FANUC/ SIEMENS	0i Mate Model

2.2 Design of FSW Tool

The tool material is selected as per survey of research papers showing the use of steel tools for plate materials such as Aluminium or Magnesium alloys, and Aluminium matrix composites (AMCs) commonly welded by FSW. Steel tools have also been used for the joining of dissimilar materials in both lap and butt joint configurations. The present experiments have been performed using tool steel-H13 & HCHCr with different tool pin profiles. The tool steel-H13 having chemical composition with more carbon content was hardened after making the tool configurations for reducing tool wear during FSW process.

Table 3. Tool Design

Sr No	Shoulder Diameter(D) mm	Shoulder Length(L) mm	Pin Diameter(d) mm	Pin Length (l) mm	Tool Material	Tool Pin Profile
A	20	30	8.25	5.4	HSS, Tool Steel	Cylindrical Flute Pin
B	24	40	6.0	5.5	HCHCr	Cylindrical Threaded Pin
C	24	15	6.0	5.8	H13, Tool Steel	Cylindrical Groove Pin
D	30	15	8.0	5.8	H13, Tool Steel	Cylindrical Threaded Pin
E	24	14	6.0	5.8	HCHCr	Cylindrical Threaded Pin

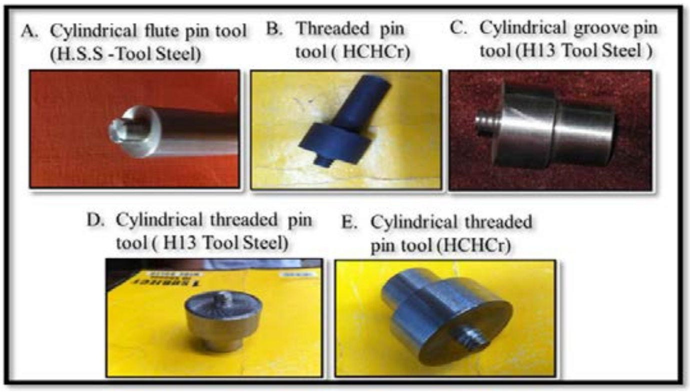


Fig. 6 Different tool geometry with its material

2.3 Welding Parameters

2.3.1 Selection of tool rotational speed and welding speed

For the three different tool geometries the range of tool rotational speed and welding speed was selected as shown in table 4. The choices of feed rate and rotational speed are crucial for the heat generation. In order to create good flow of the material around the tool pin, the forces on the tool should be minimum. The ratio of feed rate to rotational speed is usually reduced to a single parameter referred to as pitch. The properties of the welds are usually related to the pitch, which is believed to be an important parameter in FSW[7].

Table 4. Welding Parameters

Alloy	Rotational speed, rpm	Welding speed, mm/min
AA6061 Al alloy & AZ31 Mg alloy	800 to 2000	10 to 40

The minimum and maximum values of the welding parameters, the tool rotational speed and welding speed, were varied for different experiments as shown in table 5 below and friction stir welding for dissimilar metal alloys AA6061 and Mg AZ31 was carried out with two circular plates of size 200 mm outer diameter x 95 mm inner diameter x 6 mm thick and 95 mm diameter x 6 mm thick respectively.

Table 5. The variations in experimental parameters [***** Tool notations as per fig. 6]

Exp No	Parameters: Speed (rpm)	Parameters: Feed (mm/min)	Tool*	Welded Side (Up/down)	Welding Quality	Remark
1	2000	120	A	-	Poor	Not welded
2	1000	25	B	Upside	Good	Weld occur
3	1000	80	B	Upside	Partially Good	Weld occur but tool break
4	800	40	A	-	Poor	Not welded
5	1200	40	A	Upside	Partially Good	Weld occur but spread out
6	1400	40	A	Both side	Good	Weld occur but spread out
7	1000	38	C	Upside	Partially Good	Weld occur but tool break
8	2000	14	E	-	Poor	Not welded
9	2000	10	E	-	Poor	Not welded
10	1200	10	E	Both side	Good	Proper welded
11	1400	6	E	Upside	Partially Good	Weld occur but spread out
12	1300	8	E	Upside	Partially Good	Weld occur but spread out
13	1000	12	E	Both side	Good	Weld occur but spread out
14	1000	14	E	Both side	Good	Weld occur but spread out
15	1200	10	E	Both side	Good	Proper welded
16	1200	10	E	Both side	Good	Proper welded

3. Results and Discussion

Tool with cylindrical flute pin design ‘A’ was used with highest welding parameters. In this case, the plates were not welded successfully due to the following reasons:

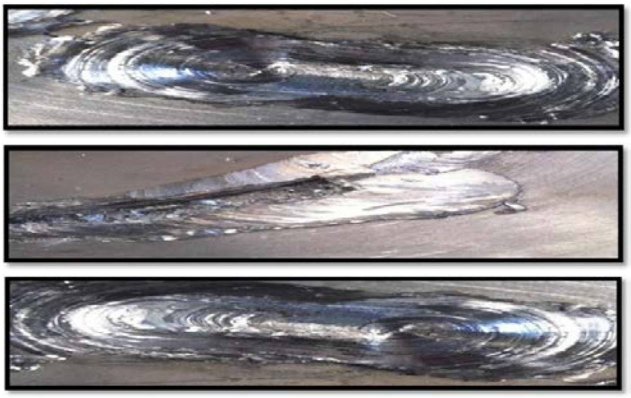
1. Path of welding
2. Pin geometry used during FSW
3. Higher value of welding parameter, being the prime reason.

Another experiment was carried out successfully using cylindrical threaded tool pin design ‘B’ and threaded pin tool was found broken during the experiment. The possible reasons for tool pin breakage are:

1. Higher value of welding speed of 80 mm/min
2. Tool material being HCHCr

Experimentation for friction stir welding with tool design 'C' resulted in failure of welding as tool got broken. In the current case, tool couldn't resist axial load and pin got broken due to too high load along the z- axis.

Tool design 'E' is used to weld Aluminium 6061 alloy and AZ31 Magnesium alloy with different parameters of tool as can be observed in table 5. Welding took place with less surface finish (macro level observation) in case of FSW using tool design ‘E’. Figure 7 shows the plates welded by using tool design 'E'. It shows the proper weld areas, while using optimized parameters for the experiments.



1.
2.
3.

Fig. 7 Welded plates using same parameters (Results of Expt. No. 10, 15 & 16)

3.1. Tensile Test of Welded Plate

Tensile test was carried out on Universal Tensile Testing Machine with 40,000 kgf capacity. Welded plates were cut as per required dimensions of standard specimen on UTM m/c. as shown in figure 8(a) below. Figure 8(b) shows the sample welded at 1200 rpm and 40 mm/min failed under tensile testing. The tensile strength of welded joints for experiment number 10, 15, 16 is shown in table 5 in terms of tensile loads.

a **b**

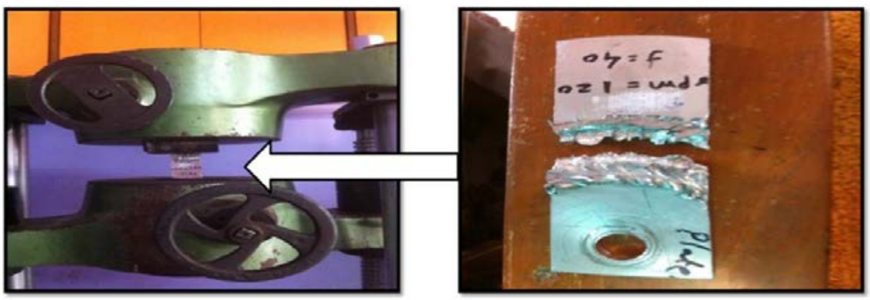


Fig. 8 (a) Tensile Testing of welded plate (b) Failed welded sample

Table 6. The Tensile Test Results with Welding Parameters

Weld no.	Weld plate	Tool Rotational Speed (rpm)	Welding Speed (mm/min)	Tool	Tensile load (N)	Load (kgf)
1	Linear welding	1400	38	Threaded pin tool	2055 (Ref. 4)	209.5 (Ref. 4)
2	Peripheral welding	1200	10	Threaded pin tool	1320	134.60
3	Peripheral welding	1200	10	Threaded pin tool	1350	137.66
4	Peripheral welding	1200	10	Threaded pin tool	1310	133.58

4. Conclusions

Within the range of experimental conditions in the present study, the following conclusions, which can be useful for Friction stir welding of circular butt weld joint between Aluminium alloy AA6061 and Magnesium alloy AZ31.

1. AL 6061 and Mg AZ31 can be welded using FSW by proper selection of tool pin profile and welding parameters.
2. As the path of welding is circular, more difficulties have been faced compared to linear path welding.
3. Different tool designs and specifications affect the appearance as well as properties of welded joint.
4. Tool rotational speed of 1200 rpm and welding speed of 10 mm/min were found to be the most influential parameters, affecting mechanical properties of circular butt weld joint between AA6061 and AZ31 when welded by using cylindrical threaded pin tool of HCHCr material.
5. The experiments that lower values of Tool rotational speed and welding speed are better for FSW of dissimilar alloys under consideration when using HCHCr tool material.

5. References

[1] Esther T. Akinlabi, and Stephen A. Akinlabi," Friction Stir Welding Process: A Green Technology", World Academy of Science, Engineering and Technology 71, 2012.

[2] A Technical handbook of "Friction stir welding", ESAB AB Welding Automation SE-695 81 LAXÅ, Sweden (www.esab.com)

[3] V. Firouzdor And S. Kou, "Al-to-Mg Friction Stir Welding: Effect of Positions of Al and Mg with Respect to the Welding Tool", Supplement to The Welding Journal. Sponsored by the American Welding Society and the Welding Research Council. Nov- 2009.

[4] GAO Yefei, Tsumura Takuya, Nakata Kazuhiro "Dissimilar Welding of Titanium Alloy and Steels" Transactions of JWRI is published by Joining and Welding Research Institute, Osaka University, Ibaraki, Vol 41, no.2 ,07-12, (2012).

[5] Saad Ahmed Khodir and Toshiya Shibayanagi, "Dissimilar Friction Stir Welded Joints between 2024-T3 Aluminium Alloy and AZ31 Magnesium Alloy" , Materials Transactions, The Japan Institute of Metals, Vol. 48, No. 9 pp. 2501 to 2505, (2007).

[6] K. Kimapong And T. Watanabe, "Friction Stir Welding of Aluminium Alloy to Steel", The Welding Journal, 277 – 282, Oct- 2004.

[7] R.S. Mishra , Z.Y. Ma , "Friction stir welding and processing", Materials Science and Engineering R 50 1–78, (2005).

[8] I. Galvão , D. Verdera , D. Gesto , A. Loureiro , D. M. Rodrigues, "Analyzing The Challenge of Aluminium to Copper FSW" AIMEN, Relva 27A Torneiros, 36410 Porriño, Spain.

[9] Sajin G. Sajan, Manish Meshram, Pankaj, Palli Srinivas, Suhash R. Dey, "Friction Stir Welding of Aluminium 6082 with mild steel and its joint analyses" , Department of Materials Science and Engineering, Indian Institute of Technology Hyderabad, Ordnance Factory Estate,Yeddumailaram-502205.

[10] K.D.Bhatt, Bindu Pillai, A.M. Trivedi," Effect of Size of Tool on Peak Temperature & Viscosity during Friction Stir Welding of AA6061-T6 Aluminium Alloy Using HyperWorks", International Journal of Innovative Research in Science, Engineering and Technology ,Vol. 2, Issue 4, April 2013.

[11] Woong-Seong Chang, S.R. Rajesh, Chang-Keun Chun and Heung-Ju Kim," Microstructure and Mechanical Properties of Hybrid Laser-Friction Stir Welding between AA6061-T6 Al Alloy and AZ31 Mg Alloy", scienceDirectJ. Mater. Sci. Technol., 27(3), 199-204, 2011

[12] R. Rai, A. De, H. K. D. H. Bhadeshia and T. DebRoy," Review: friction stir welding tools", Science and Technology of Welding and Joining, VOL 16, NO 4, 325 to 341, 2011.

[13] Yuhua Chen, Changhua Liu and Geping Liu," Study on the Joining of Titanium and Aluminium Dissimilar Alloys by Friction Stir Welding", The Open Materials Science Journal, 5, 256-261, 2011.

[14] A. Kurt, I. Uygur, And U. Paylasan" Effect of Friction Welding Parameters on Mechanical and Microstructural Properties of Dissimilar AISI 1010-ASTM B22 Joints" Welding Research, vol-90, 102s-106s ,May 2011.