



MECHANICAL BEHAVIOUR OF MAGNESIUM MATRIX HYBRID COMPOSITE REINFORCED WITH ALUMINIUM OXIDE AND TiB_2

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Abstract

In this present work an effort has been made to fabricate and study the properties of magnesium metal matrix composites. The specimens were fabricated using centrifugal casting technique. Nowadays, the growing interest in developing Magnesium (Mg) towards the development of advanced material. Although corrosion is a concern for Mg, other physical properties, such as low density and young's modulus, combined with good compatibility, lead to significant research and development in this area. Nowadays Titanium based matrix was used for automobile applications from past decade. But the effective non- infected magnesium matrix is going to be developed for the replacement of Titanium matrix due to low cost, low density, mechanical and chemical characteristics. Centrifugal casting has the advantages of being able to make uniform work pieces but the disadvantages equipment and maintenance costs are expensive. The aims of this study were to compare the tensile strength and hardness of the centrifugal casting method. The material used in this study is Mg with TiB_2 and Al_2O_3 reinforced composite. Tensile test procedure using ASTM E8 standard and hardness test procedure using ASTM-E92. The results showed that the highest tensile strength in the Mg 94% + 2% TiB_2 + 4% Al_2O_3 centrifugal casting is 82 MPa. The hardness test was carried out to find out the hardness of the cast composites using micro hardness testing machine. The hardness test and its results show that the hardness value of Mg 92% + 2% TiB_2 + 6% Al_2O_3 composite is higher than other reinforcements. Morphology of the different composition cast composites reinforced with TiB_2 and Al_2O_3 were studied in detail by optical microscopy to analyze particle distribution in the magnesium metal phase.

Keywords- Hybrid Composite, powder metallurgy, Stir casting, Optical Microscopy.

1. INTRODUCTION

Composites Are Widely Used In Aerospace, Defence And It In Automotive Industries Because Of Its Unique Properties Like High Specific Strength, Wear Resistance, High Hardness, Strength-To-Weight, Strength-To-Cost, Etc. Efforts Had Been Taken To Pioneer Hard Ceramic Particulates Like TiB_2 , Al_2O_3 And B_4C Into Magnesium Metal Matrix. Literature Study Shows That Among The Reinforcements TiB_2 Are Al_2O_3 Are Chemically Compatible With Magnesium Metal Matrix And Forms An Adequate Bond With The Metal Matrix Without Forming Inter- Metallic Phase And Has Other Benefits Such As Good Thermal Conductivity, Required Workability At Low Cost. In Many Of Today's Industries Like Aerospace, Automobiles Etc. Finding Increasing Applications Of Metal Matrix Composites Due To Their Properties. The Magnesium Alloys And Composites Have Attracted Significant Research Intention Due To Their Low Densities. The Hardness Plays A Significant Role In Selecting The Metal Matrix Composites For Using In Various Industries, Automobiles Etc. Metal Matrix Composites (Mmcs) Are The Composite Materials, With Two Ingredient Elements, One Being Metal Essentially, The Other Constituent May Be A Dissimilar Metal Or A Different Material, Such As A Ceramic Or Organic Compound. For E.G. Al_2O_3 Particle Reinforced In A Magnesium Matrix And Silicon Carbide Reinforced With The Magnesium Matrix Composites. With The Different Types Of Metal Matrix Composites, Light-Weight Mmcs Such As Magnesium (Mg) Based Composites Are Of More Interest Due To Their Potential Applications In Aerospace, Sports Equipment, And Automobile Industries. Magnesium Metal Matrix Composites Have Better Properties Such As Elastic Modulus, Hardness, Tensile Strength At Room And Elevated Temperatures And Significant Weight Savings Over Unreinforced Alloys.

In A Composite Material The Function Of The Reinforcement Is Basically One Of Enhancing The Mechanical Properties Of The Efficient Resin System. The Unlike Fibres / Particulates Used In Composites Have Various Properties And Thus Change The Properties Of The Composite In Special Ways. The Matrix Is The Continuous Phase In Which Reinforcement Is Scattered, And Due To This There Is A Lane Through The Matrix To Any Location In The Material, Which Is Not Occurs In Sandwich Structure. The Matrix Used Usually A Lighter Metal Such As Magnesium, Aluminium, Or Titanium, And Gives A Better Support For The Reinforcement In Structural Applications.

2.

MATERIALS AND PROCEDURE

2.1 Materials

The Magnesium Powder Has Been Used As Matrix Material Which Is Compatible With The Adding Reinforcement And Also Which Has Been Attained Superior Mechanical Properties. Titanium Diboride Is Taken As A Reinforcement, Which Is The More Stable With Magnesium And Also Withstands High Temperature. The Particulate State Of The Reinforcement Has Been Attaining Better Distribution In The Matrix Also To Provide Isotropic Property For The Composite. The Purchased Magnesium Powder As Shown Fig 1. The Properties of Magnesium And Titanium Diboride Were Displayed In Table 1 And Table 2. Tib2 Is Resistant To Oxidation In Air Up To 1000 °C. It Is Also Resistant To Hcl And Hf But Reacts With H2so4 And Hno3. It Is Readily Attacked By Alkalis. Hot Pressing Of Tib2 (With Small Additions Of Metallic Or Carbide Sintering Aids) Is Carried Out At 1800 - 1900 °C And Achieves Close To Theoretical Density. Pressureless Sintering Requires Higher Levels Of Sintering Aids And Sintering Temperatures In Excess Of 2000 °C.

| | |
|----------------------|-------------------------|
| Material | Magnesium |
| Phase | Solid |
| Melting point | 923 K (650 °C, 1202 °F) |
| Boiling point | Boiling point |
| Density | 1.738 g/cm ³ |
| Heat of Fusion | 8.48 kJ/mol |
| Heat of vaporization | 128 kJ/mol |

Table 2.1 Properties of Magnesium

| | |
|------------------------|-----------------------------------|
| Melting point | 2,072 °C (3,762 °F; 2,345 K) |
| Boiling point | 2,977 °C (5,391 °F; 3,250 K) |
| Hardness | 15 – 19 GPa (9 on the Mohs scale) |
| Electrical resistivity | 1012 – 1013 Ωm |
| Mechanical strength | 300 – 630 MPa |
| Compressive strength | 2,000 – 4,000 MPa |
| Thermal conductivity | 20 – 30 W/mK |
| Molecular mass | 101.96 g/mol |
| Density | 3.95 g/cm ³ |
| Appearance | 3.95 g/cm ³ |

Table 2.2 Mechanical properties of Al₂O₃

| Property | Value |
|--------------------------------------|------------|
| Density (g.cm-3) | 4.52 |
| Melting Point (°C) | 2970 |
| Modulus of Rupture (MPa) | 410 – 448 |
| Hardness (Knoop) | 1800 |
| Elastic modulus (GPa) | 510 – 575 |
| Poisson's Ratio (0) | 0.1 - 0.15 |
| Volume resistivity (ohm.cm) at 20 °C | 15x10-6 |
| Thermal conductivity (W/m.K) | 25 |

Table 2.3 Mechanical Properties of TiB2

2.2 Applications

Due to its high hardness, extreme melting point and chemical inertness, TiB2 is a candidate for a number of applications.



Figure 2.1. Mg Matrix material



Figure 2.2 Horizontal centrifugal casting set up



Figure 2.3 Stir casting machine set

Figure 2.1 shows the photograph of the Mg Matrix material, Figure 2.2 shows that Horizontal centrifugal casting set up and Figure 2.3 Stir casting machine set. The mould dimensions are shown below and it was made of mild steel. Molten metal was poured into the mould through tundish.

2.2 Microstructural Studies

Microstructural studies were carried out by using:

1. Optical microscope
2. Image analysis system

Microstructure studies were carried out at the following location:

- Near outer surface of the casting
- At middle surface of casting
- Inner section of the casting

The details of the studies are described in the following sections:

2.3 OPTICAL MICROSCOPY

Optical microscopy shows the size, shape and distribution of primary silicon, α -Al dendrites and eutectic at inner, middle and outer section of centrifugally cast cylinders.

2.4 TENSILE TEST

Tensile tests were carried out for outer section of all specimens. Effects of speed of mould rotation and pouring temperature on tensile strength of outer section of cylinders were examined. Tensile samples of 25 mm gauge length and 5 mm gauge diameter were prepared from Al-Si alloys. Samples were extracted from the central region of the castings. Tensile tests were conducted at 31 room temperature on tensometer at a cross speed of 0.5 mm/min.

2.5 HARDNESS MEASUREMENT

The hardness values of the sample were determined using the Rockwell hardness tester on "B" scale with 1/16" inch steel ball indenter along with minor load of 10 kg and major load of 100 kg. All the samples were polished before conducting the test. The thorough cleaning of the mating surface of the indenter, plunger rod and test samples were always ensuring for reproducibility of results thus obtained. The calibration of the testing machine using the standard block was carried out before every test.

2.6 SPECIMEN



Figure 2.3 Fabricated Mg Matrix Composite Specimen

Parameters for Stir Casting Machine

- 1) Stirrer -Speed while mixing: 450 RPM - Time: 5 mins,
- 2) Speed while pouring: 750 RPM
- 3) Melt Temperature: For Al: 750 C
- 4) Reinforcement Temperature: 250 C
- 5) Mould Temperature: 400 C
- 6) pouring type: bottom pouring
- 7) Centrifugal rpm-12

3. RESULTS AND DISCUSSION

3.1 HARDNESS TEST

Hardness: By Micro Hardness tester.

Load: 0.5 Kgf Dwell time: 10 seconds.

Indenter: 136 included angle inverted diamond pyramid. Unit: Vickers to be written as "H.V. @ 0.5 Kg load.

| S.No | Composition | Hardnes | | |
|------|-----------------------------|---------|--------|-------|
| | | Inner | Middle | Outer |
| 1. | Mg 96% + 2% TiB2 + 2% Al2O3 | 42 | 48 | 51 |
| 2. | Mg 94% + 2% TiB2 + 4% Al2O3 | 50 | 49 | 54 |
| 3. | Mg 92% + 2% TiB2 + 6% Al2O3 | 53 | 54 | 57 |

Table 3.1 Hardness Results for different Volume of Composites

All the samples were polished before conducting the test. The hardness was taken near the inner, middle and outer surface. At least six reading were taken from different places in inner, middle & outer section and average values of hardness are reported. The hardness test was carried out to find out the hardness of the cast composites using micro hardness method. The hardness test and its results show that the hardness value of Mg 92% + 2% TiB2 + 6% Al2O3 composite is higher than other reinforcements.

3.2 TENSILE STRENGTH TEST

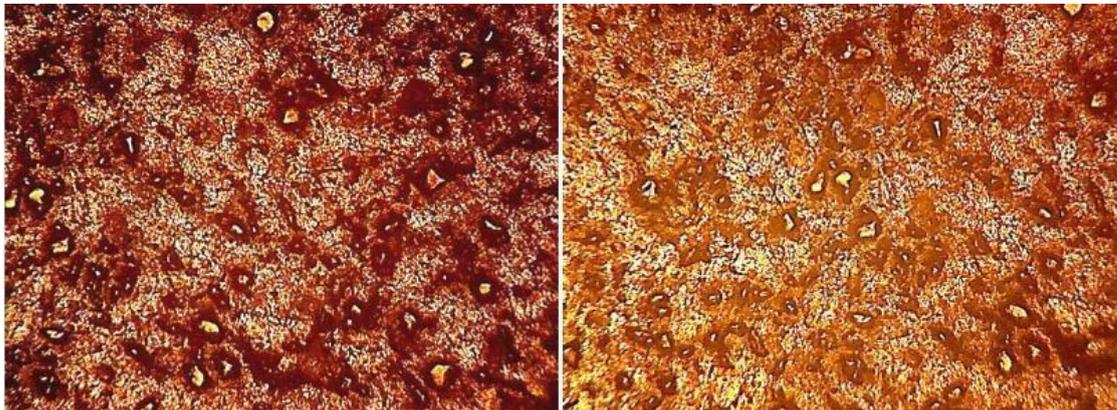
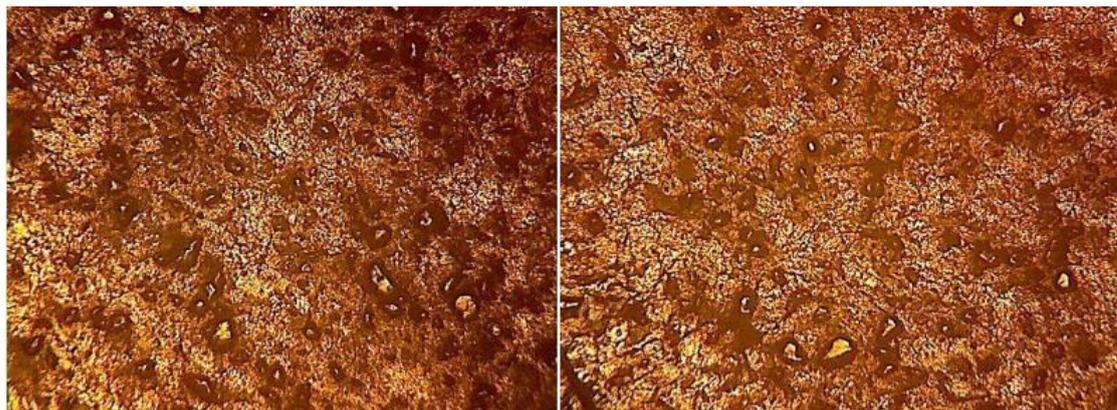
Two workpieces tensile specimens were fabricated from each hollow cylinder fabricated to the final dimensions of 100x200 mm according to Hi-Tech tensile testing machine and ASTM E8: 2016 standard, The ultimate tensile strength of horizontal centrifugal castings of Mg based Al2O3 matrix with mould rotation speed. Results show that ultimate tensile strength of horizontal centrifugal castings increase with increasing speed of mould rotation, in both, with and without melt treatment. Furthermore, vertical centrifugal castings show higher value of tensile strength compared to horizontal centrifugal castings at 1200rpm with and without melt treatment. The maximum (ultimate) tensile strength, the proof stresses and percentage elongation obtained for the hypoeutectic Mg 94% + 2% TiB2 + 4% Al2O3 is 82 MPa.

| S.No | Composition | Tensile strength (MPa) |
|------|--|------------------------|
| 1 | Mg 96% + 2% TiB ₂ + 2% Al ₂ O ₃ | 74 |
| 2 | Mg 94% + 2% TiB ₂ + 4% Al ₂ O ₃ | 82 |
| 3 | Mg 92% + 2% TiB ₂ + 6% Al ₂ O ₃ | 79 |

Table 3.2 Tensile strength Results for Composites

3.3 MICROSTRUCTURAL ANALYSIS

Microstructure of fabricated casting in horizontal centrifugal casting machine shows that the grain bond between particles. In Middle portion of casting had coarse form of aluminum oxide. The “As polished” matrix of the metal matrix composite produced by powder metallurgical matrix shows the distortion of the Composite particles. The increase in concentration of the TiB₂ and Al₂O₃ increased the concentration in the fabricated matrix. The particles are uniformly distributed in the matrix that has been fabricated matrix shows the distribution of the particles which are very distinct but in Mg 94% + 2% TiB₂ + 4% Al₂O₃ of the particles are clearly resolved in the matrix. The matrix shows no voids/pores between the grains. This indicates the effective compactness. The “As polished” matrix of the metal matrix composite produced by powder metallurgical matrix shows the distortion of the Composite particles. The micro structural analysis shows that heterogeneous structure is obtained in all the fabricated composites.

Figure 3.1 Microscopic image of Mg 96% + 2% TiB₂ + 2% Al₂O₃ compositeFigure 3.2 Microscopic image of Mg 94% + 2% TiB₂ + 4% Al₂O₃ composite

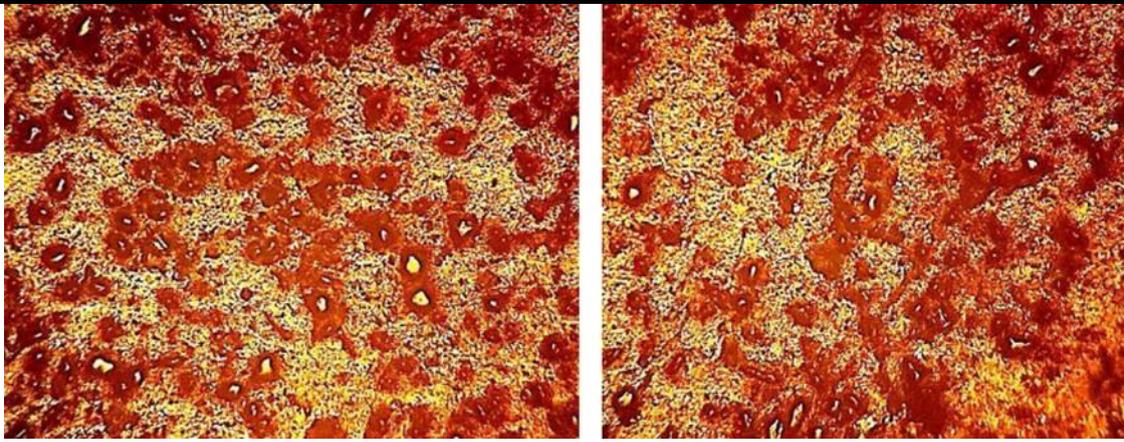


Figure 3.3 Microscopic image of Mg 92% + 2% TiB₂ + 6% Al₂O₃ composite

4. CONCLUSION

In this study, Mg matrix reinforced with TiB₂ and Al₂O₃ hybrid composites were successfully fabricated using centrifugal casting and evaluation of physical and mechanical behavior are done. The following conclusion have been drawn.

- The hardness test and its results show that the hardness value of Mg 92% + 2% TiB₂ + 6% Al₂O₃ composite is higher than other reinforcements.
- The maximum (ultimate) tensile strength, the proof stresses and percentage elongation obtained for the hypoeutectic Mg 94% + 2% TiB₂ + 4% Al₂O₃ is 82 MPa.
- Higher values of strength and hardness are observed in castings when teemed at 1200°C.
- The “As polished” matrix of the metal matrix composite produced by powder metallurgical matrix shows the distortion of the Composite particles.
- The micro structural analysis shows that heterogeneous structure is obtained in all the fabricated composites.

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