Concentration of Nano Silicon Carbide Particle on Functional Characteristics of Az91d Magnesium Alloy Composite Via Vacuum-Aided Stir Cast

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Abstract: This work examines the influence of nano-sized silicon carbide reinforcements on the mechanical properties and corrosion resistance of AZ91D magnesium alloy fabricated by a controlled vacuum-assisted stir casting method. Four composite versions were produced by sequentially adjusting SiC content from 1 wt% to 5 wt%, and systematically assessed for impact toughness, tensile strength and corrosion resistance in a saline environment. The integration of nano SiC significantly improved mechanical strength and corrosion resistance by facilitating grain refinement, efficient load transfer and the development of stable passive coatings. The composite with 3 wt% SiC demonstrated the most optimal performance shows the adverse impacts of particle agglomeration seen at higher filler concentrations and these findings show the proper use of AZ91D with SiC nano composites for high performance weight critical applications in the automotive and transportation industries.

# Introduction

Magnesium alloys especially AZ91D are well known for their high specific strength and low weight, which makes them perfect for automotive and structural parts, but insufficient hardness and poor corrosion resistance prevent further usage. In harsh conditions nanoparticle reinforcement can improve durability and mechanical integrity particularly when combined with high-hardness ceramics like SiC. Recent research on magnesium based hybrid nanocomposites has revealed that dual and multi-phase reinforcing processes can work together to make the materials stronger [1-4]. It showed that mixing magnesium fluoride with nano AlO₃ and SiC made the AZ91 alloy much stronger and better able to handle heat [5]. They showed that when SiC nanoparticles are equally spread out in AZ31 alloy, they make it harder and stronger by refining the grains [6]. Researchers [7] used squeeze casting to put SiN₄ into AZ91D and found that the microstructure was uniform and that the material compressive strength and hardness increased significantly. Researchers [8-10] showed that adding nano SiC to AZ91 made it denser and better able to hold weight. Researchers [11-13] looked at friction stir processing as a viable approach for surface engineering and showed that FSP can make magnesium composites last longer and resist corrosion better as well as improve the structure of the grains. Researchers [14-16] studied the behaviour SiC mixed into AZ31 hybrid nanocomposites and found that better particle dispersion made the materials more ductile and stronger in tension.

Using Taguchi grey relational analysis, Researchers [17] found a trade off between bettercorrosion resistance and microhardness by tweaking FSP parameters for AZ91/SiC composites and Researchers [18] observed the increase in the amount of SiC in AZ91 affects how it wears down and found that more SiC makes the material more resistant to abrasion. By using both classic stir casting and ultrasonic vibration treatment and Ponhan [9] reduced porosity concerns and helped nanoparticles spread out evenly. Researchers [19-20] analysed AZ63/BN nanocomposites that were made better with SiC and found that they had good hardness and tensile strength values when looking at other alloy systems. They employed FSP to make hybrid reinforced magnesium composites that were much stronger against breaking and hitting and found that adding SiC to the AZ91 Ca Sb alloy improved the bonding of the matrix reinforcement, which made the alloy stronger and more flexible [21-25]. Researchers [26] made AZ91 SiC composites using powder metallurgy and made them denser and harder than standard casting. At nanoparticle-reinforced magnesium composites and found that choosing the right procedure, making sure the particles are well distributed and managing the particle-matrix interface are all important for getting balanced properties [27-29]. When added fly ash and SiC to the AZ91E alloy, they found that the compressive strength went up and the density went down, making it better for lightweight structural applications [30].

This work uses a vacuum die aided stir casting method that reduces porosity and enhances particle dispersion to examine the impact of different nano SiC concentrations on AZ91D.

# Materials and Methods

## Materials

Because of its exceptional strength to weight ratio and castability the magnesium alloy AZ91D was chosen as the basis matrix. To improve the mechanical performance nano sized silicon carbide (SiC) particles (about 30 nm) were used as reinforcements. To stop oxidation the AZ91D alloy was melted at about 700°C in an inert argon environment. After being heated to remove moisture and increase wettability SiC nanoparticles were progressively introduced to the melt and spread out using mechanical stirring for eight minutes at 600 rpm. To reduce porosity and encourage consistent matrix–reinforcement bonding, the resultant slurry was poured into a heated metallic die with vacuum assistance [31-36]. As indicated four composite formulations with different SiC concentrations (1–5 wt%) were created.

## Composite Formulations

**TABLE 1.** Mechanical Composite Formulations Table

|  |  |
| --- | --- |
| **Sample ID** | **Composition** |
| Sample 1 | AZ91D (Unreinforced) |
| Sample 2 | AZ91D + 1 wt% SiC |
| Sample 3 | AZ91D + 3 wt% SiC |
| Sample 4 | AZ91D + 5 wt% SiC |

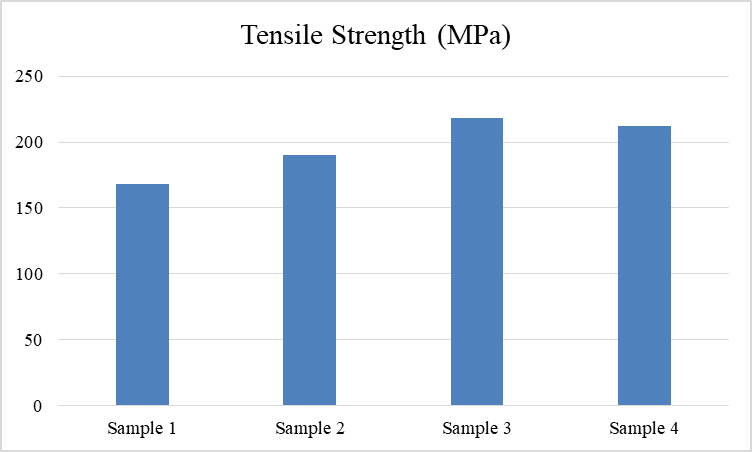
# Results and Discussion

## Tensile Strength

Adding nano-sized SiC particles to the AZ91D matrix made it much stronger under tension. This was mostly because the grains were better refined and the load transfer mechanisms worked better. Sample 3 (AZ91D + 3 wt% SiC) had the highest tensile strength of 218 MPa, which suggests that this is the best level of reinforcement with the least amount of particle agglomeration. Sample 4 (5 wt% SiC) similarly had stronger strength than the base alloy, but it was a little weaker than Sample 3. This is because nanoparticles cluster together which can make stress concentrate and make it harder to spread stress evenly [37-39].

**TABLE 2**Tensile Strength

|  |  |
| --- | --- |
| **Sample** | **Tensile Strength (MPa)** |
| Sample 1 | 168 |
| Sample 2 | 190 |
| Sample 3 | 218 |
| Sample 4 | 212 |



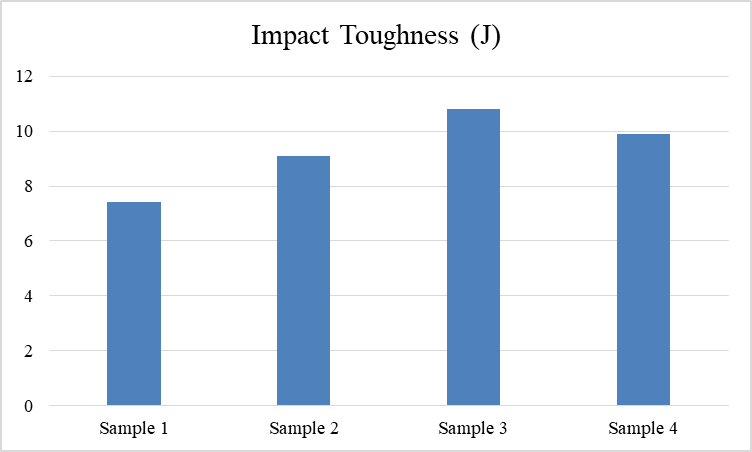
**Figure 1.** Tensile Strength

## Impact Toughness

Adding nano SiC particles to the AZ91D alloy matrix made the composite better at absorbing impact energy. The best performance was seen when the SiC loading was 3 wt%. Sample 3 had the highest impact toughness at 10.8 J. This was because the particles were better dispersed and the bonds between them were stronger which helped the material handle stress when it was suddenly loaded. Sample 4 exhibited a little drop in toughness because the nanoparticles stuck together propogating cracks start and lower the material's ability to absorb energy [40-45].

**TABLE 3.** Vickers Hardness

|  |  |
| --- | --- |
| Sample | Impact Toughness (J) |
| Sample 1 | 7.4 |
| Sample 2 | 9.1 |
| Sample 3 | 10.8 |
| Sample 4 | 9.9 |



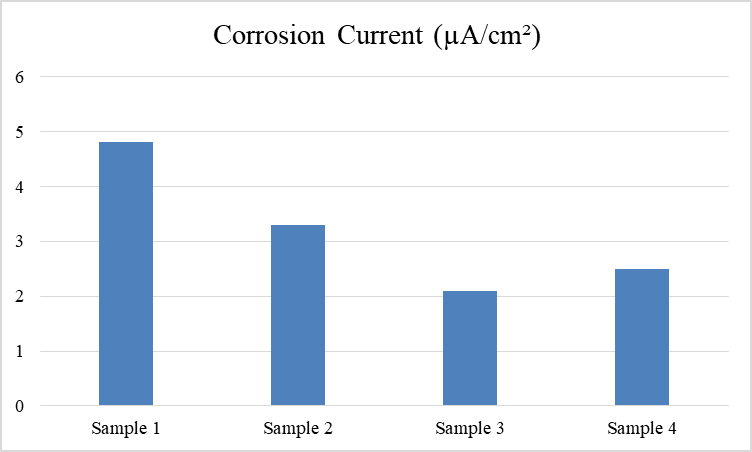
**Figure 2.** Impact Toughness

## Corrosion Resistance

Adding nano sized SiC particles to the AZ91D matrix made the composites more resistant to corrosion. This improvement is due to the barrier effect of the evenly spaced ceramic particles keeping corrosive chemicals from getting through [52] and keeps the passive film on the surface stable. There was a clear trend towards a lower corrosion current density and a more noble corrosion potential. Sample 3 (3 weight % SiC) had the best resistance to corrosion at 2.1 µA/cm² but the unreinforced alloy had 4.8 µA/cm². Localized agglomeration induced micro galvanic cells could be why Sample 4 doesn't work as well as the others [46-51].

**TABLE 4.** Corrosion Resistance

|  |  |
| --- | --- |
| Sample | Corrosion Current (µA/cm²) |
| Sample 1 | 4.8 |
| Sample 2 | 3.3 |
| Sample 3 | 2.1 |
| Sample 4 | 2.5 |



**Figure 3.** Corrosion Resistance

# Applications in Automotive Structural Frames

The AZ91D and SiC nanocomposites have higher tensile strength, impact toughness and corrosion resistance makes them be used in challenging structural applications in the auto sector where performance and weight loss are very important. Sample 3 (AZ91D mixed with three weight % SiC) is useful for internal support frames, chassis brackets and lightweight outer body panels. These composites provide an appealing alternative to heavier metals by combining mechanical robustness with long term environmental stability. Because of this they help the platforms of the next generation of cars use less fuel and stay strong [53-54].

# Conclusion

This study shows that the vacuum assisted stir casting method works well for adding nano sized SiC to the AZ91D magnesium alloy matrix, which makes the material much stronger and more resistant to corrosion. Sample 3, which had the highest tensile strength, highest impact toughness and lowest corrosion current density, showed that the best reinforcement ratio was 3 wt% SiC. The even distribution of SiC helped to refine the grains, increase load transfer, and make the surface less reactive and results show that AZ91D/SiC nanocomposites could be used in the automotive and transportation industries to make lightweight and corrosion resistant structures.

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