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Friction Stir Welding of Magnesium Alloys: A Review

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Abstract **- The Increasing global demands for energy conservation and environmental protection have encouraged manufacturers to develop lightweight components. Magnesium alloys are characterized by unique properties and offer opportunities for lightweight applications. There is a challenge to join the materials with a variety of applications along with cheaper value and high strength to weight ratio. Friction stir welding (FSW) is a solid state joining process used for light weight alloys. In this article, the recent developments of the FSW of magnesium alloys are reviewed to assist researchers to develop an in-depth understanding of the current state of the Friction Stir Welding of Magnesium Alloys.**

Keywords**:Friction stir welding, FSW process parameters, Microstructure, Magnesium alloys.**

I.INTRODUCTION

Friction stir welding (FSW) is basically a solid state metal joining technique [1-5] which was developed by W.M. Thomas at The Welding Institute of UK, in 1991. Many researchers termed this technique as “Green Technology” because it is energy efficient and environmentally friendly [2]. Amongst all the traditional welding welding technique FSW is an energy proficient and versatile method of joining metals, alloys and composite. FSW does not melt the base material and therefore completely eliminates the problems associated with solidification that usually appear in fusion welding [6- 10]. This technique was first used to join aluminium and its alloys. Recently it is being used to weld magnesium alloys and other alloys [6]. FSW has many potential applications in major industries, i.e. shipbuilding, aerospace, automobile, railway and many industrial applications [11, 12].

Magnesium is a white colored silvery metal characterized by its reduced density in comparison to all the other structural metals [13]. Presently, Magnesium (Mg) alloys are found to rapidly replace copper, steel and aluminium in a variety of automotive and structural applications [14-19]. Mg alloys have low density value (1.74 g/cm^3), greater thermal conductivity, excellent damping property, sound castability, high machinability, and improved electromagnetic interference shielding capabilities [20-24]. Although Magnesium (Mg) alloys have limited workability at room temperature owing to their hexagonal close packed structure [25,26], they have good formability at high temperature [27-33]. Even though the wider use of Mg alloys requires feasible joining methods, there is still a lack of efficient & effective welding techniques for Mg alloys [19]. Friction stir welding (FSW) is capable of joining magnesium alloys without melting and thus it can eliminate problems related to the solidification. As FSW does not require any filler material, the metallurgical problems associated with it can also be eliminated and good quality weld can be obtained [22]. Friction stir welding process is associated with many advantages which are illustrated in the table 1.

TABLE 1: ADVANTAGES/BENEFITS OF FRICTION STIR WELDING [EDITED FROM [1]]

Sr. No.	Area	Benefits
1	Metallurgical	a. Fine microstructure. b. Absence of cracking. c. Solid phase process. d. No loss of alloying elements. e. Low distortion and shrinkage, even in long welds. f. Good dimensional stability and repeatability. g. Excellent metallurgical properties in the joint area. h. Replace multiple parts joined by fasteners.
2	Environmental	a. Eliminate grinding wastes. b. No shielding gas required. c. No surface cleaning required. d. Eliminate solvents required for degreasing. e. Consumable materials saving, such as rugs, wire or any other gases.
3	Energy	a. Improved materials use allows reduction in weight. b. Very Less energy needed (only 2.5% of the energy needed for a laser weld). c. Decreased fuel consumption in light weight aircraft, automotive, structure and ship applications.
4	Safety	a. No welding arc or fumes. b. No UV-radiations. c. No spatter.
5	Mechanical Characteristics	a. High weld strength and toughness. b. Weld resists fatigue stress. c. Minimal distortion of the joined parts.

II.WORKING PRINCIPLE OF FRICTION STIR WELDING PROCESS

In Friction stir welding, a non-consumable rotating tool with a specially designed pin and shoulder is inserted into the abutting edges of plates to fabricate the joint and traversed along the line of the joint.

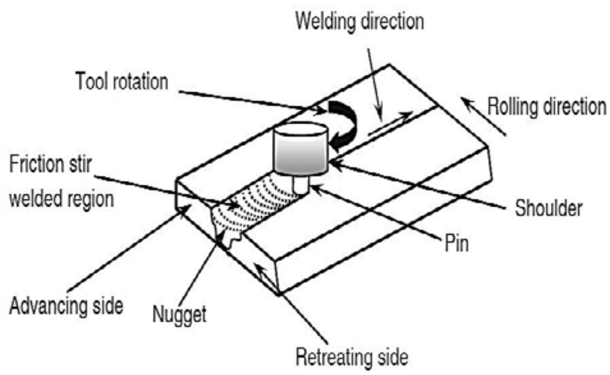

Fig. 1 Schematic illustration of friction stir welding Process [3]

In this process, the heating is accomplished by friction between the tool and the workpiece and plastic deformation of workpiece [2,3]. The localized heating softens the material around the pin before it reaches its melting point and combination of tool rotation and translation leads to the 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' [19].

III.FSW PROCESS PARAMETERS

The FSW process involves very complex phenomena related to material movement and plastic deformation during the process. Welding parameters, tool geometry and design of joint exert a significant role on the material flow pattern and temperature distribution [1,5]. The major factors affecting FSW process are:

1. Tool geometry:
   a. Shoulder
   b. Pin
2. Welding parameters:
   a. Tool rotation rate (RPM) in clockwise or counterclockwise direction
   b. Tool traverse speed (mm/min) along the line of joint
   c. Angle of spindle or tool tilt with respect to the workpiece surface
   d. The insertion depth of pin into the workpieces (Target Depth)
3. Joint design:
   a. Square butt
   b. Edge butt
   c. T butt joint
   d. Lap joint
   e. Multiple lap joint
   f. T lap joint
   g. Fillet joint

IV.FRICTION STIR WELDING OF MAGNESIUM ALLOYS

Magnesium alloys have inferior formability, sheet material of magnesium alloys is made commercially by casting or die casting processes except some wrought alloys such as AZ31 [30]. It is usually difficult to weld these cast magnesium alloys due to the porosity formation in the weld [8]. Mg alloys also have relatively large coefficient of expansion, which causes large deformation/ distortion of the weld. Therefore, solid-state welding technique should be the optimum choice for joining magnesium alloy [1].

FSW studies have been recently reported on AM50, AM60, ZK60, AZ91, AZ61 and AZ31. The Mg alloys plates of thickness 1.5 mm to 6.5 mm have been used in previous reported work for butt and lap joint configuration for FSW. The friction stir welding parameters range used in previous studies [2,3,6-11,14,16,17,19-22,24,27-29,32,33] for FSW process are summarized in Table 1.

TABLE II FSW PARAMETERS RANGE USED IN PREVIOUS STUDIES

Sr. No.	Used Parameters	Used Range	
		Minimum	Maximum
1.	Tool Diameter (mm)	6	20
2.	Tool Pin Diameter (mm)	3.175	7
3.	Tool Probe Length (mm)	4	5.8
4.	Welding Speed (mm/min)	22	2000
5.	Tool Rotational Speed (RPM)	400	2000
6.	Axial Force (KN)	3	22

The important observations of friction stir welded magnesium alloys are:

1. The quality of friction stir welded joint is highly sensitive to tool rotation rate and traverse speed [22,7,20,19,11,3,17,32,2,16].
2. Three microstructural zones are identified (fig. 2) i.e., stirred (nugget) zone, thermo-mechanically affected zone (TMAZ), and heat-affected zone (HAZ) [3,6-8,11,17,19,20,32].
3. Fine recrystallized grains generation in the stirred zone [3,6,8,11,17,19,20,32] and in case of cast magnesium alloy, the coarse α-Mg phase and β-intermetallic compound disappeared after FSW [7,8].

4. The hardness of the stirred zone is higher than that of the base materials due to refined grain structure in the stirred zone [2,6,11,].
5. Improvement in mechanical properties of magnesium alloys depends on the selection of FSW parameters [2,3,6-11,14,16,17,19-22,24,27-29,32,33].

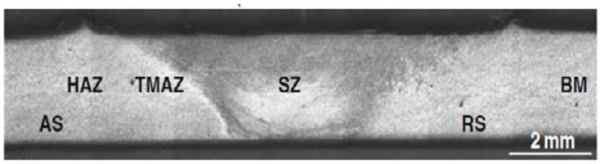

Fig. 2 A typical macrograph showing various microstructural zones in FSW AZ31 [3].

V.CONCLUSION

The current state of development of the FSW of magnesium alloys has been addressed. Tool geometry and welding parameters are very important to produce sound and defect-free weld. There is a considerable improvement in strength, ductility, fatigue, and fracture toughness by FSW as compare to another traditional welding. But other joint configurations may be used for FSW rather than butt and lap joint configurations. Furthermore, following aspects require more understanding:

- Welding of dissimilar alloys and metals
- Microstructural Stability
- Tool Geometry Design
- Material Flow
- Tool Wear

REFERENCES

[1] Mishra, R. S., & Ma, Z. Y. (2005). Friction stir welding and processing. *Materials Science and Engineering: R: Reports*, *50*(1), 1-78.

[2] Naik, B. S., Chen, D. L., Cao, X., & Wanjara, P. (2013). Microstructure and fatigue properties of a friction stir lap welded magnesium alloy. *Metallurgical and Materials Transactions A*, *44*(8), 3732-3746.

[3] Chowdhury, S. H., Chen, D. L., Bhole, S. D., Cao, X., & Wanjara, P. (2013). Friction stir welded AZ31 magnesium alloy: microstructure, texture, and tensile properties. *Metallurgical and materials transactions A*, *44*(1), 323-336.

[4] Rai, R., De, A., Bhadeshia, H. K. D. H., & DebRoy, T. (2011). Review: friction stir welding tools. *Science and Technology of Welding and Joining*, *16*(4), 325-342.

[5] Nandan, R., DebRoy, T., & Bhadeshia, H. K. D. H. (2008). Recent advances in friction-stir welding–process, weldment structure and properties. *Progress in Materials Science*, *53*(6), 980-1023.

[6] Afrin, N., Chen, D. L., Cao, X., & Jahazi, M. (2008). Microstructure and tensile properties of friction stir welded AZ31B magnesium alloy. *: A*, *472*(1), 179-186.

[7] Sunil, B. R., Reddy, G. P. K., Mounika, A. S. N., Sree, P. N., Pinneswari, P. R., Ambica, I., ... & Amarnadh, P. (2015). Joining of AZ31 and AZ91 Mg alloys by friction stir welding. *Journal of Magnesium and Alloys*.

[8] Choi, D. H., Ahn, B. W., Kim, S. K., Yeon, Y. M., Kim, Y. J., Park, S. K., & Jung, S. B. (2011). Microstructure evaluation of friction stir welded AZ91 with CaO Mg alloy. *Materials transactions*, *52*(4), 802-805.

[9] Cao, X., & Jahazi, M. (2009). Effect of welding speed on lap joint quality of friction stir welded AZ31 magnesium alloy. In *Trends in Welding Research: Proceedings of the 8th International Conference, June 1-6, 2008, Callaway Gardens Resort, Pine Mountain, Georgia, USA* (Vol. 1, p. 72). ASM International.

[10] Cao, X., & Jahazi, M. (2011). Effect of tool rotational speed and probe length on lap joint quality of a friction stir welded magnesium alloy. *Materials & Design*, *32*(1), 1-11.

[11] Singh, I., Cheema, G. S., & Kang, A. S. (2014). An experimental approach to study the effect of welding parameters on similar friction stir welded joints of AZ31B-O Mg alloy. *Procedia Engineering*, *97*, 837-846.

[12] Welding, F. S. (2011). Technical Handbook. *ESAB2011*.

[13] Micari, F., Buffa, G., Pellegrino, S., & Fratini, L. (2014). Friction Stir Welding as an Effective Alternative Technique for Light Structural Alloys Mixed Joints. *Procedia Engineering*, *81*, 74-83.

[14] Sevvel, P., & Jaiganesh, V. (2014, September). Improving the mechanical properties of friction stir welded AZ31B magnesium alloy flat plates through axial force investigation. In *Applied Mechanics and Materials* (Vol. 591, pp. 11-14).

[15] Darras, B. M., Khraisheh, M. K., Abu-Farha, F. K., & Omar, M. A. (2007). Friction stir processing of commercial AZ31 magnesium alloy. *Journal of materials processing technology*, *191*(1), 77-81.

[16] Afrin, N., Chen, D. L., Cao, X., & Jahazi, M. (2007). Strain hardening behavior of a friction stir welded magnesium alloy. *Scripta Materialia*, *57*(11), 1004-1007.

[17] Chowdhury, S. M., Chen, D. L., Bhole, S. D., & Cao, X. (2010). Tensile properties of a friction stir welded magnesium alloy: Effect of pin tool thread orientation and weld pitch. *Materials Science and Engineering: A*, *527*(21), 6064-6075.

[18] Kim, N. J. (2014). Critical Assessment 6: Magnesium sheet alloys: viable alternatives to steels?. *Materials Science and Technology*, *30*(15), 1925-1928.

[19] Sevvel, P., & Jaiganesh, V. (2014). Characterization of Mechanical Properties and Microstructural Analysis of Friction Stir Welded AZ31B Mg Alloy Thorough Optimized Process Parameters. *Procedia Engineering*, *97*, 741-751.

[20] Ugender, S., Kumar, A., & Reddy, A. S. (2014). Microstructure and mechanical properties of AZ31B magnesium alloy by friction stir welding. *Procedia Materials Science*, *6*, 1600-1609.

[21] Robson, J. D. (2015). Critical Assessment 9: Wrought magnesium alloys. *Materials Science and Technology*, *31*(3), 257-264.

[22] Singarapu, U., Adepu, K. & Arumalle S. R. (2015). Influence of tool material and rotational speed on mechanical properties of friction stir welded AZ31B magnesium alloy. *Journal of Magnesium and Alloys*.

[23] Cole, G. S., Long, S., & Osborne, R. J. (2011). *Wrought Magnesium Components for Automotive Chassis Applications* (No. 2011-01-0077). SAE Technical Paper.

[24] Babu, S. R., Pavithran, S., Nithin, M., & Parameshwaran, B. (2014). Effect of Tool Shoulder Diameter During Friction Stir Processing of AZ31B Alloy Sheets of various Thicknesses. *Procedia Engineering*, *97*, 800-809.

[25] Chai, F., Zhang, D., & Li, Y. (2015). Microstructures and tensile properties of submerged friction stir processed AZ91 magnesium alloy. *Journal of Magnesium and Alloys*, *3*(3), 203-209.

[26] Woo, W., Choo, H., Prime, M. B., Feng, Z., & Clausen, B. (2008). Microstructure, texture and residual stress in a friction-stir-processed AZ31B magnesium alloy. *Acta materialia*, *56*(8), 1701-1711.

[27] Commin, L., Dumont, M., Rotinat, R., Pierron, F., Masse, J. E., & Barrallier, L. (2012). Influence of the microstructural changes and induced residual stresses on tensile properties of wrought magnesium alloy friction stir welds. *Materials Science and Engineering: A*, *551*, 288-292.

[28] Chowdhury, S. H., Chen, D. L., Bhole, S. D., Cao, X., & Wanjara, P. (2012). Lap shear strength and fatigue life of friction stir spot welded AZ31 magnesium and 5754 aluminum alloys. *Materials Science and Engineering: A*, *556*, 500-509

[29] Liu, D., Xin, R., Zheng, X., Zhou, Z., & Liu, Q. (2013). Microstructure and mechanical properties of friction stir welded dissimilar Mg alloys of ZK60–AZ31. *Materials Science and Engineering: A*, *561*, 419-426.

[30] Kulekci, M. K. (2008). Magnesium and its alloys applications in automotive industry. *The International Journal of Advanced Manufacturing Technology*, *39*(9-10), 851-865.

[31] Friedrich, H. E., & Mordike, B. L. (2006). *Magnesium technology* (Vol. 788). Berlin [etc.]: Springer.

[32] Commin, L., Dumont, M., Masse, J. E., & Barrallier, L. (2009). Friction stir welding of AZ31 magnesium alloy rolled sheets: influence of processing parameters. *Acta materialia*, *57*(2), 326-334.

[33] Naik, B. S., Chen, D. L., Cao, X., & Wanjara, P. (2014). Texture development in a friction stir lap-welded AZ31B magnesium alloy. *Metallurgical and Materials Transactions A*, *45*(10), 4333-4349.