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EFFECT OF REINFORCED PARTICULATES (SiC and Al_2O_3) ON FRICTION STIR WELDED JOINT OF MAGNESIUM ALLOY AZ91

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ABSTRACT:

This work was focused on to study the changes in behavior of Magnesium alloy friction stir welded joint by inserted additional 'SiC' and 'Al_2O_3' Reinforced particles with an appropriate volume fraction at weld interface by providing gap provision and interlocking between two metal plates to form a metal matrix composite at weld interface which were enhanced the mechanical properties. Used a friction stir welding apparatus to stir reinforced particles into two base materials and a friction stir weld was formed. Moreover, metallurgical bonding was achieved between the reinforced particles and the base materials. Quality assessment included the visual inspection, temperature measurement in welding region, Tensile strength testing, impact strength testing, and hardness measurements. Research aimed at the recognition of FSW abilities to weld Magnesium alloys by inserting reinforced particles at weld interface and influence of reinforced particles and interlocking on weld properties. The research results have revealed that magnesium alloy AZ91 were weldable with reinforced particles using FSW process. Further it is concluded that Adding of reinforcement particles at weld interface increasing the mechanical properties such as hardness, yield strength, and small reduction in ultimate strength than base metal. But at the same time elongation decreases and the behavior of Material changes from ductile to brittle.

Keywords: Magnesium Alloy AZ91, Reinforced Particles Sic, Al_2O_3, Interlocking, Mechanical Properties.

1. Introduction:

Magnesium has the density as small as 1.7 g/cm^3, which is the lowest among all the structural metals or alloys [1]. Such an outstanding property makes it extremely important for manufacturing light weight structures. However, magnesium is very soft. It is necessary to add either alloy elements or reinforcements to make it stronger. Recently, friction stir processing particle reinforced magnesium has been studied [2, 3, 4, 5–8]. In the work performed by Lee et al. [8], Nano scale SiO_2 with the dimension of 20 nm was added into an AZ61 magnesium alloy.

Magnesium alloys are unique structural materials having high specific strength and capability to absorb shock and vibration energy [9]. cast Mg alloy AZ91D containing 9 % Al(mass) and 1 %Zn(mass)has been most widely used in engine building industries and aircraft due to its low density, high castability and good mechanical properties. However, the main drawback of Mg alloy as a structural material is its high chemical activity leading in many cases to a low weldingcharacteristics and corrosion resistance. This means that in the conventional fusion welding process there should be such a treatment procedure before or after welding of Mg alloys. Mg alloys are currently welded by arc techniques, such as gas metal arc welding and gas tungsten arc welding. Whilst reasonable welding speeds can be achieved, problems can be experienced with high welding residual stresses and changes in metallurgical structure due to the melting and re solidification. High purity shielding gases are required to prevent a weld contamination. Mg alloys can also be electron beam welded, or laser but melt zone problems and porosity in the weld zone can occur [9-11] due to these reasons the conventional fusion welding methods were rarely used in the welding of Mg alloys. Thus, it is, very desirable that new joining technologies should be developed and made accessible for industrial usage. Friction Stir Welding (FSW) seems to be such a reasonable welding process at this point. FSW was developed and patented in the early 1990s and then has rapidly become an important industrial joining process [12]

This new technique has resulted in low distortion and high joint strength compared to other techniques. Moreover FSW is capable of joining all kinds of Al alloys. But very little is known about the weldability of Mg alloys [13, 14] since recent studies have nearly restricted to that of Al alloys. There have to be more knowledge about the weldability of Mg alloys. The objectives of this work are to develop an understanding of the micro structural development of friction stir welds on an AZ91Mg alloy, and to determine the weldability of magnesium alloys by adding reinforced particulates at weld interface, effect of reinforced particles on the mechanical properties of FSW of Magnesium alloy AZ91.

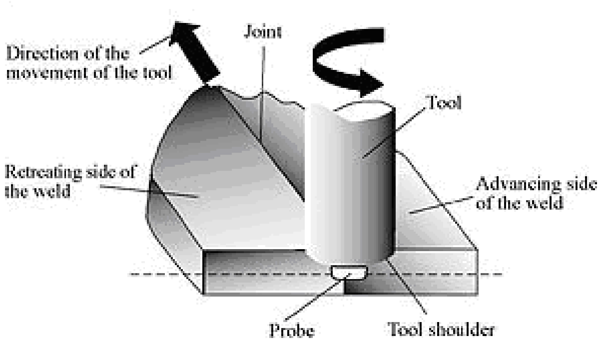

Fig.1: Friction Stir Welding Process

Frictions stir welding is a solid-state joining technique, The main principle of FSW involves inserting a non-consumable rotating tool with a specially designed pin and shoulder into the butting edges of plates or sheets to be joined and traversed along the line of joint (Fig. 1). The tool provides two primary functions i.e heating of work piece, and movement of material to produce the joint. The heating is accomplished by friction between the tool and the work piece and plastic deformation of work piece. 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' [9-10]. Because of various geometrical features of the tool, the material movement around the pin can be quite complex [11]. During FSW process, the material undergoes intense plastic deformation at elevated temperature, resulting in generation of fine and equiaxed recrystallized grains [12-15].

The metal-coated reinforcement particles with an appropriate volume fraction are inserted into the gap between two metal plates or two metal matrix composite (MMC) plates.The reinforcement particles are stirred into the metal plates or the MMC plates by friction stir welding (FSW) to form a butt weld metal containing reinforcement particles. Or the metal-coated reinforcement particles deposited on the surface of the metal plates or the MMC plates and then are stirred into base material of the metal plates. The metal-coated reinforcement particles are uniformly distributed in a weld metal by such stirring, the coated metal layer on the surface of the reinforcement particles form an alloy with metallurgical bonding [16].

The addition of micron-scale reinforcement particles such as Al_2O_3 or SiC a particulate into aluminum alloy matrix to form reinforced MMC has been developed for more than thirty years. After particulate reinforcement, the mechanical properties of metal matrix alloy are improved effectively so that MMC has been applied to components requiring higher strength and light weight. The most common way of adding Al_2O_3 or Sic reinforcement particles is smelting. The particles are added into a liquid-phase material during the smelting process and are further stirred during the solidification process. Other than this process, there is hardly further technical information regarding adding particles into aluminum alloy for producing MMC [16].

In this present research reinforced particulates were added at weld interface by providing provision between two metal pieces to be weld. Investigated the effect of adding reinforced particulates at weld interface by studying mechanical properties of weld and microstructures.

2. Experimental Procedure:

The material used for butt joints were 8mm thickness magnesium alloy AZ91 plate. The plates were machined to required dimensions of 100 mm X 75 mm X 8 mm. The plates were machined to get the desired geometry which was considered in figure1 and 2 to fill the reinforced particles and to provide interlocking between two pieces to be weld. Before welding the plates were cleaned chemically by ethanol to remove surface contaminations. Commercially available Al_2O_3 powder and Sic with sizes 99.9% pure was used. Separately The Al_2O_3 powder and SiC powder was filled into a groove of dimensions 3 mm (width) 3 mm (depth) 100 mm length machined on the plate of 8-mm thickness before the FSW was carried out. Reinforced particles such as silicon carbide and aluminium oxide were filled where the provision was provided to fill the reinforced particulates. H13 tool steel was used for welding AZ91 magnesium alloy having the shoulder diameter of 36mm. The tool had a pin height of 7.6 mm and a 12 mm pin diameter and taper profile. The vertical milling machine of HMT FM-2 and capacity of 10 H.P, 3000 R.P.M has been used to perform the welding process.The work pieces clamped to the fixture and the tool is placed in the tool holder by using collect of 25mm diameter. The initial welding has been done on the work pieces of Magnesium alloy AZ91 and Sic reinforced particulates at rotational speed of 1400 R.P.M and feed of 25mm/min and Second Welding has been done on the work pieces of Magnesium alloy AZ91 and Al_2O_3 at rotational speed of 1400 R.P.M and feed of 25mm/min. Temperatures were measured at different weld zones at different timings and at different spaces along the length of weld surface by using Infrared Thermometer of accuracy plus or minus 2^0C and with response time 500 ms

After welding, the specimens were prepared by using wire EDM to test the mechanical properties such as Ultimate tensile strength, yield strength, impact strength and hardness at different weld zones.

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2.1 Input Data:-

Material: Magnesium Alloy AZ91
Thickness 8 mm
Length 100 mm each
Width 75 mm each
Rotational Speed 1400 R.P.M
Feed 25 mm/min

Reinforced Particulates:
Silicon Carbide (SiC)
Aluminum Oxide (Al_2O_3)
Experiment-1 Magnesium Alloy AZ91+ Silicon Carbide (SiC)

Experiment-2 Magnesium Alloy AZ91+ Aluminum Oxide (Al_2O_3)

2.2 Friction stir welding tool:

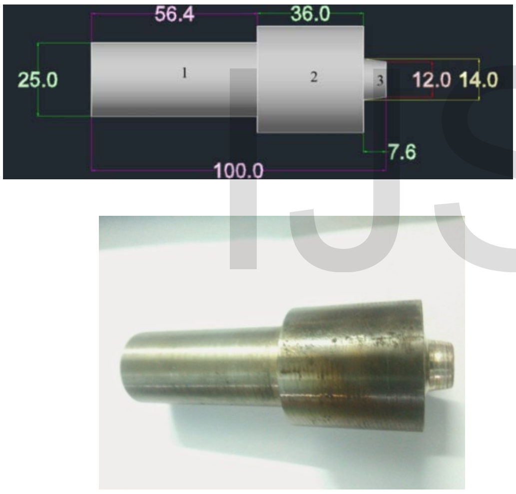

Fig.2: Friction Stir Welded tool
1-Tool Shank 2- Tool Shoulder 3- Tool Pin

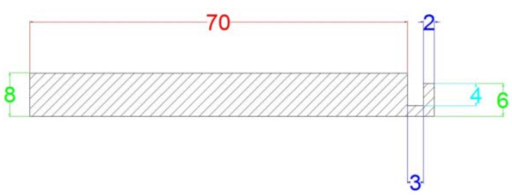

Fig.3: Work piece Geometry-1(Male)

Fig.4: Work piece Geometry-2(Female)

Element	Al	Zn	Mn	Cu	Si	Fe	Ni	Mg
Weight (%)	9.14	0.86	0.30	0.09	0.13	0.01	0.01	Remainder

Table 1: Chemical Composition of Base Metal AZ91

Mg Alloy AZ91 Properties	UTS (MPA)	YS (MPA)	% Elongation	HV
	195	98	5.08	85

Table 2: Mechanical Properties of Base Metal Mg alloy AZ91

Fig.5: FSW Joint of AZ91 with Sic

Fig.6: FSW Joint of AZ91 with Al_2O_3

Fig.7: Tensile specimen of FSW AZ91 with SiC Reinforced

Fig.8: Tensile specimen of FSW AZ91 with Al_2O_3 Reinforced

3. Results and discussions:

The following results were obtained after conducting the Mechanical tests on friction stir welded joint of magnesium alloy AZ91 with additional SiC reinforced particulates at weld interface.

3.1 Output Data of Experiment-1

Ultimate Tensile strength	183.3 MPA
Yield Strength	146.64 MPA
Percentage of Elongation	3.81%
Final Gauge Length	51.907 mm
Load at Yield	14 KN
Load at Break	17.6 KN
Load at Peak	17.6 KN
Elongation at Yield	10.98 mm
Elongation at peak	13.58 mm

The Ultimate Tensile strength, Yield strength, and percentage of elongation of base metal AZ91 is 195 Mpa, 98 Mpa and 5.08% respectively. When the Magnesium alloy AZ91 was welded by Friction stir welding at 1400 R.P.M Rotational speed and 25 mm/min feed and adding additional Reinforcement particulatessuch as Silicon Carbide (Sic) at weld zone by 22.5% volume, The Mechanical properties were obtained as, Ultimate Tensile strength 183.3 Mpa, Yield Strength 136.260 Mpa, Percentage of Elongation 3.81%. By observing above results, the Ultimate tensile strength and Percentage of Elongation of Welded joint was decreased 6% and 25% respectively than base metal, but yield strength of welded joint was increased than base metal because due to adding of reinforced particulates such as Sic at weld portion. These Sic particles were dislocated in base metal hence failure of Specimen occurs at low strain and high stress because Siliconcarbide was composed of tetrahedral of carbon and silicon atoms with strong bonds in the crystal lattice. This produces a very hard and strong material. Due to adding Sic particulates, it withstands more loads before plastic deformation. Hence the stress strain diagram shows a steeper curve with rapid formation of successive yield points due to quick diffusion and dislocations effects. Due to adding Sic particulates, hardness and impact strength of welded specimen was increased than base metal and increases brittleness than base metal.

The following results were obtained when Al_2O_3 Powder was used as additional reinforced particulates at weld interface.

3.2 Output Data of Experiment-2

Ultimate Tensile strength	174.6 MPA
Yield Strength	136.26 MPA
Percentage of Elongation	4.02%
Final Gauge Length	52.01 mm
Load at Yield	13.08 KN
Load at Break	14.99 KN
Load at Peak	16.77 KN
Elongation at Yield	24.65 mm
Elongation at peak	27.27 mm

When the Aluminum Oxide (Al_2O_3) Powder was used as additional Reinforcementparticulates at weld zone by 22.5 % volume. The Mechanical properties were recorded as, Ultimate Tensile strength 174.689 Mpa, Yield Strength 146.64 Mpa, Percentage of Elongation 4.02 %. By observing above results, the Ultimate tensile strength and Percentage of Elongation of Welded joint was decreased by 10.4% and 20.8% respectively than base metal, but yield strength of welded joint was increased than base metal because due to adding of reinforced particulates such as Al_2O_3 at weld portion. These Al_2O_3 particles were dislocated in base metal hence failure of Specimen occurs at low strain and high stress.Aluminium oxide was from family of ceramics which provide enhanced mechanical properties. Due to adding

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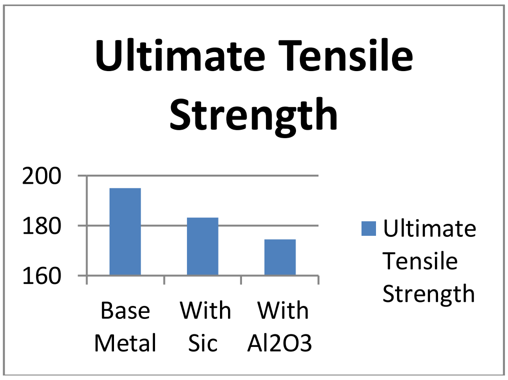
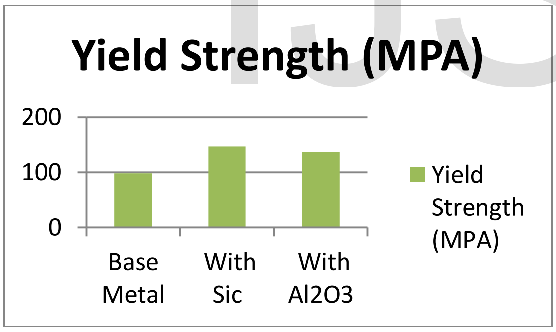
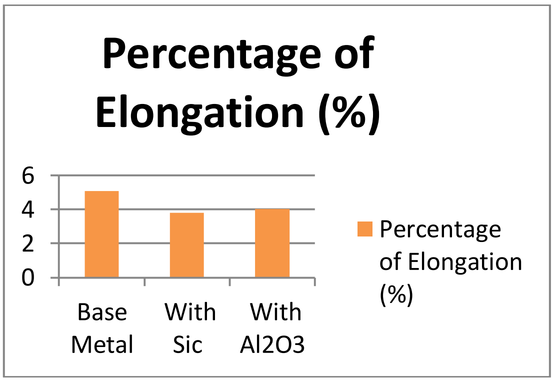
Al_2O_3 particulates, it withstands more loads before plastic deformation. Hence the stress strain diagram shows a steeper curve with rapid formation of successive yield points due to quick diffusion and dislocations effects. Due to adding Al_2O_3Particulates, hardness and impact strength of welded specimen was increased thanbase metal and increases brittleness thanbase metal.



Graph 1: Effect of Reinforced particulates on UTS



Graph 2: Effect of Reinforced particulates on Y.S

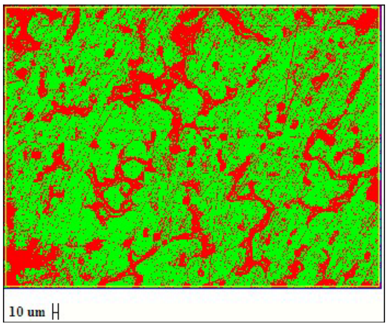


Graph 3: Effect of Reinforced particulates on % Of Elongation

Experimental results of friction stir welded joint of AZ91 with silicon carbide reinforced particles were compared with results of FSW join of AZ91 with Aluminium oxide reinforced particles, the weld joint with Sic reinforced particles obtained more Mechanical properties such as Ultimate tensile strength, Yield strength and hardness over weld joint with Al_2O_3 reinforced particles because Sic particles having yield strength was 10,000Mpa more harder than Al_2O_3 which yield strength was 5000 Mpa. But Percentage of elongation was reduced in FSW joint of AZ91 with Sic reinforced particles over weld joint with Al_2O_3 reinforced particles. This was due to more brittle nature of Sic over Al_2O_3 reinforced particles. So the FSW joint which was made with Sic Reinforced particulates were more brittle over FSW joint which was made with Al_2O_3 reinforced particles.

Due to adding of reinforced particulate at weld zone the hardness of weld was improved and it was varied from 90 HV to 110 HV in the stir zone and it was varied from 85-90 in the Heat affected zone.

3.3 Micro Structure Analysis:



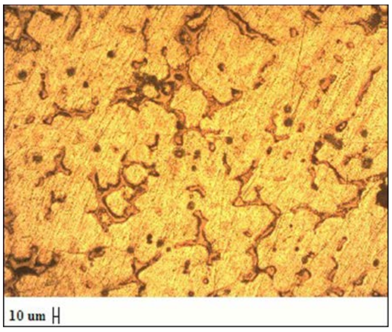
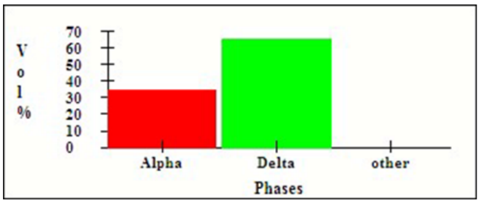


Fig.9: Micro structure of Base metal AZ91 (10X)



Graph 4: Phases of Base Metal AZ91

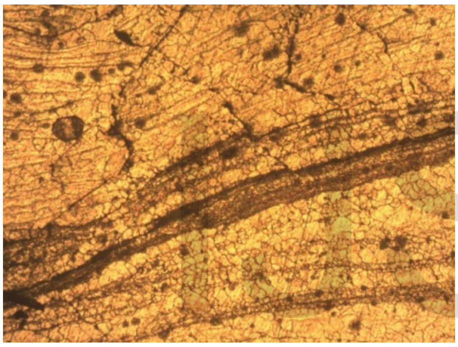


Fig.10: Microstructure at Stir Zone (10X)

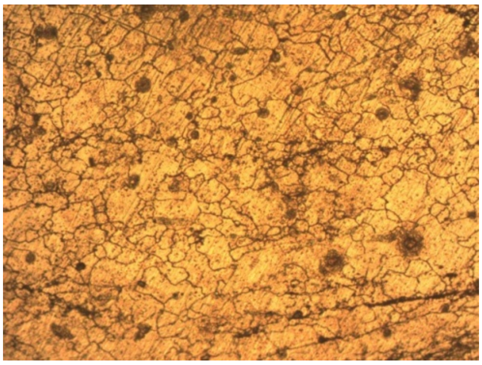


Fig.11: Microstructure at TMAZone (10X)

GrainSize analysis :Results Summary

Fields measured	1
Analysed Area	.2376(sq mm)
Standard used	ASTM E 112

ASTM Grain size#	8.5
Intercepts	331
Mean Int.length(um)	17.00558
Std dev.	.
95% CI	.
%RA	.

Table 4: Grain Size Analysis

Magnesium alloy AZ91 consist of Two Phases i.e Alpha and Delta Phases and its percentages are 34.57 and 65.43 respectively. It was observed that the grain size was refined and reformed in the stir Zone and TMAZ compared to base metal. Reinforced Particles such as Sic and Al_2O_3 were mixed and combined perfectly in the weld zone with base metal.

4. Conclusion:

Mechanical Properties of friction stir welded joint of Magnesium alloy AZ91 was enhanced due to adding reinforced particulates such as Silicon carbide and Aluminium oxide at weld portion. By adding Reinforced particulates at weld portion, yield strength was increased than base metal. Effect of Sic reinforced particulates were more on the improvement of mechanical properties than Aluminium oxide. However adding of reinforced particulates can be change to enhance mechanical properties according to required applications and required mechanical properties.

5. REFERENCES:

1. Patent US7905383B1, “Manufacturing Method of Metal Matrix Composite using Friction stir Welding; March15, 2011.

2. C.I Chang, X.H. Du and J.C. Huang; Producing Nanograined micro structure in Mg-Al-Zn alloy by Two step friction stir processing ; Science Direct; Script Materialia 59 (2008); P.P 356-359.

3. Chang, C.I.; Lee, C.J.; Huang, J.C. Relationship between grain size and Zener - Holloman parameter during friction stir processing in AZ31 Mg alloys. Scr. Mater. 2004, 51, P.P 509–514.

4. Chang, C.I.; Du, X.H.; Huang, J.C. Achieving ultrafine grain size in Mg-Al-Zn alloy by friction stir processing. Scr. Mater. 2007, 57, P.P 209–212.

5. P.J. Hsieh, C.J. Lee, J.C. Huang, "Mg based Nano composites Fabricated by Friction Stir Processing", Scripta Materialia, Volume 54, 2006, P.P 1415-1420.

6. Morisada, Y.; Fujii, H.; Nagaoka, T.; Fukusumi, M. MWCNTs/AZ31 surface composites fabricated by friction stir processing. Material Science Engineering-A., 2006, 419, 344–348.

7. Lee, W.B.; Lee, C.Y.; Kim, M.K.; Yoon, J.I.; Kim, Y.J.; Yoen, Y.M.; Jung, S.B. Microstructure and wear property of friction stir welded AZ91 Mg/SiC particle reinforced composite. Composite Science Technology. 2006, 66, 1513–1520.

8. Suhuddin, U.F.H.R.; Mironov, S.; Sato, Y.S.; Kokawa, H.; Lee, C.-W. Grain structure evolution during friction-stir welding of AZ31 magnesium alloy. ActaMater. 2009, 57, 5406–5418.

9. S. Lee, S. H. Lee and D. H. Kim: Metal. Mater. Tran. **29A** (1998) 1221–1235.

10. A. Munitz, C. Cotler, A. Stern and G. Kohn: Material science Engineering. A, 302(2001), P.P 68–73.

11. S. A. Lockyer and M. J. Russell: Proceedings of Third International Symposium on Friction Stir Welding, ed. by P.Treadgill, (The Welding Institute, 2001).

12. Nakata, S. Inoki, Y. Nagano, T.Hashimoto, S. Jorgan and M. Ushio:J. of Jpn. Inst. of Light Met. 51 (2001) 528–533.

13. W. B. Lee, Y. M. Yeon, Shae. K. Kim, Y. J. Kim and S. B. Jung: Magnesium Technology 2002, ed. by H. I. Kaplan, (TMS (The Mineral, Metal and Materials Society), 2002) pp. 309–312.

14. Y. S. Sato, H. Kokawa, M. Enomoto and S. Jorgan: Metall. Mater.Trans. A 30A (1999) 2429 – 2437.