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Damping Performance of Heat-Treated Magnesium AZ91 Alloy Hybrid Composites

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Abstract

Stir casting was used to synthesize SiC and graphite particle-reinforced AZ91 magnesium matrix hybrid composites with particle sizes of 25 µm. Each reinforcement quantity was modulated from 0 to 3 weight percent in increments of 1 weight percent. Heat treatment was carried out on hybrid composite samples (solutionized and age hardened). ***Aim:*** *The aim is to find out that reinforcements and heat treatment have a significant impact on the damping capacity of the composites.* ***Methods:*** *Damping experiments on cantilever samples were performed using a Dynamic Mechanical Analyzer across a range of temperatures from ambient to 400°C.* ***Results:*** *It was evident from the results that the damping capacity of the hybrid composites was directly proportional to the reinforcement content and temperature as well.*

Major Findings: *The microstructure showed that SiCp and Grp reinforce particles are distributed uniformly and are well attached to the matrix of grains. Grain refining was aided by reinforcement particles. The inclusion of reinforcement particles enhances the composite samples' damping capacities till 250°C, after which there is a drop in damping capacities.*

Keywords: *Dynamic Mechanical Analysis, Graphite, Hybrid Composites, Heat Treatment, Magnesium Alloys, SiC*

1.0 Introduction

Magnesium-based alloys are becoming more popular because of their ability to meet the growing demand for lightweight, energy-efficient, low-cost, high-strength, and high-damping materials in several applications such as defense, space, aircraft, and automotive[1-3]. Composites with magnesium as the matrix are proving to be very encouraging options in this regard. Magnesium alloy-based composites are proving to be important candidates in several sectors in recent years[4-8]. Magnesium-based composites with graphite particles as reinforcement are a special type of superior framework composite. Although the usage of graphite particles with high inherent damping leads to an increase in the damping capabilities of magnesium alloys, it may prove to be detrimental to several mechanical aspects[9,10]. Granules are added to the composites to compensate for the mechanical characteristics. It is widely acknowledged that adding SiC particles as reinforcements (SiC/Grp/AZ91) can greatly enhance the mechanical characteristics of magnesium alloys[11-15]. As a result, magnesium-based composites supplemented with graphite and SiC particles may prove to be a better choice, with graphite particles providing damping capacity and SiC particles providing mechanical qualities. Due to the poor intrinsic damping of SiC

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particles, the inclusion of SiC particles is expected to cast a negative impact on the damping capacity of SiC/Grp/AZ91 composites. The Thermal Expansion Coefficients (CTE) of the reinforcing ceramic material and the metallic matrix are frequently considerably different in metal-matrix composites. As a result, each temperature change causes thermal stresses, which affect microstructural integrity along with mechanical and thermal properties[16,17]. Furthermore, the property evaluation of SiCp/Grp/Mg composites has rarely been carried out, and data on their damping capacity and thermal behavior remain largely unknown. In this study, stir casting was used to make the SiCp/Grp/AZ91 magnesium matrix. The goal of this study is basically to understand the role of SiC and graphite reinforcement on the damping capacity and thermal behavior of AZ91 composites. Apart from the damping capacity, the thermal properties were also examined along with the damping mechanisms that may be prevalent. Further, the impact of heat treatment on the damping capacity of the composites is also explored.

2.0 Materials and Methods

The base alloy used in the present study, AZ91, has a chemical composition which is as shown in Table 1. AZ91 has a high strength-to-weight ratio and is essential in various engineering applications such as aerospace, automotive, marine, and defense. The hybrid particle reinforcements were comprised of graphite and SiC particles with a mean size of 25µm. The alloy was made by melting 99.95% pure Mg along with commercially available zinc and aluminum ingots. Melting took place in a steel crucible, with Magrex-60 flux to prevent melting surface oxidation. The content of the reinforcing silicon carbide and graphite particles used for reinforcement was in the range of 1% to 3% in increments of 1% by weight.

The stir casting technique was used to make composites. A ceramic-coated stirrer was used to generate a vortex in the liquid matrix melt. The liquid melt was meticulously mixed, suitably degassed, and later poured into split-type preheated metallic molds[18,19]. An electric muffle furnace was used to heat treat the cast samples. The as-cast materials were later solutionized at a temperature of 415°C for 4 hours, followed by chemical aging for 16 hours at a temperature of 168°C.

Specimens for microscopic tests were processed according to the ASTM E3 standard. Nital agent was used to etch the samples, which were later observed using a Nikon optical microscope (ECLIPS 150 model).

A Dynamic Mechanical Analyzer (DMA) was used of in the present study to determine the damping efficiency. The Dynamic Mechanical Analyzer (DMA) used was of type TA Q-800, which is a very high-precision instrument used to determine the viscoelastic properties of materials. The device basically involves a non-contact direct drive motor that can generate the requisite oscillatory force. Air bearings were provided for increased precision, and a linear optical encoder with high resolution measures the displacement. The apparatus includes a bifilar wound furnace with advanced automated controls for accurate temperature regulation, which was utilized to analyze the mechanical characteristics of the samples. The samples with nominal dimensions of 60mm x 10mm x 1mm were used for assessing the damping capacity. The effect of hybrid reinforcement particles on the visco-elastic characteristics of AZ91 base alloy containing varying percentages of graphite and SiC, as well as the influence of heat treatment on damping capacity were investigated using this instrument[20].

3.0 Results and Discussion

Microstructures have a significant impact on the overall efficiency of alloys and composites. The optical morphology of a magnesium alloy-based hybrid composite material containing 3% SiC and graphite is shown in Figure 1. Optical microscope analysis of the matrix reveals a very similar distribution of the particles.

Table 1. Composition of base alloy AZ91 (weight %)

Al	Zn	Si	Mn	Fe	Cu	Ni	Mg
9.0	1.0	0.035	0.035	0.005	0.0005	0.001	Balance

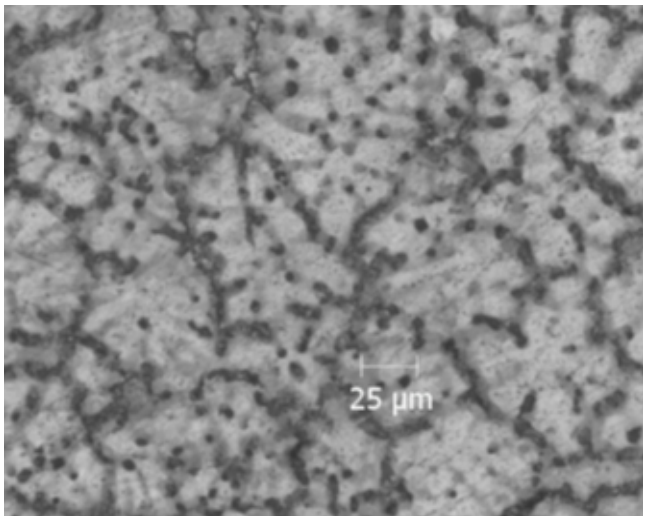


Figure 1. Optical micrograph showing the microstructure of the composite with 3 wt.%SiC and graphite particles.

responsible for matrix grain refinement. The restriction imposed by SiC particles for the growth of Mg grains during the process of solidification, as well as specific crystallographic orientations and interactions between the particle and the matrix, contribute to the reduction in grain size in a big way[20]. The combination is made up of α-matrix grains (solid solution of Al and Zn in Mg) and $Mg_{17}Al_{12}$ (β-phase) intermetallic precipitate.

The XRD pattern of the composite sample containing 3 wt. percent reinforcement is shown in Figure 3, and the β-phase composition was also observed. In addition, there was no evidence of phases associated with Si–O and Mg–O systems in the samples, thereby confirming the absence of oxide products. In all samples studied, the interfacial veracity of SiC particles with the base matrix was resolved as being quite advantageous. The presence of adequate bonding and the absence of interfacial reaction products are termed as interfacial integrity. It was verified

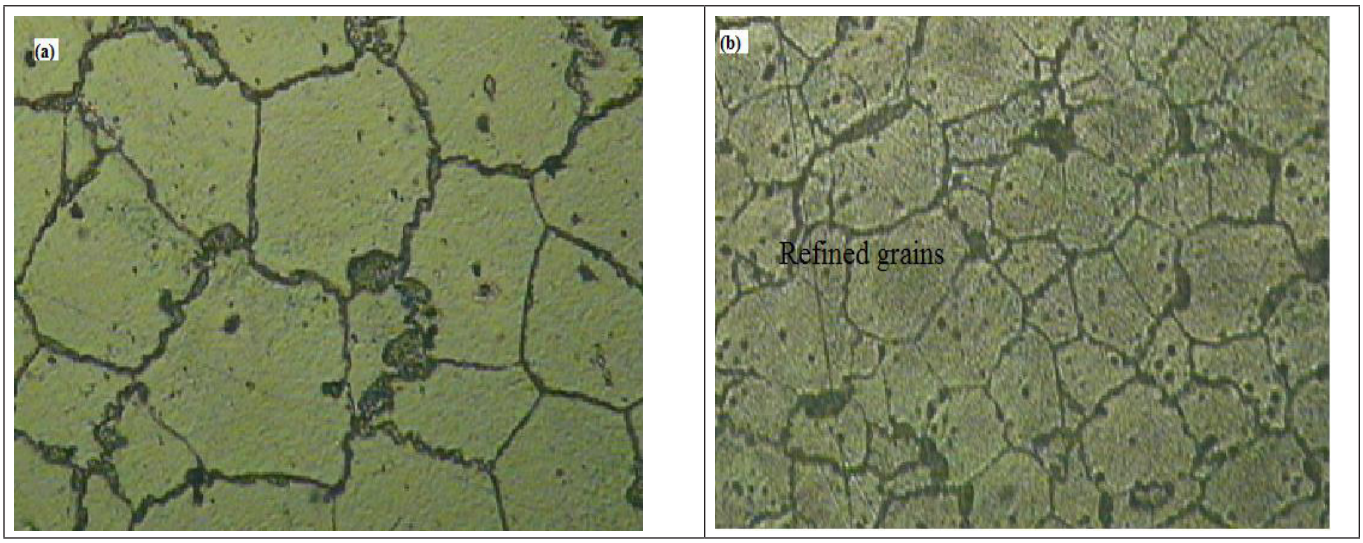


Figure 2. Etched micrographs of **(a)** as-cast alloy and **(b)** 3 wt. % reinforced as-cast composites.

There are no flaws in the reinforcement particles because they are properly linked to the matrix.

Figures 2(a) and 2(b) are the microstructures of unreinforced and reinforced samples, respectively, which clearly reveal the grains in the base alloy, and also the reinforcing particles are evenly distributed at the grain boundaries and within the primary Mg grains in the composite. The inclusion of the reinforcing particles leads to a reduction in the matrix grain size. The nucleation of the primary Mg phase, which is heterogeneous, is mainly by XRD, and similar observations have been reported elsewhere too[21].

The optical microstructure of the heat-treated (solutionized and aged) hybrid composite enhanced with 1 wt.% augmentation is shown in Figure 4. It is worth noting that substantial Mg17Al12-phase precipitation has occurred both at grain boundaries and within grains, resulting in considerable microstructural alterations.

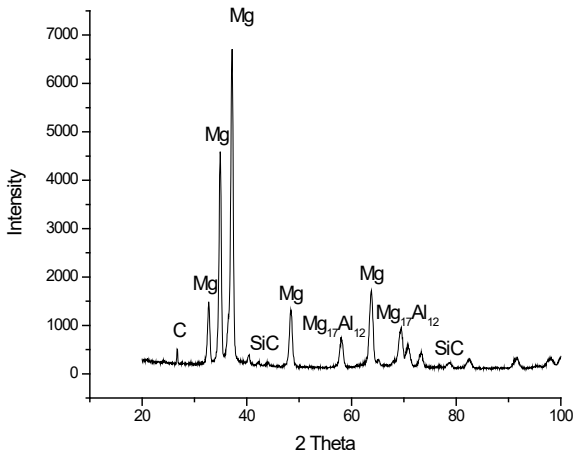


Figure 3. The XRD patterns show Mg and Mg17Al12-phase peaks, as well as graphite (carbon) and SiC in of 3 wt.% composite.

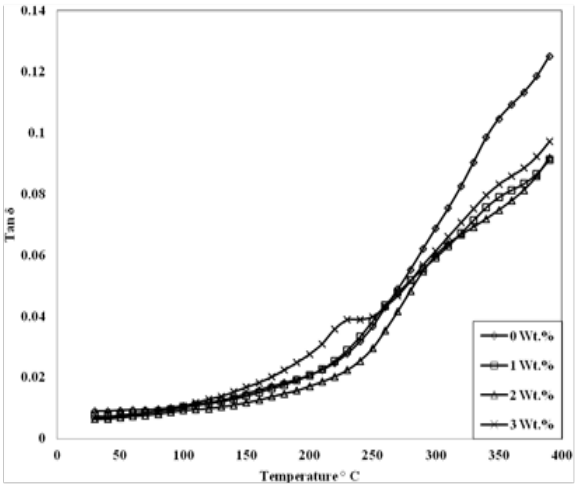


Figure 5. Graph showing temperature v/s damping capacities of matrix and composites.

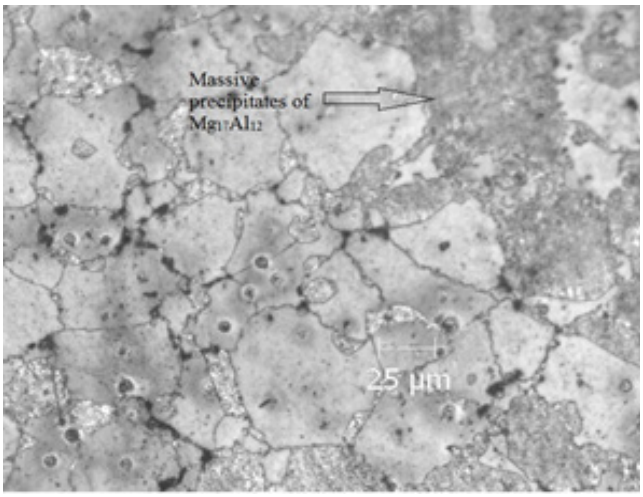


Figure 4. Optical micrograph showing the microstructure for heat treated (solutionized and aged) composite with 1 wt. % reinforcement.

The graph of temperature dependency plotted against the damping capabilities of the samples studied is as shown in Figure 5. The damping characteristics are highly independent or just slightly reliant on specified temperature below roughly 125°C, as seen in Figure 5. Between 125 and 250°C, the composite's damping capacity was found to be slightly greater than that of a cast alloy. However, above a temperature of 250°C, the damping capability of both alloys as well as composites increases dramatically. This suggests that damping capacities in the vicinity of 250°C are governed by various damping mechanisms. The intrinsic damping effect contributed by graphite and the matrix dislocation damping are anticipated to be prevalent damping processes below 250°C, while sliding of the grain boundary and the interface are most probably the dominating damping mechanisms above 250°C[22-26]. As a result of the variable graphite particle volume fraction, the damping capacity of as-cast composites is found to be higher than that of as-cast alloy in the temperature range of ambient to 250°C. Furthermore, at around 250°C, the damping characteristics of the as-cast alloy nearly match those of the as-cast SiCp/Grp/AZ91 composite. This is due to the variation in Coefficients of Thermal Expansion (CTEs) between the matrix and the reinforcements, which can lead to dislocation formation. The density of freshly formed dislocations (a rise in dislocation density) in the composite gets enhanced due to thermal stresses, which can be assessed as follows[27]:

$$\rho = \frac{Bf\Delta\alpha\Delta T}{b(1-f)t} \quad (1)$$

where f = volume fraction of reinforcements.
t = minimum size.
b = Burger's vector.
B = geometrical constant

Δα=difference in CTE of the matrix and the reinforcements

T = temperature change.

It was found that the CTE of graphite varies from -1.4 parallel to the basal plane to 23.5 (in units of 10−6/ ∘ C) and 5.0 for SiC, while the AZ91 alloy has a CTE of 30.7[21,28]. As a result, the dislocation density of the as-cast SiCp/Grp/AZ91 composite will be far greater than the base alloy. Owing to the greater dislocation density in case of as-cast SiCp/Grp/AZ91 composite compared to AZ91 alloy, the involvement of dislocation damping to the observed damping increases as the temperature rises from ambient to 250°C. This results in improved damping values in the as-cast SiCp/Grp/AZ91 composite in comparison with the AZ91 base alloy. The change of main damping mechanisms causes different variations in damping levels over 250°C. The damping capacity increases significantly as the temperature rises above 250°C, with the as-cast AZ91 alloy having the maximum rate of increase in damping capacity among the as-cast composites. Given the sliding actions of the grain boundary and the interfaces being the prevalent damping mechanisms above 250°C, their impact on damping will improve significantly owing to the viscous boundary sliding. Since there are no reinforcements, the grain boundaries of the as-cast AZ91 base alloy find it simpler to slide in comparison with the as-cast composite samples.

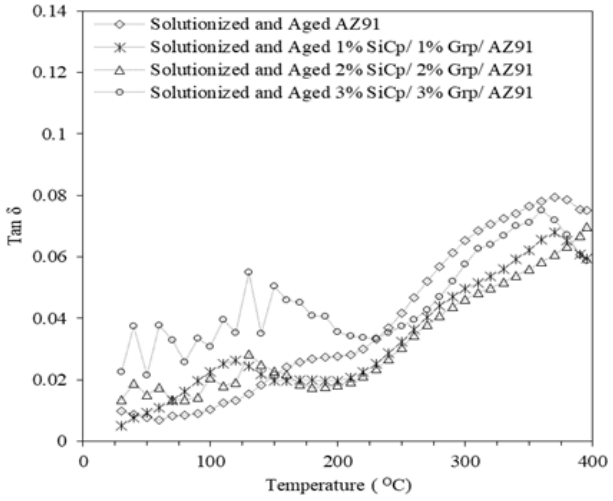


Figure 6. Graph showing temperature v/s damping capacities of matrix and composites after heat treatment.

Figure 6 shows the impact of temperature on the damping abilities of alloys and composites after heat treatment. With heat treatment, the damping capacities of hybrid composites have increased even more. However, the hybrid composites' performance was similar in both as-cast and heat-treated conditions. Changes in the microstructure are assumed to be responsible for increased damping capacities in heat-treated composites. Up to a temperature of about 250°C, secondary β-β-phase precipitation has caused a rise in damping capacity.

4.0 Conclusion

In summary, it can be stated that the stir casting technique was used to fabricate the AZ91 alloy-based hybrid composites with SiCp and Grp as reinforcement. The thermal characteristics and damping capacity were studied, and some important conclusions can be drawn as follows:

a.The microstructure showed that SiCp and Grp reinforce particles are distributed uniformly and are well attached to the matrix of grains, including a minor amount of Mg17Al12 (phase) intermetallic precipitate. Grain refining was aided by reinforcement particles.

b. The inclusion of reinforcement particles enhances the composite samples' damping capacities till 250°C, after which there is a drop in damping capacities.

c. The impact of temperature on the damping abilities of alloys and composites could be divided into two parts, with different governing damping mechanisms in each part. The temperature at the point where the two regions meet is around 250°C.

d. When compared to cast counterparts, the damping capacity of heat-treated composites was marginally greater for temperatures up to 250°C, and it was observed that the β-phase dissolves at higher temperatures.

5.0 Author's Contribution

Writing-review and editing, Girish; Writing-original draft preparation, Satish; methodology, Shubha; formal analysis, Mohith. All authors have read the manuscript and agreed to the published version of the manuscript.

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