AN OVERVIEW OF FRICTION STIR WELDING OF MAGNESIUM ALLOYS

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Abstract – Magnesium is a chemical active element, which can form intermetallic compounds with other alloying elements such as aluminum, calcium, copper etc. and due to its low density and light weight it has wide range of applications in the field of automobiles, aerospace, electronics, medicines, sports etc. Friction stir welding (FSW) is a promising welding technique used for joining Magnesium alloys. The present paper gives an overview of friction stir welding of magnesium alloys explored through various research studies and experiments in a systematic and chronological order. It also gives the impact of different welding parameters on the microstructure and mechanical properties of the FSW joints of magnesium alloys.

Index Terms- Friction Stir Welding, Magnesium alloys, Microstructure, Mechanical properties, Parameters

I. Introduction

Magnesium is a structural metal, lightest in weight and is one of the most abundant elements on this earth which has high rigidity, specific strength, electrical and heat conductivity. Because of high specific mechanical properties, low weight and low density, magnesium has a wide range of applications in automobile industry used in gear boxes, steering wheels, fuel tank cover, wheel assembly; in aerospace for making aircrafts, spacecrafts, missiles; in medicines as orthopedic biomaterials; optical application in the form of frame of eye wear, in sports as handles of rackets, bows of archery, frame of bicycle and golf clubs. Materials containing magnesium is also used in the bodies of cell phones, computers, laptops, media players etc. showing wide application in the field of electronics [1]. Magnesium is a chemical active element which can easily form intermetallic compounds with other alloying elements such as aluminum, beryllium, calcium, cerium, copper, iron, lithium, manganese, molybdenum, nickel, tin, titanium, zinc etc. Due to wide applications of magnesium and being an active element, there has been a rapid progress in joining magnesium to its alloys and to alloys of other elements.

II. FRICTION STIR WELDING

Friction stir welding is a method of welding materials in a solid state which was researched in United Kingdom in the year 1991 at The Welding Institute for joining aluminium alloys [2]. It is an environment friendly and energy efficient technique which is used for welding various metallic alloys as no emissions or fumes are produced during the process. In this non consumable & rotating tool is used to produce welds by softening the work piece locally with the help of heat produced due to friction between tool and the material which further reduces the residual stresses and distortion. This technique is used for welding of both thick and thin materials. FSW tool comprises of a shoulder which moves on the top of the work piece and a pin of a small diameter which moves between the interface of two plates and gets penetrated. The shoulder prevents the escaping of the soft material when the tool is rotated and puts up the forging action on the tool to form the joint. The pin is mainly cylindrical in shape with threads; which makes the material to flow and retains the material within the weld zone. The downward force acting on the tool keeps the contact between the shoulder and the surface of the working material. The movement of tool with respect to material surface causes friction, which helps in heat generation [3]. Figure 1 shows the schematic working of friction stir welding.

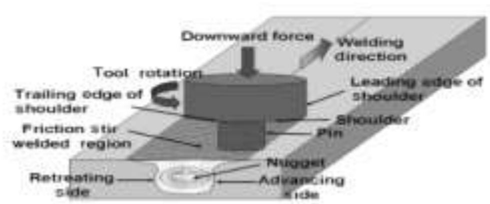

Fig. 1 Schematic workings of friction stir welding [4]

Friction stir welding process is known for its mechanical, metallurgical &environmental advantages which are given as:

1. Improvement in the mechanical properties as compared to other conventional welding techniques.
2. Refined grain structure is obtained.
3. Less consumption of fuel due to usage of light materials.
4. Less consumption of energy.
5. Very less wastage of material during the process.
6. No harmful emissions during welding process.
7. Weld obtained is free from defects.
8. There is low distortion and good stability of the structure obtained after welding.

III. FRICTION STIR WELDING PARAMETERS

Material of the tool

Quality of the weld and wear of the tool is considered while selecting material of the tool. Proper heat generation and dissipation depends upon the material which will affect the quality of the weld. The tool material selected must be able to bear compressive load. It must have good shear strength. The tool must have proper dimensional stability, wear resistance and oxidation resistance. To minimize the loss of heat, tool material should have low thermal conductivity to minimize heat loss. H13 steel, high carbon steel & high speed steel are some materials which are widely used to weld magnesium alloys.

Shape of the tool

FSW tool have a shoulder and pin. Concave shape of the shoulder helps in escaping the material which is deformed by the pin. It also maintains downwards pressure which forges the material behind the tool. It prevents material to come out from the sides of the shoulder. Pin of the tool causes the stirring action and helps in the flow of the material. Different pin shapes such as cylindrical, threaded, tapered, square etc are used to weld magnesium alloys.

Rotating speed of the tool & tool tilt

Increasing the rotating speed of the tool will enhance the heat input which will help in the plastic deformation of material and grain refinement but increasing the tool rotating speed after certain limit will result in high temperature which can cause defects and coarse grain structure in some materials. It is also been find out that tilting the tool at certain angle assists in better bonding of joints. Tilting the welding tool by few degrees have improved the welding of magnesium alloys.

Feed rate & Transverse speed of the tool

Feed rate is very important parameter in FSW. Low feed rate helps to transverse the welding tool easily along the welding line as low feed rate helps in generation of sufficient heat which softens the material ahead of the tool. High feed rate can result in insufficient heat generation which can cause voids and cracks in the weld and even results in breakage of the tool due to high forces.

Forces acting on the tool during welding

There are three types of forces which are considered during the FSW process. Firstly, the downwards force which maintains the position of the tool. Second is the traverse force which is parallel to the movement of the tool and is always positive. This force is developed due to resistance between material and movement of the tool. Third is the lateral force which is perpendicular to the tool traverse direction. All the forces acting on the tool should be small as possible.

IV. Literature Review

Thorough literature review has been done to study every single detail in FSW of Mg alloys and with alloys of other metals. Table 1 summarizes the review studies with a brief detail:

Table 1 Overview of the Review of FSW of Magnesium Alloys

Sr. No.	Name of the Researcher	Year	Contribution	Workpiece material	Parameters & Properties selected	Major Findings
1.	Lee *et al.*	2003	Study on the FSW of AZ91 magnesium alloys.	AZ91D, 4 mm thick	Feed rate & Welding speed	Butt joints of good quality were obtained.
2.	Lee *et al.*	2003	Study on the FSW of AZ31B magnesium alloys.	AZ31B–H24, 4 mm thick	Rotational speed and Welding speed	Increase in rotational speed and decline in welding speed produce joints which were free from defects.
3.	Gharacheh *et al.*	2006	Study of effect of tool rotation and traverse speed on mechanical properties of FSW AZ31 magnesium alloy joints.	AZ31 Mg alloy	Welding pressure, Rotational speed and Traverse speed	By increasing the ratio of rotational speed to traverse speed, the size of nugget can be increased.
4.	Pareek *et al.*	2007	Metallurgical study of AZ31B magnesium alloys.	AZ31-H24 Mg alloy, 3.175 mm thick	Welding speed and Tool rotation	FSW joints have enhanced corrosion resistance as compared to base metal.
5.	Afrin *et al.*	2008	Study of tensile properties & microstructure of AZ31B magnesium alloy.	AZ31B-H24 Mg alloy	Tool speed and Welding speed	Improvement in tensile properties was observed by increasing welding speed.
6.	Kwon & Shigematsu	2008	Study of dissimilar FSW joints of aluminium and magnesium.	Al and Mg alloy plates, 2 mm thick	Tool rotation speed	Defect free joints & smooth surface joints were obtained at higher rotational speed.
7.	Zeng *et al.*	2008	Study of tensile properties & microstructure of AM50 magnesium alloy.	AM50 Mg alloy	Elongation, Tensile strength and Yield strength	The hardness of the weld joint is improved but tensile properties were decreased as compared to that of base metal.
8.	Cao & Jahazi	2009	Study of impact of welding speed on FSW butt joints of a magnesium alloy.	AZ31B Magnesium alloy	Welding speed	The yield strength& hardness of stir zone increases with increasing welding speed.
9.	Commin *et al.*	2009	Study of influence of process parameters on the FSW AZ31 alloy.	AZ31 Mg alloy	Shoulder diameter, Tool rotation speed, Welding speed	By increasing the shoulder diameter & tool rotation speed and on the other hand, by decreasing the welding speed generation of heat can be increased. This can also promote the grain growth.
10.	Chowdhury *et al.*	2010	Study of effect of pin tool having threads and weld pitch on tensile properties of AZ31 alloy.	AZ31B-H24 Magnesium alloy	Welding speed, Rotational speed and Pin tool with threads	Yield strength and ultimate tensile strength became less due to increase in strain hardening.
11.	Firouzdor & Kou	2010	Study of effect of position of material, feed rate and rotational speed on FSW joints of aluminium & magnesium.	6061 Al alloy and AZ31 Mg alloy	Tool traverse speed, Welding tool and Tool rotation speed	These conditions give the heat input which further affects the formation of liquids and intermetallics as well as material flow.
12.	Sirong, et al.	2010	Study of microstructure & mechanical properties of FSW AZ31B magnesium alloy containing cerium.	AZ31B Magnesium alloy	Ultimate tensile strength and Percentage elongation	The increase in micro hardness is seen in the welded joints.
13.	Yong et al.	2010	Study of dissimilar FSW joints of aluminum and magnesium alloy.	5052 Al alloy and AZ31 Magnesium alloy, 6 mm thick	Tool rotation and Traverse speed	Defect free joints were obtained at low rotation speed and welding speed.
14.	Cao & Jahazi	2011	Study of effect of rotational speed and probe length on the friction stir welded lap joints of magnesium alloy.	AZ31B-H24 Magnesium alloy, 2 mm thick	Tool rotational speed and Probe length	Tensile shear strength was increased by increasing the probe length. Lap joints with fewer defects were produced.

15.	Rose et al.	2011	Study of effect of axial force on the mechanical characteristics of friction stir welded AZ61 magnesium alloy.	AZ61A Magnesium alloy	Axial force, Ultimate tensile strength, Hardness	The joint formed with increase of axial force had better tensile properties.
16.	Malarvizhi & Balasubramanian	2012	Study of the effect of ratio of shoulder diameter of the tool to thickness of plate on tensile properties of friction stir welded joints of aluminum &magnesium alloys.	AA6061 Aluminum and AZ31 Magnesium alloy	Rotating tool speed	The joints fabricated at shoulder diameter which is 3.5 times the thickness of plates have better tensile properties.
17.	Venkateswaran & Reynolds	2012	Study of FSW joints between aluminum and magnesium alloys.	Aluminum alloy AA6063 and AZ31B Magnesium alloy	Tool rotational speed, Tensile strength, Elongation	The good transverse strength of dissimilar joints of aluminium and magnesium due to mechanical interlocking of the metallic phases.
18.	Yang et al.	2013	Study of tool speed on mechanical and microstructure properties of FSW joints of magnesium alloy.	AZ31 Mg Alloy	Tool rotation	Tool rotation improves the tensile strength of the welded joints.
19.	Motalleb-Nejad et al.	2014	Study of microstructure & mechanical properties by taking into account the pin shape of the tool used for friction stir welded AZ31B magnesium alloy.	AZ31B Mg alloy	Tensile strength and Hardness	Taper and cylindrical pins with threads resulted in defect free joints.
20.	Nagasawa et al.	2016	Study of mechanical properties of friction stir weld joints of magnesium alloy AZ31.	AZ31 Mg alloy	-	FSW can be applied to weld magnesium alloys.

Good quality of butt joints were obtained using FSW on AZ91Mg alloy plates with the thickness of 4mm with increase in travel speed and tool rotation [5]. Defect free welds were obtained at higher rotational speed and lower transverse speed for 4 mm thick AZ31B Mg alloy sheet [6]. By increasing the ratio of rotational speed and transverse speed the size of weld nugget got increased during FSW ofAZ31 magnesium alloy [7]. The mechanical properties of the friction stir weld showed better corrosion resistance than the base metal in 3.175 mm thick AZ31 Mg alloy plates [8]. The yield strength of the joint was increased by enhancement of the welding speed [9, 10].There was also increase of ultimate tensile strength due to reduction in heat input during friction stir welding of AZ31B magnesium alloy [9]. The hardness of the welded joints was improved [9, 10]. The tensile strength, yield property and percentage elongation were decreased as compared to that of base metalAZ31B Mg alloy [11]. By increasing the shoulder diameter & tool rotation speed and simultaneously by reducing the welding speed will produce high heat input which will promote grain growth in AZ31 Mg alloy [12]. Friction stir welding decreases yield strength and ultimate tensile strength but increases strain hardening of AZ31B magnesium alloy [13]. The welding conditions results in formation of liquids and intermetallics during FSW of 6061 Al and AZ31 Mg alloy [14]. The micro hardness was increased from top to bottom of the weld in FSW of AZ31B magnesium alloy sheet added with 0.5 wt.% Ce [15]. Defect free welds were produced at tool rotation of 600 r/min and transverse speed of 40 mm/min in FSW of 6 mm thick 5052 Al alloy and AZ31 Mg alloy plates [16]. Friction stir welding technique can be easily applied to weld magnesium alloys [18, 23]. FSW lap joints with high tensile strength and without any defects were successfully obtained [18]. Tensile shear load was increased by increasing probe length during friction stir welding of AZ31B magnesium alloy [17]. The joint of AZ61 magnesium alloy formed at certain axial force exhibited improvement in tensile properties due to formation of smaller grains in the stir zone and there was increase in hardness of the stir zone [18]. AA6061 Aluminum and AZ31 Magnesium alloys joints were formed using a shoulder diameter which is 3.5 times the plate thickness which had improved tensile properties [19]. The improved tensile strength of dissimilar welds of aluminium and magnesium were obtained to due proper interlocking between the metallic phases [20]. The ultimate tensile strength of the joints was enhanced due to high rotational speed during FSW ofAZ31 Mg Alloy [21]. Taper and cylindrical pins with threads produced defect free joints in AZ31B Mg alloy [21]. With the increase in rotational speed defect-free welds were successfully obtained [24].

V. CONCLUSION

After thorough investigation of the studies related to friction welding of magnesium alloys it can be concluded that FSW has a great potential in welding magnesium alloys as compared to other conventional welding techniques due to advantages of FSW technique. FSW technique can be applied to weld similar and dissimilar magnesium alloys as well as with other alloys such as aluminium, copper, composite materials etc. There is a wider scope to analyze the impact of different FSW parameters with certain levels on the mechanical properties of welded joints of magnesium alloys and also to optimize the process parameters using different techniques such as Taguchi, Finite element method, Response surface methodology etc.

REFERENCES

1. Gupta M, Ling SN. Magnesium, magnesium alloys, and magnesium composites. John Wiley & Sons; 2011 Mar 31.
2. Thomas WM, Nicholas ED, Needham JC, Murch MG, Templesmith P, Dawes CJ. GB Patent Application No. 9125978.8, December; 1991.
3. Lohwasser D, Chen Z, editors. Frictions stir welding: From basics to applications. Elsevier; 2009 Dec 18.
4. Mishra, R.S. and Mahoney, M.W. Friction Stir Welding and Processing. 2007.
5. Lee WB, Kim JW, Yeon YM, Jung SB. The joint characteristics of friction stir welded AZ91D magnesium alloy. Materials Transactions. 2003;44(5):917-23.
6. Lee WB, Yeon YM, Jung SB. Joint properties of friction stir welded AZ31B–H24 magnesium alloy. Materials Science and Technology. 2003 Jun 1;19(6):785-90.
7. Gharacheh MA, Kokabi AH, Daneshi GH, Shalchi B, Sarrafi R. The influence of the ratio of "rotational speed/traverse speed"(ω/v) on mechanical properties of AZ31 friction stir welds. International Journal of Machine Tools and Manufacture. 2006 Dec 31;46(15):1983-7.
8. Pareek M, Polar A, Rumiche F, Indacochea JE. Metallurgical evaluation of AZ31B-H24 magnesium alloy friction stir welds. Journal of materials engineering and performance. 2007 Oct 1;16(5):655-62.
9. Afrin N, Chen DL, Cao X, Jahazi M. Microstructure and tensile properties of friction stir welded AZ31B magnesium alloy. Materials Science and Engineering: A. 2008 Jan 15;472(1):179-86.
10. Zeng RC, Dietzel W, Zettler R, Jun CH, Kainer KU. Microstructure evolution and tensile properties of friction-stir-welded AM50 magnesium alloy. Transactions of Nonferrous Metals Society of China. 2008 Dec 1;18:s76-80.
11. Cao X, Jahazi M. Effect of welding speed on the quality of friction stir welded butt joints of a magnesium alloy. Materials & Design. 2009 Jun 30;30(6):2033-42.
12. Commin L, Dumont M, Masse JE, Barrallier L. Friction stir welding of AZ31 magnesium alloy rolled sheets: Influence of processing parameters. Acta Materialia. 2009 Jan 31;57(2):326-34.
13. Chowdhury SM, Chen DL, Bhole SD, Cao X. Tensile properties of a friction stir welded magnesium alloy: Effect of pin tool thread orientation and weld pitch. Materials Science and Engineering: A. 2010 Aug 20;527(21):6064-75.
14. Firouzdor V, Kou S. Al-to-Mg friction stir welding: effect of material position, travel speed, and rotation speed. Metallurgical and Materials Transactions A. 2010 Nov 1;41(11):2914-35.
15. Sirong YU, Xianjun CH, HUANG Z, Yaohui LI. Microstructure and mechanical properties of friction stir welding of AZ31B magnesium alloy added with cerium. Journal of rare earths. 2010 Apr 1;28(2):316-20.
16. Yong Y, Zhang DT, Cheng QI, Zhang W. Dissimilar friction stir welding between 5052 aluminum alloy and AZ31 magnesium alloy. Transactions of Nonferrous Metals Society of China. 2010 Jul 31;20:s619-23.
17. Cao X, Jahazi M. Effect of tool rotational speed and probe length on lap joint quality of a friction stir welded magnesium alloy. Materials & Design. 2011 Jan 31;32(1):1-1.
18. Rose AR, Manisekar K, Balasubramanian V. Effect of axial force on microstructure and tensile properties of friction stir welded AZ61A magnesium alloy. Transactions of Nonferrous Metals Society of China. 2011 May 1;21(5):974-84.

19. Malarvizhi S, Balasubramanian V. Influences of tool shoulder diameter to plate thickness ratio (D/T) on stir zone formation and tensile properties of friction stir welded dissimilar joints of AA6061 aluminum–AZ31B magnesium alloys. Materials & Design. 2012 Sep 30;40:453-60.
20. Venkateswaran P, Reynolds AP. Factors affecting the properties of Friction Stir Welds between aluminum and magnesium alloys. Materials Science and Engineering: A. 2012 May 30;545:26-37.
21. Yang J, Wang D, Xiao BL, Ni DR, Ma ZY. Effects of rotation rates on microstructure, mechanical properties, and fracture behavior of friction stir-welded (FSW) AZ31 magnesium alloy. Metallurgical and Materials Transactions A. 2013 Jan 1;44(1):517-30.
22. Motalleb-Nejad P, Saeid T, Heidarzadeh A, Darzi K, Ashjari M. Effect of tool pin profile on microstructure and mechanical properties of friction stir welded AZ31B magnesium alloy. Materials & Design. 2014 Jul 31;59:221-6.
23. Nagasawa T, Otsuka M, Yokota T, Ueki T. Structure and mechanical properties of friction stir weld joints of magnesium alloy AZ31. InEssential Readings in Magnesium Technology 2016 (pp. 517-521). Springer International Publishing.
24. Kwon YJ, Shigematsu I, Saito N. Dissimilar friction stir welding between magnesium and aluminum alloys. Materials Letters. 2008 Aug 31;62(23):3827-9.