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Tool Optimization of Friction Stir Processing of ZE41A Rare Earth Magnesium Alloys

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Abstract: ***In this study, the effect of tool pin geometry on the microstructure and mechanical properties friction stir processed (FSP) specimens of ZE41 magnesium alloy were investigated. The four different tool pin profiles such as triangular, square, taper cylindrical and threaded taper cylindrical with process parameters of 1120 RPM, 25mm/min and tool tilt angle 10 were considered. Microstructures of the processed specimens are examined using scanning electron microscope (SEM) and the wear behavior was observed using pin on disk tribometer. The consequences show that the triangular tool pin produced defect free joints, finest microstructure, higher mechanical and wear properties.***

Index Terms: **ZE41 mg alloy, FSP, Tool profiles, SEM.**

I. INTRODUCTION

The requirement of light weight material structures as compared to aluminum has turned the research on magnesium alloys [1]. ZE41 is a rare-earth Mg alloys has creep resistance and high strength. ZE41 is a Mg-Zn-RE based alloy, is used for aircraft gear box, particularly in military helicopters, which are exposed to corrosive environments [2]. FSP is a processing technique for improving surface properties that uses non consumable tool and invented in 1991 at The Welding Institute (TWI). Y. N. Zhang et al [3] found that the friction stir processing is developed from FS welding and is used for metal matrix composites (mmc). During friction stir processing, the rotating tool is enforced in to the material and travelled linearly along specimen under processing conditions, so that a high degree of plastic distortion is conveyed to the specimen by stirring of the rotating tool pin improves the mechanical properties due to grain refinement in FSP [4-5].

In this investigation, the single pass friction stir processing [6-7] was performed on ZE41 mg rare earth alloys of 6 mm thick plates using different tool pin profiles. The mechanical and metallurgical behaviour is deliberated in this study by varying tool pin profiles maintaining constant tool speed and feed. The experiments were steered on ZE41 alloy in vertical axis milling machine. Microstructures (MS) All the processed specimens are tested by SEM and MS are analysed. Tensile strength and hardness for each processed specimen were measured by Universal Testing Machine and Vickers hardness test respectively. The results of tensile strength and hardness for FSP of ZE41 alloys obtained at various tool pin profiles were analyzed. Improved mechanical properties and wear resistance were observed for triangular tool pin profile. The addition of Silicon Carbide to Ze41 significantly improved the mechanical properties and wear resistance [8]. In specific, the alloys comprising Zn and Rare-earths such as Ze41, castoff in this exertion have moderate strength and creep resistance combined with good cast ability [9]. Although the corrosion resistance of ZE41 is poor, due to its moderate cost it is preferred for certain applications [9] and as it retains decent mechanical resistance, though it demonstrations deprived superficial possessions [10].

II. EXPERIMENTAL PROCEDURE

In this study, Ze41 mg rare earth alloys with chemical composition is shown in table 1 was used as a base metal and silicon carbide particles were used as strengthening. The mechanical properties of base material are shown in TABLE 2. The size of the Mg ZE41 rare earth alloy plates used in this study were 100mm X 100mm and 6 mm thickness as shown in Fig.1.

Fig 1 Representation of composite fabrication by FSP

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Table 1 Standard chemical-composition of specimen

Alloy	Element	Zirconium (Zr)	Zn	Rare earth	Remaining
ZE41	%by weight	0.3	4.3	1.8	Magnesium

Table 2 : Mechanical Properties

Alloy	Yield strength	Ultimate Tensile Strength	% Elongation	Hardness
ZE41 Magnesium alloy	1.34	193	5	60HV

Friction stir processing tool pins produce frictional heating to processing surfaces. The process has been done in vertical milling machine with the non-consumable H13 hardened tools [11] of square, triangular, taper cylindrical and taper cylindrical threaded pin profiles were used in this study as exposed in Fig 2. The mechanical properties of tool material are shown in Table3. The process parameters used were tool rotational-speed 1120 RPM, tool travel speed 25mm/min and tool tilt angle 1 degree. The surface of base material and the handled samples were metallo-graphically polished using different graded emery sheets followed by polishing utilizing diamond paste and etched with acetone. The microstructure of the base-material and treated samples was inspected using scanning electron microscopy (SEM). Vickers hardness was stately in the stir zone (SZ) using DVMHM model OMN Tech MVH Auto and it was associated with the micro structural changes.

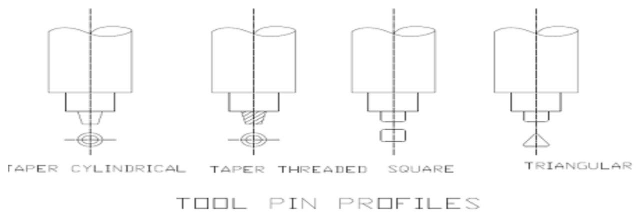

Fig 2 : various tool pin profiles for friction stir processing

Table 3: Mechanical & Physical properties of H13 tool-steel

Tensile Strength	Yield strength	Hard-ness	% Elon-gation	Dens-ity	Elastic Modulus
1995 MPa	1600 MPa	548 HV	9	7.756 g/cm^3	185-210 GPa

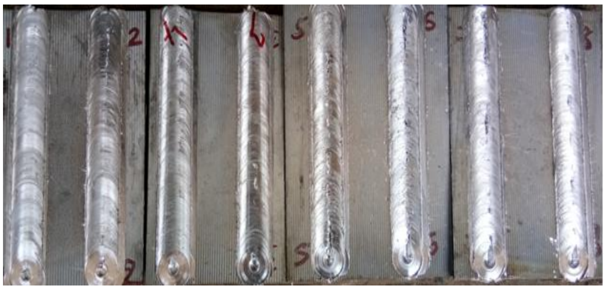

Fig 3. ZE41 Processed specimens using four tool pin profiles

When the tool rotational-speed is lesser than 1100 rpm, the flaw was perceived due to inadequate heat generation and metal filling and when the tool rotational-speed is higher than 1100 rpm, due to excess heat cohort the tunnel defect was observed. It was observed that when the traverse speed is lower than 25mm/min, the pin holes due to extreme heat cohort and when the traverse speed is greater than 40 mm/min, an inadequate flow of material was observed. The fault free surface was observed for the tool tilt-angle of 1 degree. Based on the experimental values, the process parameters are fixed as 1120 RPM, 25mm/min traverse speed and 1 degree tool tilt angle for processing of ZE41magnesium rare earth alloys.

III. RESULTS AND DISCUSSION

3.1. Effect of tool profile on mechanical properties

Hardness:

The Vickers Hardness Number (VHN) of friction stir processed specimens of ZE41 Mg alloy of various tool pin profiles at constant tool speed and tool feed are tabulated in Table 4 and represented in Fig. 3. The load 100 grams and 10s dwell time were considered during the micro hardness test.

Table :4 Tool Pin Vs Hardness

Sl.No	Tool pin profile	Hardness
1	Triangle	110.33
2	Taper cylindrical threaded	92.8
3	Square	90.63
4	Taper cylindrical	68.17

From the resulted table 4, it is identified that the hardness value for triangular tool pin-profile is well when related with the results obtained from other tool pin profiles. Whereas, for the taper cylindrical threaded and square tool pin profile values achieved were close with one and other when compared with triangular and taper cylindrical tool pin profiles. The results obtained for the hardness value of taper cylindrical tool pin profile is far low when comparing with triangular tool pin profile, that was noticed from Fig.3.

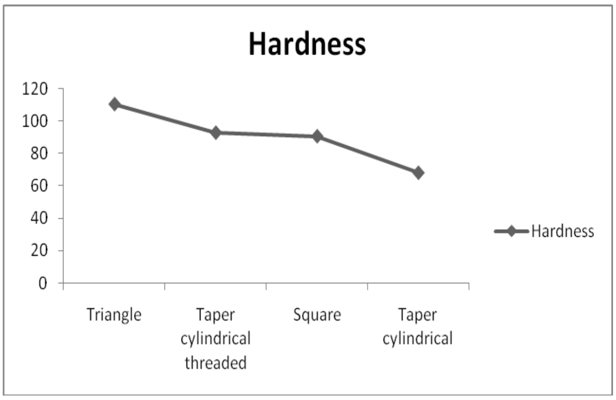

Fig 3. ZE41 Mg alloy (1120RPM, 40 mm/min)

Tensile properties:

The results of FSP samples under investigation of UTS, yield strength and calculation of elongation for triangular, taper cylindrical eased, square and taper cylindrical have been presented in a Table 5 and represented in Fig .4. From the table.5, Tensile Strength (TS) for a triangular tool pin profile was found to be more; this is purely due to the action of the tool pin profile with respect to the rotational speed of the tool. Ultimate yield strength was found to be maximum for triangular tool pin profile and again for the same tool pin profile percentage of elongation is high whereas, this property for square tool pin profile is quite low as for triangular tool pin profile.

Table: 5. Tensile strength for various tool pin profiles

S.No	Tool Pin Profile	Ultimate Tensile Strength (N/mm^2)	Ultimate Yield Strength (N/mm^2)	% Elongation
1	Triangle	155.75	129.57	4
2	Taper cylindrical threaded	137.65	116.42	3.37
3	Square	130.92	112.82	3.9
4	Taper cylindrical	129.71	109.84	3

However, the predicted properties have achieved better results for triangular tool pin profile. When it is equated with other tool pin profiles and it is found to be maximum in case of tensile and yield strengths and for the percentage of elongation, mere and near values has been resulted.

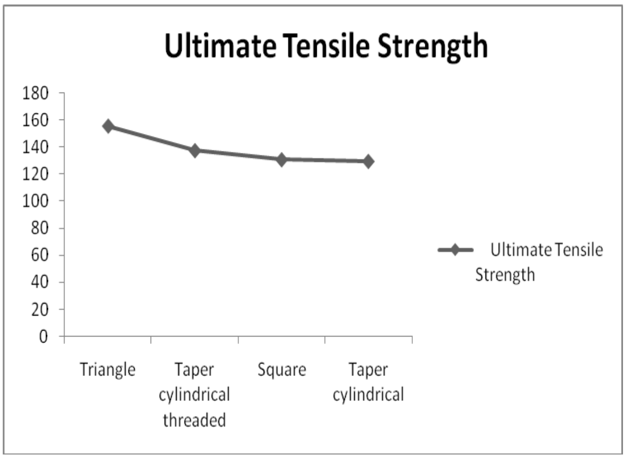

Fig. 4. Tensile strength for various tool pin profiles

Wear Analysis:

The wear behavior of the specimens were found using Pin on Disk Tribometer. The wear examination was conceded out with loads of 10N, 20N, 30N and 40N and sliding velocities 0.2, 0.3, 0.5 and 1 m/s at constant track distance of 70mm at 550 RPM. The duration of the test was 25 min and wear depth of 500µm. The wear testing contraption continuously noted the wear rate and friction factor. The weight of the samples were taken before and after the test to observe the loss of mass throughout the test. Volume loss through the wear-test was resolute from the mass-lost using the alloy density, letting decisive the wear-rate. The Archard's law is used to assess the wear mechanisms of the material under dissimilar conditions:

$$V/L = K\,W/H = KW$$

In the above equation,

V - wear volume
L - Sliding distance
V/L - wear rate
W - Applied load
H - Sample hardness
K - Archard's constant and
k - Specific wear rate

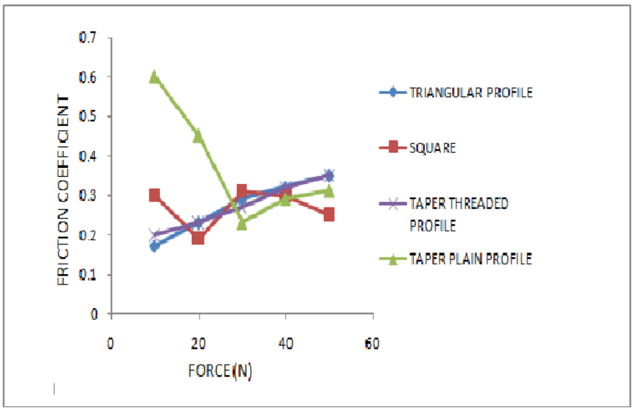

Fig. 5. Variation of normal force and friction coefficient

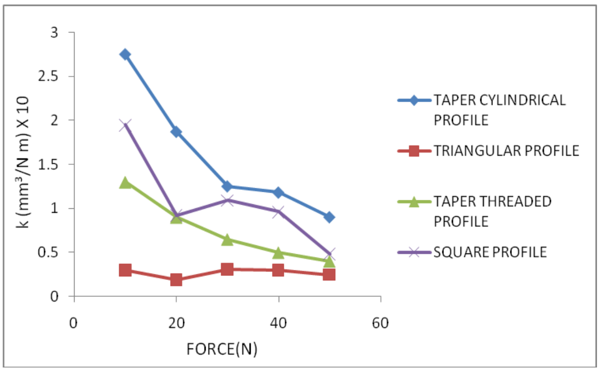

Fig .6.Variation of normal force and Specific wear rate

Taper cylindrical profile:

Rate of specific wear was high at low normal force which is due the effect of the reinforcement of the material considering in stir processing and the effect of specific wear rate (on y-axis) with respect to the normal force considered (on x-axis) assumed, one that can be seen and it is clear from the graph, shown in Fig.5. Whereas, triangular tool pin profile was headed at 10 N.

Taper plain profile:

The friction coefficient is high at low normal force, it is due to the effect FSP and the effect of ze41 material, have shown with a friction coefficient (on y-axis) with respect to the normal force considered (on x-axis), one that is clear from the graph, as shown in the Fig.6. Whereas taper threaded profile was found to be 10 N at friction coefficient against the normal force (on abscissa) However, for taper cylindrical tool pin profile, specific wear rate was found to be high comparatively other tool profiles.

Microstructure Analysis:

The micro structures of processed specimens of ZE41 alloy for various tools were observed after experimental studies. The observations are presented in Fig 5.

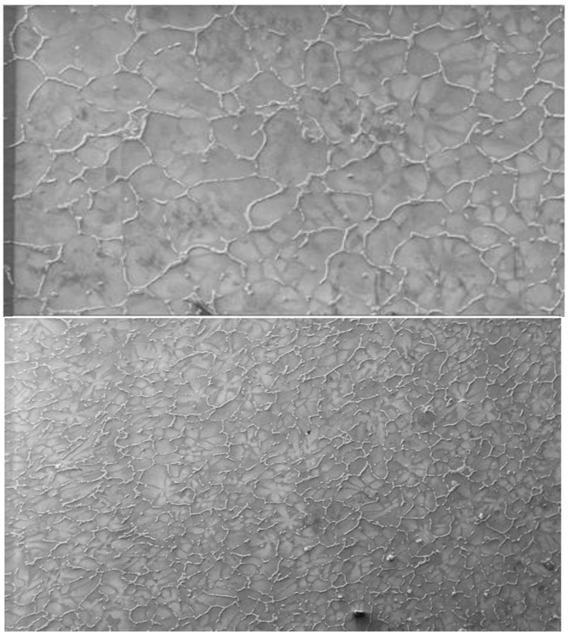

Fig 5a. Microstructure of ZE41 processed specimen with triangular tool pin profile

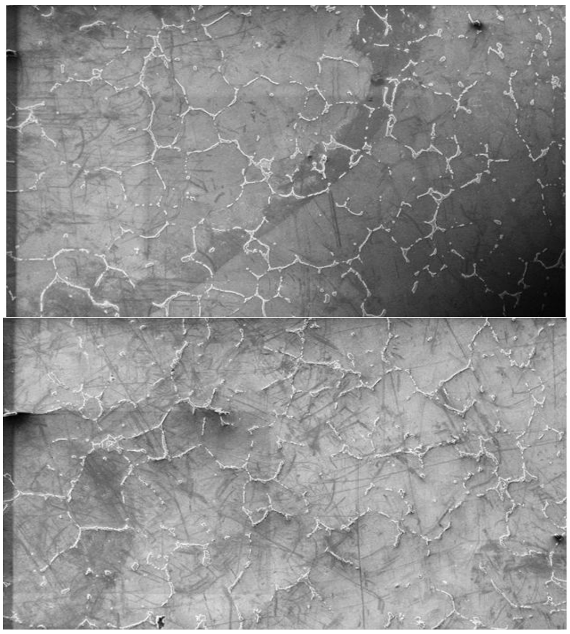

Fig 5b. Microstructure of ZE41 processed specimen with square tool pin profile

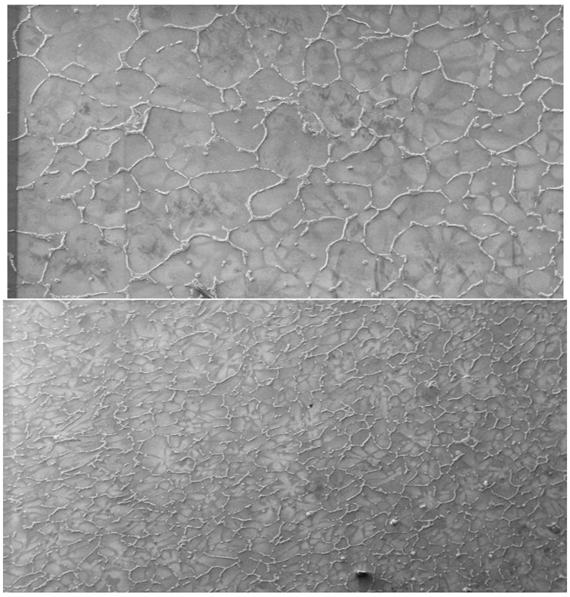

Fig 5c. Microstructure of ZE41 processed specimen with taper cylindrical tool pin-profile

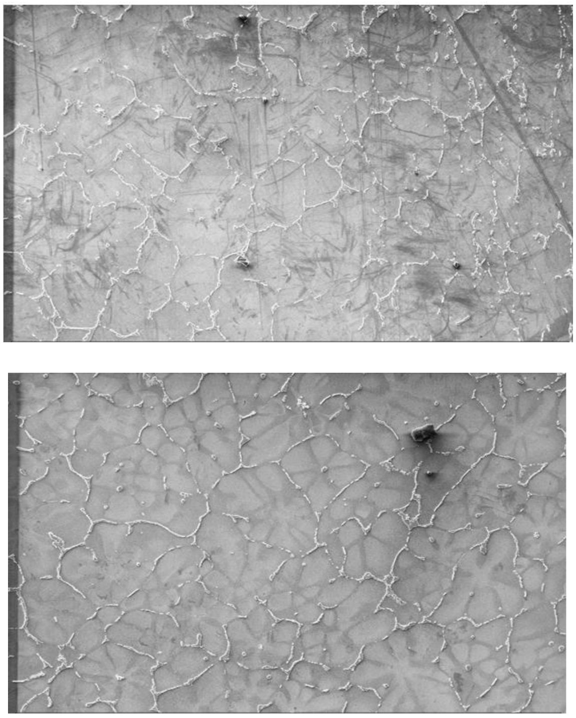

Fig 5d. Microstructure of ZE41 processed specimen with taper cylindrical threaded tool pin-profile

In this investigation, the microstructure analysis was focused on dynamically recrystallized stir/nugget zone and thermo instinctively pretentious zone. The FSP [12] region is alienated in to 3 regions namely, heat affected zone, and thermo mechanically pretentious zone and SZ. The Scanning Electron Micrographs were considered at stir zone and thermo mechanical affected zone of the advancing and retreating side are as shown in fig. It was observed that, the refinement of the grains after friction stir process [13], and additional evenness and slighter in size than base-metal was observed. The refinement process is due to the frictional heat made during the process between the tool shoulder and the base metal. It was observed that the tool pin profile also played a significant role in the refinement of grains.

The effect of friction stir processed material using triangular tool pin profile on the microstructure is shown in Fig 7. The homogeneous distribution of particles and a very fine structure was observed. This is caused by simple plastic distortion due to the tool shoulder rotation in the stir zone.

IV. CONCLUSION

The Friction stir processing technique (FSP) was successfully used to produce the surface metal matrix composites of Ze41 mg alloys. The process parameters and tool profile plays an important role on the temperature distribution and material flow pattern during processing. The hardness of the processed specimen using triangular tool pin was observed to be even and uniform in nature due to the propagation of SiC Particles in the magnesium matrix during the process with 1120 RPM tool rotational speed. The coefficient of friction was decreased for the processed specimens using triangular tool profile as related to other tool pin profiles due to increased hardness. Hence, it can be concluded that ZE41/SiC surface composites can be produced by using triangular tool pin profile with increased hardness and better wear resistance.

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