Enrichment of Energy Absorption and Mechanical Behaviour of Magnesium Alloy Composites Via Hybrid Nanofiller Reinforcement

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Abstract: This study looks at how nano sized silicon carbide and graphite particles work together to recover the mechanical, energy absorption and thermal performance of AZ31B magnesium alloy. We made hybrid nanocomposites by gravity die stir casting, keeping the SiC content the same and changing the Gr concentrations in a planned way. The results showed that adding more graphite, especially at 4 wt% made the tensile strength, energy absorption capacity, and thermal conductivity much better. The improvements are due to the fact that SiC can hold more weight and graphite can act as a solid lubricant and conductor of heat. The AZ31B/SiC/Gr composites that were made look like they may be used in car bumpers and need to be lightweight able to withstand impact, and able to dissipate heat well.

# Introduction

Magnesium alloys like AZ31B are attractive for structural applications in the automotive sector due to their lightweight nature and adequate mechanical strength. However, their relatively low ductility and energy absorption capabilities limit their widespread use in safety-critical components such as bumpers. The incorporation of hybrid reinforcements—specifically nano-sized SiC for mechanical strengthening and graphite for lubrication and thermal enhancement—provides an avenue for performance enrichment. Recent research on hybrid and graphene reinforced magnesium composites has shown good results in the areas of mechanics, heat and friction. The SiC mixed with other materials in hybrid AZ31 nanocomposites [1-5]. They observed that when the SiC was mixed in evenly the tensile strength and ductility improved. It has employed stir casting to make AZ31B composites with graphene, which had better mechanical properties and more compact microstructures. It also employed bottom-pour stir casting to make AZ31–SiC–graphite nanocomposites made the grains smaller and stronger [6-10].

They built new energy-absorbent composites that are perfect for crashworthiness laying the groundwork for the application of reinforced magnesium in car impact protection. They did a full study of nano-enhanced magnesium matrix composites, focusing on how to build interfaces and make them useful for both structural and biological uses [11-13]. Adding graphene to AZ31B by stir casting makes it stronger, harder and more resistant to corrosion and greatly improved the tribological performance of SiC/graphite-reinforced AZ31 composites by finding the optimal combinations of parameters that caused the least amount of wear. It shown that Mg–Zn–Zr alloys with very tiny amounts of graphene nanoplatelets can increase both their mechanical and thermal properties at the same time and explored explosive welding of AZ31B/Al5052 laminates with reinforcements to find the best way to protect against corrosion and keep the microstructure intact [14-20]. SiC and chopped basalt fiber were included into AZ91E alloy composites[21-23], who were able to achieve significant gains in compressive strength and wear resistance and usefulness of graphene in AZ31B was reaffirmed] through additional experiments confirmed the conclusions of previous research regarding the material's strength and compactness [24-25]. Through the use of stir casting, investigated AZ31/SiC composites and found that they exhibited enhanced hardness as well as consistent grain size distribution [26-27].

In their evaluation of the current state of the art in graphene-reinforced ceramic matrix composites (GRCMCs), highlighted the fact that these composites have the potential to be utilized in high-performance structural components. In a third instance of research replication, reiterated graphene's persistent reinforcing benefits in AZ31B over several trials. This was done in support of the findings of the previous study. In conclusion [27-30], investigated the mechanisms of strengthening in magnesium-based nanocomposites that were processed using multi-pass friction stir processing. They detailed the evolution of the microstructure as well as the eradication of defects.

This work aims to assess the impact of increasing graphite nanoparticle content (2–6 wt%) alongside a fixed 3 wt% SiC reinforcement on the composite's energy absorption and thermomechanical behavior.

# Materials and Methods

## Materials

We chose AZ31B magnesium alloy as the basis material because it has a good strength to weight ratio is easy to cast and has a low density making it good for structural and lightweight engineering uses. Two types of reinforcements were used to improve its mechanical and tribological properties. These were nano sized silicon carbide of 30 nm) and graphite of 50 nm. Gravity die stir casting was used to make the composite. In a resistance furnace the AZ31B alloy was melted at about 670 °C and for 10 minutes, mechanical stirring at 600 rpm was used to help mix the materials evenly. Before they were added the SiC and graphite particles were heated up to get rid of moisture and make them easier to moisten in the molten metal. The reinforced melt was then poured into a metal die that had already been heated up and helped to avoid thermal shock and make sure the solidification happened correctly and this technology made to spread reinforcements evenly and create a more sophisticated composite microstructure [28-30].

## Composite Formulations

**TABLE 1.** Composite Configurations Table

|  |  |
| --- | --- |
| **Sample ID** | **Composition** |
| Sample 1 | AZ31B (unreinforced) |
| Sample 2 | AZ31B + 3 wt% SiC |
| Sample 3 | AZ31B + 3 wt% SiC + 2 wt% Gr |
| Sample 4 | AZ31B + 3 wt% SiC + 4 wt% Gr |
| Sample 5 | AZ31B + 3 wt% SiC + 6 wt% Gr |

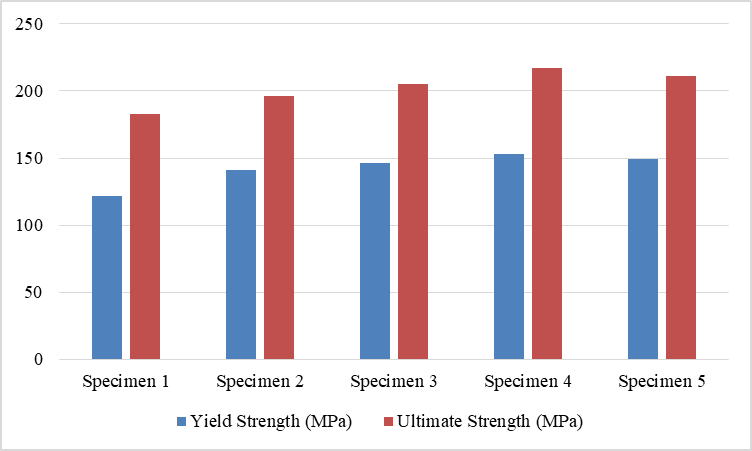
# Results and Discussion

## Stress-Strain Behaviour

The tensile properties of the AZ31B magnesium alloy were improved by the addition of graphite and nano SiC and because silicon carbide nanoparticles are extremely hard and have good load transfer capabilities made the material stiffer and stronger. By adding layers and serving as a lubricant graphite increased the flexibility [31-33]. Specimen 4 had the best overall performance out of all the samples tested. It had a yield strength of 153 MPa an ultimate tensile strength of 217 MPa and an elongation of 8% which shows that it had the best balance of strength and formability. The combination of SiC and graphite works well together making the composite perfect for uses that need both mechanical strength and flexibility when impacted [34-35].

**TABLE 2**Stress-Strain Behaviour

|  |  |  |  |
| --- | --- | --- | --- |
| Specimen | Yield Strength (MPa) | Ultimate Strength (MPa) | Elongation (%) |
| Specimen 1 | 122 | 183 | 6.4 |
| Specimen 2 | 141 | 196 | 5.7 |
| Specimen 3 | 146 | 205 | 7.1 |
| Specimen 4 | 153 | 217 | 8 |
| Specimen 5 | 149 | 211 | 7.6 |



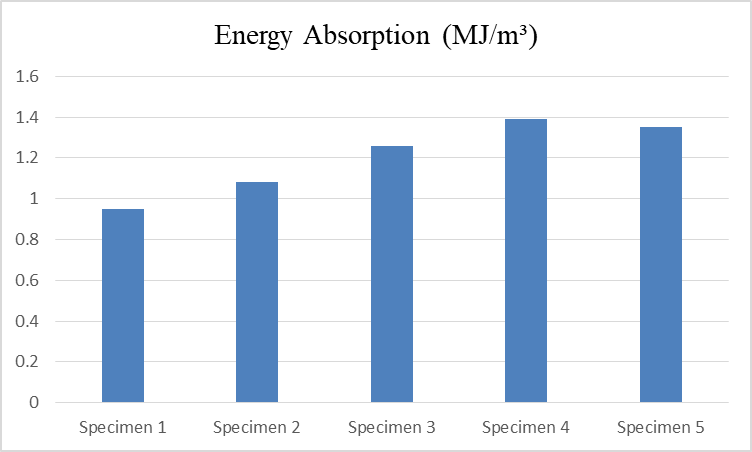
**Figure 1.**Stress-Strain Behaviour

## Energy Absorption

**TABLE 3.** Compressive Strength

|  |  |
| --- | --- |
| **Specimen** | **Energy Absorption (MJ/m³)** |
| Specimen 1 | 0.95 |
| Specimen 2 | 1.08 |
| Specimen 3 | 1.26 |
| Specimen 4 | 1.39 |
| Specimen 5 | 1.35 |

The area under the stress strain curve measures the AZ31B,SiC and Gr composite energy absorption capability steadily increased as the graphite concentration rose and this pattern is explained by the combination of the lubricating, deformable properties of graphite and the stiff SiC nanoparticles, which together improve the material resistance to and dissipation of mechanical loads. With an energy absorption of 1.39 MJ/m³, specimen 4 included 4 weight % graphite, showed the strongest resistance to impact and fracture, these results support the appropriateness for energy dissipating applications such crash resistant windows and car bumpers [36-39].

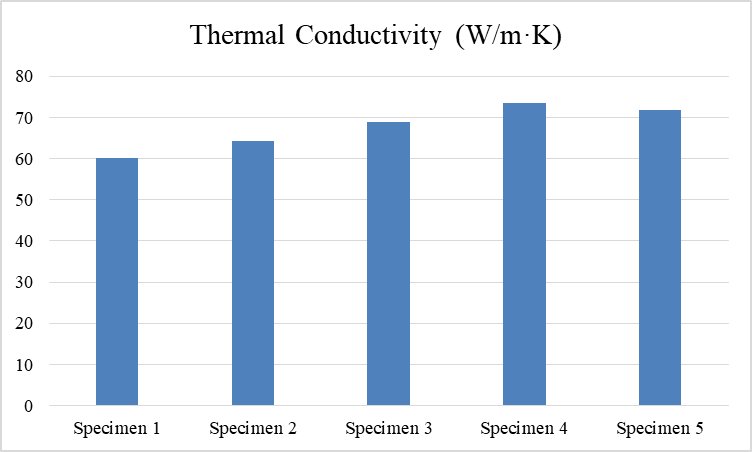


**Figure 2.** Compressive Strength

## Thermal Conductivity

**TABLE 4.** Wear Resistance

|  |  |
| --- | --- |
| Specimen | Thermal Conductivity (W/m·K) |
| Specimen 1 | 60.2 |
| Specimen 2 | 64.3 |
| Specimen 3 | 68.9 |
| Specimen 4 | 73.4 |
| Specimen 5 | 71.7 |



**Figure 3.** Wear Resistance

Because graphite naturally transfers heat well, introducing graphite nanoparticles made the AZ31B/SiC composites much better at transferring heat. As the amount of graphite in the composite matrix increased, its capacity to spread heat improved. This is especially helpful in applications where heat management is important. Specimen 4 had the best thermal conductivity at 73.4 W/m·K. It had 4 weight % graphite and the best distribution of reinforcing [40-43]. Specimen 5 (71.7 W/m·K) did reveal a little drop though which could have been caused by nanoparticle aggregation, which can get in the way of the heat conduction channel. This answer shows that 4 weight percent graphite gives the best reinforcement loading and thermal transport efficiency which makes the composite perfect for car parts that are sensitive to heat, such engine shields, bumpers and housings [44-48].

# Application in Automotive Bumper Systems

In addition to enduring high impact pressures during collisions, car bumpers also have to control heat generated by constant operation, braking or exposure to the elements. The successfully developed AZ31B/SiC/Gr hybrid nanocomposites satisfy both requirements but graphite enhanced the structure energy absorption and thermal conductivity, SiC nanoparticles increased the structure's strength and rigidity. The best balance between heat dissipation and mechanical cushioning was demonstrated by Specimen 4 (3 weight % SiC + 4 weight % Gr) which had the highest energy absorption (1.39 MJ/m³) and thermal conductivity (73.4 W/m·K) of all the designs. These properties reduce the likelihood of thermal fatigue, microstructural deterioration and impact induced deformation making this formulation perfect for lightweight, high performance bumper systems in electric and hybrid vehicles [49-50].

# Conclusion

The synergistic reinforcement effects of graphite and nano silicon carbide on the mechanical, energy absorbing and thermal performance of AZ31B magnesium alloy composites made by gravity die stir casting were effectively demonstrated in this study. For safety critical components, the hybrid technique not only increased tensile strength and ductility but also improved heat dissipation and impact resistance. The composite comprising 3 weight % SiC and 4 weight % graphite performed the most evenly across all parameters of all the tests and the viability of AZ31B/SiC/Gr composites for next generation automotive applications is confirmed by these results particularly in bumper systems where thermal efficiency and structural durability are crucial.

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