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Friction Stir Welding Of Magnesium Alloys - A Review

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Abstract— *The modern technologies are gaining more and more importance in almost every field and Manufacturing industry not an exception. More and more research has been going on related to welding techniques [1]. Friction stir welding is one of the latest welding techniques that have found a major part in automotive sector. Magnesium alloy one of the major raw material used in these industries due to its light weight, good thermal conductivity, excellent specific strength and stiffness, exceptional dimensional stability, high damping capacity, and high recycle ability [2]. Magnesium alloys can be divided into cast magnesium alloys and wrought magnesium ones in terms of difference in processing [3]. Main commercial magnesium alloys include the AZ series (Mg-Al-Zl), AM series (Mg-Al-Mn), AE series (Mg-Al-RE), EZ series (Mg-RE-Zn), ZK series (Mg-Zn—Zr), and WE series (Mg-RE-Zr)[4]. It is thi property which entices automobile manufacturers to replace denser materials, not only steels, cast irons and copper base alloys but even aluminium alloys by magnesium based alloys. Statistically, more than 90% of the magnesium alloy structural components are produced by casting process, especially by various die-casting processes. .Magnesium has a density two-thirds that of aluminium and only slightly higher than of fibre-reinforced plastics and possesses excellent mechanical and physical properties. Compared to using alternative materials, using Mg alloys results in a 22% to 70% weight reduction. Recent developments in coating and alloying of Mg improved the creep and corrosion resistance properties of magnesium alloys for elevated temperatures and corrosive environments. The introduction of this paper gives a detailed review about Friction Stir Welding of Mg alloys. This review work may be a ready reference for subsequent researchers.*
Keywords—Friction Stir Welding, Magnesium alloys.

I. INTRODUCTION

Recently, in many industrial fields much attention has been focused on Magnesium alloys because of various unique properties. Magnesium and its alloys are becoming widely recognized as playing an increasingly important role in automotive, aircraft, and aerospace industries. As the desire to further utilize lightweight magnesium alloys in various industrial applications grows, different aspects of magnesium research must be intensified in order to improve properties of magnesium alloys and enhance their chances of being selected by the product designers. The present paper will give a general review of the recent main research of magnesium alloys.

Friction Stir Welding (FSW) is an innovative solid state welding technique which 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 [2]. 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 friction stir welding a rotating pin emerging from a cylindrical shoulder is plunged between two edges of sheets to be joined and moved forward along the joint line. The material is heated by friction between the rotating shoulder and the work piece surface and simultaneously stirred by the profiled pin leaving a solid phase bond between the two pieces to be joined.

II. MAGNESIUM AND ITS ALLOYS

Magnesium alloys are broadly divided into

- Mg-Al-base alloys
- Zr-containing alloys
- Cast Mg alloys
- Die casting

Mordike and Ebert [5] have dicussed the advantages and disadvantages of Magnesium and its alloys which include:

- High specific strength (related to low density);
- Good castability (particularly for high pressure die casting);
- Can be turned/milled at high speed;
- Good weldability;

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- Improved corrosion resistance (using high purity magnesium);
- Better mechanical properties;
- Resistant to againg;
- Better electrical and thermal conductivity;
- Recyclable

Magnesium and its alloys are not without their disadvantages [5] includes

- Low elastic modulus
- Limited cold workability and toughness;
- Limited strength and creep resistance at elevated temperature;
- High shrinkage on solidification;
- High chemical reactivity with associated poor corrosion resistance;
- Inadequate wear resistance.

Main commercial magnesium alloys include the AZ series (Mg-Al-Zl), AM series (Mg-Al-Mn), AE series (Mg-Al-RE), EZ series (Mg-RE-Zn), ZK series (Mg-Zn—Zr), and WE series (Mg-RE-Zr). Table 1&2 shows some of the magnesium alloys mechanical properties and Physical properties.

Table.1: Mechanical Properties of Magnesium Alloys at Room Temperature

Property	Unit	AZ91	AM60	AM50	AM20	AS41	AS21	AE42
Ultimate Tensile Strength	Mpa	240	225	210	190	215	175	230
Yield Strength	Mpa	160	130	125	90	140	110	145
Elongation	%	3	8	10	12	6	9	10
Elastic Modulus	Gpa	45	45	45	45	45	45	45
Brinell Hardness		70	65	60	45	60	55	60
Impact Strength	J	6	17	18	18	4	5	5

Table.2: Physical Properties of Magnesium Alloys

Property	Unit	Temp(F)	AZ91	AM60	AM50	AM20	AS41	AS21	AE42
Density	g/cu cm	68	1.81	1.8	1.77	1.75	1.77	1.76	1.79
Linear Thermal Expansion Co-efficient	µm/m	68-212	26	26	26	26	26.1	26.1	26.1
Specific Heat	Kj/kg k	68	1.02	1.02	1.02	1.02	1.02	1.02	1.02
Thermal Conductivity	W/km	68	51	61	65	94	68	84	84
Electrical Conductivity	MS/m	68	6.6	nm	9.1	13.1	nm	10.8	11.7

2.1 Welding Parameters: The welding parameters are key players during every welding technique and FSW is no exception. Proper selection of welding parameters influences the final weld quality and resulting microstrucutre. In FSW the parameters chosen are

Tool rotational speed: An increase in the tool rotational speed and decrease in tool traval speed will cause a hotter weld.

Welding speed: The grain arrangement will change abruptly with increasing welding speed.

Tilting angle: Tilting angle may be kept constant or variable

Pin Profiles: Pin profiles play important role in FSW

Axial down force: The down force will ensure the generation of frictional heat to soften the material.

2.2 Welding tool: Welding tool design is critical in FSW processes; tool material should possess high hardness at elevated temperatures and should maintain that hardness till the end of the process. Weld quality and tool wear are two important considerations in the selection of tool material, the properties of which may affect the weld quality by influencing heat generation and dissipation.H13 tool steel is usually used for FSW. The various types of pin profiles used are tapered, cylindrical, cylindrical threaded, conical etc. The shape of pin profile greatly influences the final weld microstructure, grain refinement etc. This review mainly focuses on FSW of Mg alloys. The period of review was from 2010-2016. The influence of various objectives on final weld quality,

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microstructure analysis, Optimization techniques used etc are focused in this paper.

Previous studies on FSW of Mg alloys:

Objective	**Work piece Material**	**Tool material**	**Year/Author**	**Remarks**
Effect of process parameters on weld quality	ZM21 Mg alloy 25mm thickness	H13	2010/K.L.Harikrishna Et al	GS increased at the HAZ and NZ with respect to thickness
To calculate influence of welding speed on Tensile properties	AZ61 Mg alloy 300x300x6mm	High carbon steel	2011/a.Razal Rose et al	WS hasmaximum influence on microstructure and Tensile properties
Microstructures and properties testing on joints	AZ31B-H24 Mg alloyof 2mm thickness	Tool steel	2012/S.H Chowdhury et al	Texture weakened due to TRS and decreasing of WS
To study the process parameters on weld quality	AZ61A Mg alloy 300x150x6mm	High carbon steel	2013/S.Rajkumar et al	Max tensile strength obtained
Effect on welding parameters on welded joints		High carbon high chromium steel	2014/ Inderjeetsingh et al	Proper grain refinment
Mechanical properties through optimized process parameters	AZ31B Mg alloy 150x50x5mm	High speed steel	2014/Jaiganesh et al	Defect free joints are obtained
Characterization of microstructure & mechanical properties	AZ31B-H24 Mg alloy 1200x500x2mm	H13 tool steel	2014/B.S Naik et al	Grain coarsening was seen in SZ,TMAZ,HAZ
Microstructure & mechanical properties testing	AZ31 Mg alloy 300x100x2mm	H13 tool steel	2014/Yong Zhao et al	Uniformn distributions of grains
Influence of rotational speed on microstructure & mechanical properties	AZ31B Mg alloy 240x120x5mm	High speed steel tool	2014/A.Ugender et al	TRS has significance influence on grain refinement
Parameter-Optimization using Taguchi method	AM20 Mg alloy 100x100x4mm	H13 tool steel	2015/Prakash kumar et al	SD & PD were the most influencing parameters
Influence of Process parameters	AZ80A wrought alloy 150x50x5mm	M35 HSS tool	2015/Sevel and Jaiganesh	Good quality welds were obtained
Residual stress and Tensile properties	AZ31B-H24 Mg alloy 1200x500x2mm	H13 tool steel	2015/Bhukya et al	Higher WS and lower TRS lead to higher failure
Microstructure evolution during FSW	AZ31 Mg alloy of 4mm thickness	Tool steel	2015/S.Minorva et al	Lowering of grain boundary.

GZ: Grain Size, NZ: Nugget Zone, TRS: Tool Rotational Speed, HAZ: Heat Affected Zone
TMAZ: Thermo Mechanically Affected Zone, WS: Welding Speed, SD: Shoulder Diameter
PD: Pin Diameter, SZ: Stir Zone

III. CONCLUSION

The current status of main research fields in magnesium alloys is presented. The research efforts are yielding positive results and it is expected that various industries will being to apply some of the newly developed magnesium alloys and processes to new products. In this paper FSW of various types of Mg alloy grades has been considered. Among various grades of Mg alloy AZ31 grade has been used in major.

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