Evaluation of microstructure and mechanical properties of magnesium alloys by stir casting process

A Razal Rose, R Harris Samuel*, TirthMakawana*, Raj Makawana* and Somnath Pal*
Department of Mechanical Engineering, SRM Institute of Science and Technology, Chengalpattu District, Kattankulathur, Tamil Nadu, India
E-mail: tm3596@srmist.edu.in, rm5763@srmist.edu.in, harrissr@srmist.edu.in, somnath_madhusudan@srmuniv.edu.in

Abstract. Magnesium alloys are light metal for weight reduction without compromising its overall strength to weight ratio. Mg Alloys containing Zinc, Manganese and Aluminum were found to be suitable for automobile and aerospace applications and is also cheaper to produce. Aluminum improves cast ability. Stir casting is one of the most economical processes suitable for the production of metal alloys due to its simplicity. Zinc contributes towards improvement of strength at ambient temperatures. Manganese offers corrosion resistance, but has low solubility. Change in composition of an alloy could change its properties, depending on the property imparted by the metal. In this paper, the detailed characterization of magnesium alloys was analyzed and results showed that there is a significant improvement in mechanical and metallurgical properties in novel magnesium alloys.

1. Introduction
In field of engineering, there is a huge need of metals and its alloys, composites for both structural and non structural Industrial application. Some metals and alloys have high strength but are heavier and more prone to fatigue and crack propagation. This leads to increase in demand of light metals and its alloys which have high strength and also less in weight such as magnesium and aluminium. Magnesium is one of the lightest metals available for such applications and has adequate structural strength and is a potential material for reducing specific weight especially in aerospace industry [1]. Stir casting uses closed environment argon gas for the casting of magnesium otherwise in presence of air the magnesium at high temperature will be oxidised and it will create slug [2, 3]. In this experiments, we have used aluminium because it is known to improve castability and decreases porosity. We have used Zinc as the alloying material because it increases the tensile strength of the alloy and also increases the hardness of the alloy and it also improves the fluidity of the melt [4]. The most common applications are: Aircraft and missile components, Aircraft engine mounts, control hinges, fuel tanks, wings, transmission cases, engine blocks, Bicycles, Laptop hinges, Luggage, Steering wheels and columns. The pure Magnesium has limited applications because of its reactivity and corrosion in open atmosphere. But magnesium alloy and its composite has a wide application because of its superior and lightweight properties. The low cost stir casting has been used for producing lightweight materials [5]. Zinc has no influence over the corrosion potential while Al is...
known to have minor influence on corrosion behaviour of the Magnesium [6]. The managanese is added to control the corrosion of the alloy. In this investigation, to produce a magnesium aluminium AZ41.AZ71 series alloys and detailed characterization were carried out to improve the quality of the casting. The samples were tested to evaluate their mechanical properties such as hardness (Vicker’s) and tensile strength of the magnesium alloy [7]. Magnesium alloy composites overcome the de-merits of monolithic magnesium and magnesium alloys. The addition of reinforcement particle to the magnesium alloys can significantly improve the stiffness and strength at room and elevated temperature [8]. However the application of Magnesium alloys is limited due to poor creep resistance at high temperatures and low modulus. Therefore, reinforcements are needed to improve the properties of the base metal. MMCs fabricated from magnesium will provide attractive alternatives to Aluminum MMCs [9].

2. Experimental Work

2.1. Specimen Preparation

In this experiment, we used Magnesium material as the base element for alloy preparation. In addition to that Aluminium, Zinc and manganese as alloying metals were used. The bottom pouring type stir casting furnace is used which is preheated to 850°C which is the ideal temperature for melting of Magnesium. The furnace is connected to a control panel which regulates the furnace’s temperature, stirring speed of the stirrer, opening and closing of discharge valve and preheating of runner. Now the path of the melt is prepared in which the runner is kept between the discharges of the furnace and die. The runner as well as die are coated with graphite to lubricate so that the melt does not stick inside the runner or the die. Now the magnesium pieces are added in the furnace to melt it and then Aluminium, Zinc and Manganese are added in proportion given in Table 1. The table 1 shows the composition of sample 1 and sample 2

| Sample no | Zinc % | Aluminium % | Manganese % |
|-----------|--------|-------------|-------------|
| 1         | 4      | 1           | 1           |
| 2         | 7      | 1           | 1           |

Now the mixture is melted and stirred for 45 mins at 300 rpm. Figure 1 shows the construction of the stir casting furnace. After 45 mins the discharge valve is opened and the melt is poured in the die through the preheated runner placed at the furnace discharge. The figure 1 shows the arrangement of the stir casting machine.

![Figure 1. Stir Casting Machine.](image-url)
After the melt is poured in the die, it is squeezed with the help of hydraulic arrangement. Then it is let cooled until solidification. The runner is taken out and tapped continuously so that excess material is removed. Figure 2 shows the prepared specimen after the melt is casted in the die.

![Figure 2. Specimen before (left) and after (right) machining.](image)

2.2. *Optical Microstructure*

For studying the microstructure, small specimen (Diameter 50mm and length 15mm) is cut from the whole casted specimen of Mg alloy Samples. After that it is polished using the emery papers of Grit size of 600, 800, 1000, 1500, 2000. Now the disc polishing is done using diamond paste for 5 minutes. The Aluminum based etchant (92ml distilled water, 6ml Nitric acid, 2ml Hydrofluoric acid) is used for 3 seconds and then it is washed off thoroughly. Now the microstructures were taken using metallurgical microscope with magnification of 100x, 200x and 500x. Figure 3 shows Sample 1 and 2 was prepared as per the composition in the earlier table.

![Sample 1 and Sample 2](image)

*Figure 3. Photograph of Specimens.*

2.3. *Hardness Measurement*

For Hardness measurement, Vicker’s hardness equipment is used. The load for vicker’s hardness testing instrument is set at 10 kgf with diamond indenter. Table 2 shows the values of hardness corresponding to the sample 1 and sample 2.
Table 2. Hardness Values.

| Sample No. | Load (Kgf) | Hardness (VHN) |
|------------|------------|----------------|
| 1          | 10         | 62.0           |
| 2          | 10         | 59.2           |

2.4. Tensile Test
For tensile test, another specimen was created with ASME E8 standard dimension for ultimate tensile test from both of the alloys that were prepared after the casting. Figure 4 shows the ultimate tensile test machine. Figure 5 shows the specimen dimensions.

Figure 4. UTS Machine.

Figure 5. UTS Specimen Dimensions.

3. Results and Discussion

3.1. Microstructure
The microstructure was seen with the magnification of 100x, 200x and 500x of both the samples. The grain boundaries were clearly visible as the manganese is not completely melted (obviously because it has higher melting point than furnace temperature). There were two visible phases in both the samples. Figure 6 and 7 shows the microstructure of sample 1 and 2.
3.2. Tensile Test
The tensile test was performed with the help of UTS machine in Figure 4. The results obtained clearly shows that with the increase in Zinc content, there is an increase in the Ultimate tensile strength of the alloy. Sample 1 Data and results shows the graph of Stress vs strain behaviour of sample 1. Figure 8
denotes the Tensile test graph of sample 1. Figure 9 denotes the tensile test graph of sample 2. The tensile test was conducted and after the breaking of the specimen, we can see that it is brittle fracture as there is no neck formation though the strain is higher in the graphs shown the data and results section. We can also see the cracks along the length of the tensile specimens that suggests the brittle nature of the alloys.

Sample 1 Tensile test Data and Results.

![Sample 1 Tensile Test Graph](image)

**Figure 8.** Sample 1 Tensile Test Graph.
Sample 2 Tensile test data and Results.

| Input Data                        | Output Data                  |
|----------------------------------|------------------------------|
| Specimen Shape                   | : Solid Round                |
| Specimen Type                    | : Magnesium                 |
| Specimen Description             | : 2MA 711                   |
| Specimen Diameter                | : 12.56 mm                  |
| Initial G.L. For % elong         | : 84 mm                     |
| Pre Load Value                   | : 0 kN                      |
| Max. Load                        | : 200 kN                    |
| Max. Elongation                  | : 200 mm                    |
| Specimen Cross Section Area      | : 123.9 mm2                 |
| Final Sp Diameter                | : 12.25 mm                  |
| Final Gauge Length               | : 87 mm                     |
| Final Area                       | : 117.86 mm2                |

|                  |                              |
| Load At Yield    | : 12.38 kN                   |
| Elongation At Yield | : 8.750 mm                 |
| Yield Stress     | : 99.92 N/mm²                |
| Load at Peak     | : 16.580 kN                  |
| Elongation at Peak| : 10.940 mm                 |
| Tensile Strength | : 133.818 N/mm²              |
| Load At Break    | : 0.130 kN                   |
| Elongation At Break| : 11.450 mm                |
| Breaking Strength| : 1.049 N/mm²                |
| % Reduction Area | : 4.68 %                     |
| % Elongation     | : 3.57 %                     |

![Sample 2 Tensile test Graph.](image)

4. Conclusions
The magnesium alloys were successfully casted using the stir casting machine. The microstructure, hardness test and tensile test were successfully conducted for the samples. The hardness was found to be 62 and 59.2 of sample 1 and sample 2 respectively. The microstructure of both the samples showed that there is a uniform distribution of the alloying materials. There is a clearly visible grain boundaries
that divides different phases that can be further studied. The tensile strength of specimen 1 and 2 were 121.705 N/mm² and 133.808 N/mm². There is little improvement in tensile strength as compared to specimen 1 which showed that increase in zinc contents increase in strength.

5. References

[1] Zhang DF, Shi GL, Zhao XB and Qi FG 2011 Microstructure evolution and mechanical properties of Mg-x% Zn-1% Mn (x= 4, 5, 6, 7, 8, 9) wrought magnesium alloys Transactions of Nonferrous Metals Society of China 21 15-25

[2] Kumar A, Kumar S and Mukhopadhyay NK 2018 Introduction to magnesium alloy processing technology and development of low-cost stir casting process for magnesium alloy and its composites Journal of Magnesium and Alloys 6 245-54

[3] Tiancai X, Yang Y, Peng X, Song J and Pan F 2019 Overview of Advancement and Development Trend on Magnesium Alloy J. Mag. Alloys. 7 536-44

[4] Tahreen N, Zhang DF, Pan FS, Jiang XQ, Li DY and Chen DL 2018 Strengthening mechanisms in magnesium alloys containing ternary I, W and LPSO phases Journal of materials science & technology 34 1110-8

[5] Rohit S, Rose AR and Rakshat B 2017 Development of Magnesium Composite Material by the method of Stir Casting for applications in Automotive and Aerospace Industries

[6] Gavras S, Buzolin RH, Subroto T, Stark A and Tolnai D 2018 The effect of Zn content on the mechanical properties of Mg-4Nd-xZn Alloys (x= 0, 3, 5 and 8 wt.%) Materials 11 1103

[7] Dinaharan I, Vettivel SC, Balakrishnan M and Akinlabi ET 2019 Influence of processing route on microstructure and wear resistance of fly ash reinforced AZ31 magnesium matrix composites Journal of Magnesium and Alloys 7 155-65

[8] Aravindan S, Rao PV, Ponappa K 2015 Evaluation of physical and mechanical properties of AZ91D/ SiC composites by two step stir casting process Journal of Magnesium and Alloys 3 52-62

[9] AD Gupta, AR Rose and A Mishra 2017 Mechanical and microstructure characterization of magnesium composites through stir casting