

Studies on the Influence of Squeezed Stir Casting Parameters on the Strengthening Properties of AZ91Mg Alloy

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Abstract

In this research, optimum squeeze stir casting parameters of AZ91 Mg alloy has been investigated by considering its strengthening properties. Melting temperature, squeezed pressure, and molding temperature is the key parameters that are considered for this investigation. The result of this research reveals that 750°C melting temperature, 250 MPa squeezed pressure and 250°C molding temperature represent a significant combination with its strengthening properties in AZ91Mg alloy. This combination is confirmed through the observation of proper filling of the AZ91Mg melt in the mold, the refined microstructure of AZ91 Mg, and proper heat dissipation between the mold and AZ91 Mg alloy melt.

Keywords: AZ91Mg, squeezed pressure, melting temperature, molding temperature, microstructure, strengthening properties

INTRODUCTION

Magnesium alloy-based composites are mostly used in automotive electronics, and airplane industries because of their high strength and stiffness [1]. Major challenges in the fabrication of Mg-based composites are their flammable characteristics under molten state and improper atmospheric conditions [2]. Generally, protective gases (argon) are required during fabrication to prevent the Mg-composite melt from oxidation [3].

According to the literature review, AZ91 Mg alloy is processed with different reinforcing materials (such as B₄C, Al, and Cr) to stabilize its flammability [4]. However, literature also suggests the enhancement of its corrosion resistance and oxidation properties of Mg/B₄C-based composites with the improvement of its strengthening properties under elevated temperatures through the stir casting technique [5]. Rane et al. [6] investigated the improvement of the hardness property of AZ91Mg alloy due to the extrusion-based additive manufacturing process which also enhances the toughness as well

the specific strength of AZ91Mg. Studies by Song et al. [7] have examined the up-graded microstructural properties of AZ91Mg alloy by varying heat treatment temperature conditions. The key limitation of the AZ91Mg is the limited strength at elevated temperatures which causes poor mold mixing and therefore, irregular, and fragile parts produced. The stir casting technique is one of the commonly used processes to fabricate Mg alloy components used in manufacturing industries. However, for half a decade, modified stir casting processes have evolved drastically to minimize defective parts. The addition of squeeze pressure with the stir casting process is an

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innovative and modified technique for fabricating near-net parts of AZ91Mg having good mechanical properties with the least defects. To establish the high strength of AZ91 components, suitable squeeze stir casting parameters are required. Thus, this study aims to discover a significant combination of squeeze pressure, melting temperature, and molding temperature of squeeze stir cast AZ91Mg alloys. The strengthening properties of squeezed AZ91 specimens under different squeeze stir casting parameters have been evaluated and correlated with their microstructural properties.

METHODOLOGIES

Economic AZ91Mg alloy ingots dropped into a muffle furnace with the constant flow of argon and SF₆ gas in a stir casting setup. The AZ91 Mg alloys are melted at a 750°C temperature. The AZ91 melt is continuously stirred at 450 rpm for 10 min to achieve a homogeneous distribution of AZ91 mono-composite. After continuous stirring, AZ91 melt has been released to the MS mold using the bottom pouring passage. The bottom pouring passage is a type of pre-heater having a narrow-inclined track (250°C) integrated at the bottom of the furnace to preserve the temperature of AZ91 melt. Then the compo-melt is dropped to the MS mold (cylindrical type having dimensions of 50 mm diameter and 500 mm height) and immediately squeezed pressure is enforced by the hydraulic press for 10 minutes to eliminate the residual deformities. After solidification at atmospheric temperature, fabricated specimens have been moved out from the MS mold and then slash out as per experimenting dimensions. Squeezed stir casting setup with its squeezed setup has been represented in Figure 1(a-c).



Figure 1. Sequential diagrams representing fabrication of (a) squeezed stir casting machine, (b) squeezed pressure setup before pouring, and (c) squeezed pressure setup after pouring the AZ91-melt.

However, the varying squeezed stir casting parameters considered in this study are shown in Table 1. Previously, based on numerous trial runs, different squeezed parameters of AZ91Mg alloy are selected for this research. For example, the highest mold temperature of 300°C has been considered because exceeding that temperature results in drops in the service life of the mold drastically. Although, all the other squeezed combination parameters are not drained with the selected parameters but may not result in a significant combination of tensile properties. Therefore, these trials give suitable approximation results having a significant combination of processing parameters and three squeezed stir casting trials. In the first squeeze stir casting trial run, squeezed pressures have been varied at 150 MPa, 200 MPa, and 250 MPa with the melting and molding temperature of 750°C and 250°C respectively. In the second trial run, by considering the highest hardness and tensile properties of the first trial, under the same squeezed pressure and molding temperature are preferred with varying the melting temperature of 650°C and 800°C respectively. In the last trial run, the use of best-squeezed pressure, melting temperature, and mechanical properties of the first and second trial run as

well as with the variation of molding temperature at 200°C and 300°C have been performed in the third trial.

Table 1. Squeezed stir casting parameters.

Trial run no.	Squeezed stir casting parameters	Variables
1	Squeezed pressure (MPa)	150,200,250
2	Melting temperature (°C)	650,700,750
3	Molding temperature (°C)	200, 250, 300

For the microstructural examination, 0.5 m oil-based diamond slurry has been used for polishing the AZ91 Mg specimens and their micrographs have been taken by using a scanning microscopy test (Nano-Technology Lab, Jamia Millia Islamia, Delhi). To reveal the type of microstructures, etching of AZ91Mg mono-composite has been performed by using Keller's reagent having acetic and picric acid in a distilled solution. By considering ASTM B557M-15 standards AZ91 Mg tensile specimens have been machined in a lathe machine (Shahdara Industrial Area, Delhi) for the tensile test at room temperature. Tensile AZ91 specimens are loaded on a KIPL Tensometer Software (SOM Lab, Jamia Millia Islamia, Delhi) to determine the ultimate strength of the AZ91 Mg mono-composite. However, hardness has been conducted on Rockwell hardness testing setup (Mechanics Lab, Jamia Millia Islamia, Delhi) under the load of 100 kgf considering the average of five values as the final hardness value.

RESULTS AND DISCUSSIONS

The tensile test results include the ultimate strength, yield strength, and strain percentage of AZ91 Mg specimens for all squeeze stir casting trial run as shown in Table 2, along with its Rockwell hardness test results.

Table 2. Tensile and Rockwell hardness results of squeezed stir cast AZ91Mg-specimens

	Yield strength (MPa)	Ultimate strength (MPa)	Strain (%)	Rockwell hardness (HRB)
Trial Run 1: Variable squeezed pressure, molding temperature 250°C, melting temperature 700°C Squeezed pressure (MPa)				
150	113 ± 2	175 ± 7	1.2 ± 0.2	70.7 ± 0.6
200	109 ± 5	176 ± 10	1.9 ± 0.3	71.0 ± 0.9
250	112 ± 2	192 ± 6	2.0 ± 0.0	71.8 ± 0.2
Trial Run 2: Variable melting temperature, molding temperature 250°C, squeezed pressure 250MPa Melting temperature (°C)				
650	100 ± 7	162 ± 11	1.2 ± 0.3	69.1 ± 1.1
700	112 ± 2	192 ± 6	2.0 ± 0.0	71.8 ± 0.2
750	121 ± 3	203 ± 3	2.5 ± 0.3	72.2 ± 0.4
Trial Run 3: Variable molding temperature, squeezed pressure 300 MPa, melting temperature 750°C Molding temperature (°C)				
200	110 ± 8	178 ± 12	1.4 ± 0.3	72.5 ± 0.5
250	121 ± 3	203 ± 3	2.5 ± 0.3	72.2 ± 0.4
300	109 ± 9	192 ± 12	2.3 ± 0.5	71.8 ± 0.7

It has been observed that when squeezing stir cast pressures have been varied, with the fixed melting and molding temperatures of 750°C and 250°C, the hardness and tensile properties represent peak value at 250 MPa of squeezed pressure. Figure 2(a-c) represents the microstructural results of AZ91 Mg specimens under squeezed pressures of 150 MPa, 200 MPa, and 250 MPa respectively. Microstructural results reveal that as the applied squeezed pressure increases, a decrement in dendritic spacing and short dendritic structures of AZ91 Mg mono-composites have been observed. However, the shortening of dendritic structures is due to the highest squeezed pressure of 250 MPa, and squeezed pressure eventuates the enhancement of hardness and tensile results. The rising of squeezed

pressure not only facilitates the reduction in porosity as well as results in the refined microstructure. The refined microstructure was observed because applied squeeze pressure surpasses the suitable heat transfer around the molding material and induces the refined grain structures under extensive cooling of the melt. This effect is confirmed by the transformation of the phase diagram as per Clausius-Clapeyron in Equation (1) [8]:

$$\Delta T_{freezing}/mP = T_{freezing}(V_{liquid} - V_{solid})/\Delta H_f \quad (1)$$

Where,

$T_{freezing}$: equilibrium freezing temperature,

V_{liquid} : the specific volume of liquid,

V_{solid} : the specific volume of solid,

ΔH_f : Latent heat of fusion.

The effect of squeeze pressure (P) on the freezing spot may be approximately evaluated as [9]:

$$P = P_o \exp(-\Delta H_f/RT_{freezing}) \quad (2)$$

Where, P_o , ΔH_f and R is the constant value and according to above Equation (2), $T_{freezing}$ increases with the rise of squeeze pressure after solidification.

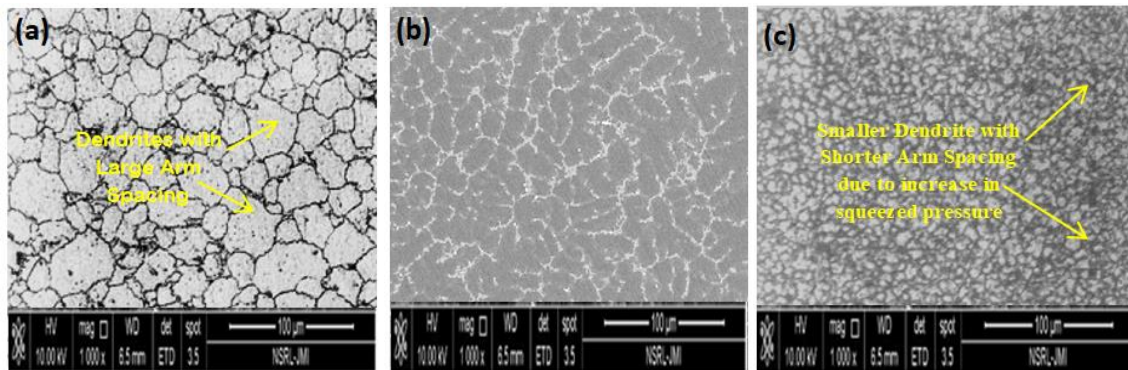


Figure 2. Microstructures of AZ91 Mg-squeezed Stir Casting Using Pressures of (a) 150 MPa, (b) 200 MPa, and (c) 250 MPa.

Another reason, under the high squeezed pressure on the AZ91-melt, the phase diagram also varies as per calculating the data values using Equations (1) and (2). The results show that the undercooling of the AZ91-melt is higher than one with a lower applied squeezed pressure of the AZ91-melt. Undercooling triggers the existing microstructural nuclei of the AZ91-melt and then initiates heterogeneous solidification. However, this solidification develops more refined microstructures under low squeezed pressure. However, under high squeezed pressure with high undercooling develops enhanced hardness and tensile properties of AZ91 Mg mono-composite.

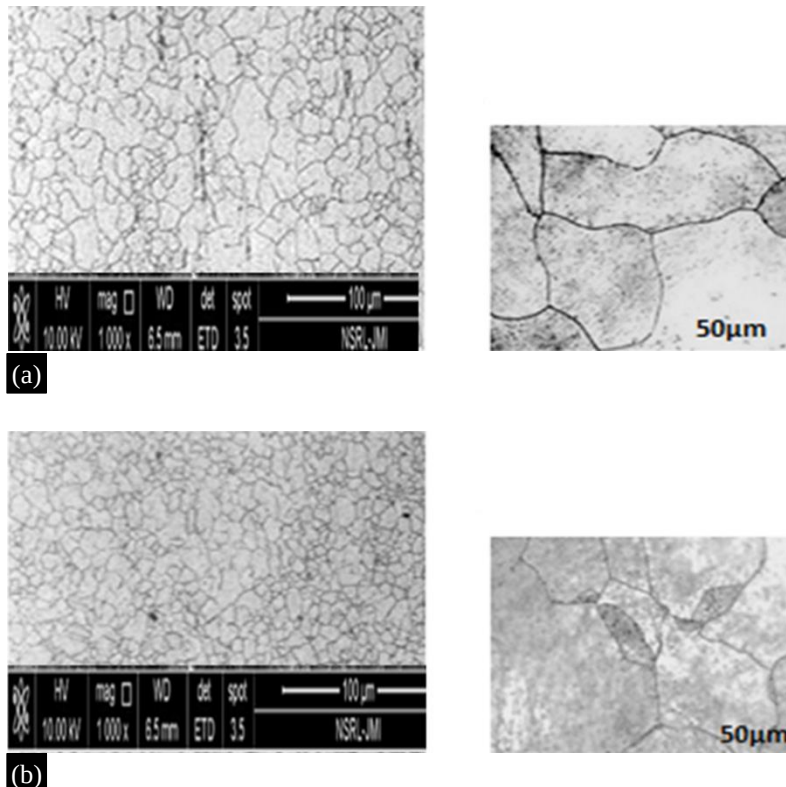
Subsequently, for trial 2, the squeeze pressure is fixed at 250 MPa with a molding temperature of 250°C. When the melting temperature has been varied, it is examined that maximum strengthening properties occur at 750°C. The dendritic structures of each AZ91 Mg squeeze cast at 650°C, 700°C, and 750°C are shown in Figure 3(a-c). These structures illustrate that at 750°C squeeze cast AZ91 fabricated specimen shows more refined microscopic images than those fabricated under lower melting temperatures. Under high magnification at 650°C melting temperature, AZ91 Mg alloy (Figure 3a) shows spiky large plate-like dendritic structures. Although, these types of spiky structures are disadvantageous to the strengthening properties of AZ91 Mg alloy. However, the dendritic

structures at 700°C and 750°C are more petite and homogeneous than those discovered at 650°C. This is due to the superheating of AZ91 Mg alloy melt because AZ91 Mg melt is heated above the liquidity line. After squeeze pressure was applied, AZ91 Mg melt started cooling naturally which causes the microstructural particles to be more refined [10]. Ocal et al. [11] proposed that refined microstructural particles are to be a kind of Mg compound having impurity elements. These elements include Mg-Al, and Mg-Zn types inform of intermetallic compounds. These microstructural particles administrate the growth of nucleation sites in the microstructure and produce a more refined and uniform microstructure of AZ91 mono-composite. As the rise in the superheating temperature of AZ91 Mg melt, the homogenous microstructure is observed as well as significant strengthening properties (yield strength and hardness) are demonstrated.

In the last trial, under 250 MPa squeezed pressure and 750°C of melting temperature, higher strengthening properties have been observed at the molding temperature of 300°C. When the molding temperature is set at 200°C, moisture is observed on the mold surface. This indicates an improper removal of moisture from the mold. The lower molding temperature restricts the proper filling; inhomogeneous coverage and premature solidification of AZ91 Mg melt are the key factors for the improper removal of moisture from the mold.

These factors lead to low mechanical properties of AZ91 Mg melt at a molding temperature of 200°C. At a molding temperature of 300°C, Figure 4 shows insignificant dendritic structures whereas in Figure 2(c) same AZ91 Mg melt represents dendritic structures that are comparatively larger at 250°C molding temperature.

The most improved strengthening properties have been observed at the molding temperature set at 250°C, with a melting temperature of 750°C and squeezed pressure of 250 MPa when compared with other varying parameters. This results in a good amalgamation of AZ91Mg-melt and leads to improved hardness and tensile properties. This proper heat dissipation shows a good amalgamation of AZ91 Mg melt and results in improved hardness and tensile properties.



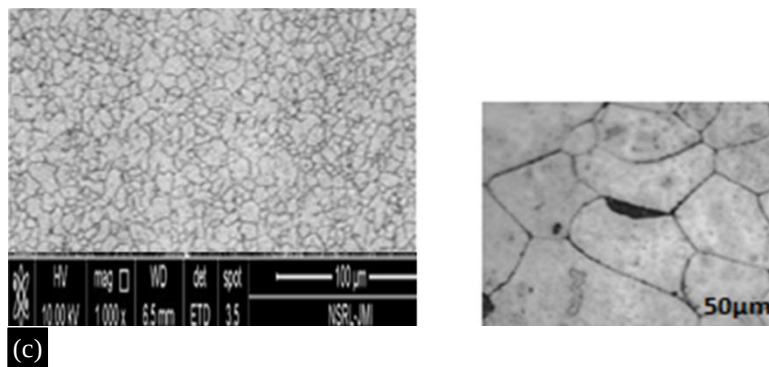


Figure 3. Dendritic structures of AZ91 Mg alloys squeeze stir cast at melting temperatures of (a) 650°C, (b) 700°C and (c) 750°C with the pressure of 250 MPa and molding temperature of 250°C (in 200 μm and 50 μm magnifications).

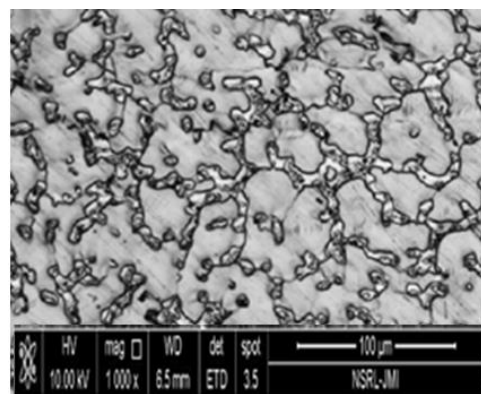


Figure 4. AZ91 Mg specimen squeeze stir cast using 300°C molding temperature.

CONCLUSIONS

The following outcomes have been withdrawn from this research work:

1. Successful research studies varying on the influence of different squeeze stir casting parameters on the strengthening properties of AZ91 Mg alloy have been carried out.
2. A significant combination of the Highest hardness and tensile properties has been obtained observed at 250 MPa squeezed pressure and the molding and melting temperature of 250°C and 750°C respectively.
3. The refined microstructure has been observed due to proper at the above-recommended squeezed stir casting parameters. These parameters depict significant optimum melting temperature and squeeze pressure to be maintained through superheating during fabrication and through undercooling after fabrication. This achieves these shall provide improved strengthening properties for AZ91 Mg alloy.

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