Featuring of Nano Silicon Carbide and Alumina Particles and Tribo-Wear Behaviour of Magnesium Alloy Composites

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Abstract: The purpose of this work is to analyze the mechanical and tribological performance of AZ91D magnesium alloy that has been reinforced with nano sized particles of silicon carbide and alumina (Al2O3). In order to create five composite samples a two step stir casting approach was utilized. The Al2O3 content of the samples ranged from 0 to 2 weight % while the SiC percentage remained at 1.5 weight % throughout the process. The Vickers hardness, wear rate and coefficient of friction were all components of the comprehensive testing that were carried out under sliding wear conditions. The tests were done at a constant speed of 1 meter per second, with variable loads of 10 N, 20 N and 30 N. According to the findings there is aimportantrise in hardness and wear resistance with increasing Al2O3 content. This can be due to the action of reinforcements and uniform dispersion that is accomplished through ultrasonic-assisted stirring. The hybrid nanocomposite that was developed is good contender for high performance, lightweight applications such as brake pads for automobiles, where both wear resistance and thermal stability are essential.

# Introduction

Because the automotive industry needs lightweight, high performance materials more and more for brake systems and interest in magnesium based metal matrix composites has grown. The magnesium alloy AZ91D is quite popular because it has a strong strength to weight ratio and can be cast easily. Its direct application in dynamic contact situations, like brake pads, is limited by its natural poor wear resistance and the way its surface breaks down when it is under frictional stress [1-3]. Recent advances in nano reinforcement technology show that adding ceramic nanoparticles like silicon carbide and alumina can greatly improve the hardness, load bearing capacity and wear behavior of light alloys. The goal is to find and use the synergistic effects of these two reinforcements to improve the tribological properties of the material system, specifically its hardness, wear resistance and coefficient of friction, so that it can be used in high friction, thermally demanding automotive brake pad applications. They studied the effect of reinforcements on the mechanical and tribological performance of magnesium based composites and focused onbehaviour of nanoparticles can improve tensile strength, hardness and wear resistance [4-9]. The impact of load and sliding speed that affects the dry sliding wear behavior of AZ91E nanocomposites. They discovered that greater loads and speeds made wear resistance worse [10-11]. It also made AZ91 Mg₂SiSiC hybrid composites and observed improvements in tribological and microstructure properties because of the reinforcement activities. The roles of graphene and AlO₃ in AZ91 alloy and found that better hardness and wear resistance came from a more even distribution of reinforcement and finer grain structures [12-13]. A sustainability focused approach by using materials to make functionally graded magnesium matrix composites. These composites demonstrated promising mechanical properties [14-16]. The AZ91D/AlO₃/SiC nanocomposites using friction stir processing and multi response methods to find the best process parameters [17-19]. It used stir casting to make AZ91D composites with tricalcium phosphate (TCP) as a reinforcement. They found that the composites were harder and less likely to corrode [20]. A study compared micro and nano SiC reinforced Al 5052 utilizing FSP [21]. It shed light on what the scale of reinforcement means, with nano reinforcements demonstrating better tribological benefits. In the advanced machining [23-25], employed the Box–Behnken Design and NSGA II algorithms to WEDM Ti6Al4V alloy and used optimization approaches to make it easier to work with biocompatible materials [26-27]. This made the interfacial bonding stronger and the yield and tensile strengths higher [28-30]. They looked at rutile and silver as reinforcements in magnesium composites with FSP and establish that the surface hardness and wear resistance improved significantly [31-33]. It was compared different combinations of reinforcements, such as Y₂O₃/HA, HA/ZrO₂ and Y₂O₃/ZrO₂ and found that AZ91D surface composites produced by FSP had better bio tribological behavior that was suitable for biomedical applications [34-35]. It was found that AZ91D composites that were lubricated with tungsten disulphide (WS₂) had a longer wear life and less friction when they were put under a range of loads [36-39]. It employed gray relational analysis and Taguchi design to test how easy it is to machine AZ61A composites. This showed how important it is to optimize process parameters [40-42]. It talked about how reliable FSP is when used with statistical optimization to customize composite behavior for engineering purposes. They also talked about their results on AZ91D/AlO₃/SiC nanocomposites again [43].

# Materials and Methods

## Materials

**TABLE 1.** Mechanical Composite Formulations Table

|  |  |
| --- | --- |
| **Sample ID** | **Composition** |
| Sample 1 | AZ91D (Unreinforced) |
| Sample 2 | AZ91D + 1.5 wt% SiC |
| Sample 3 | AZ91D + 1.5 wt% SiC + 2 wt% Al₂O₃ |
| Sample 4 | AZ91D + 1.5 wt% SiC + 4 wt% Al₂O₃ |
| Sample 5 | AZ91D + 1.5 wt% SiC + 6 wt% Al₂O₃ |

Due to its low density and castability the AZ91D magnesium alloy was selected because it is an excellent choice for applications that require a lightweight material. Reinforcements consisting of nano sized SiC particles (50 nm) and Al2O3 particles (30 nm) were utilized in order to enhance the mechanical and tribological performance of the material and to improve dispersion, both were pre dried at a temperature of 150 degrees Celsius. Two-step stir casting was used to process the alloy after it was melted at 720 degrees Celsius, cooled to 600 degrees and then processed. During the stirring stage nanoparticles were added and then a second stirring stage was performed to verify that the mixture was evenly mixed. The molten composite was then cast into steel molds that had been heated beforehand [44-48]. As shown in Table 1, five samples were generated with a constant SiC content of 1.5 weight % and a variable Al2O3 content ranging from 0 to 6 weight % in order to investigate the impact of these two factors on the behavior of composites.

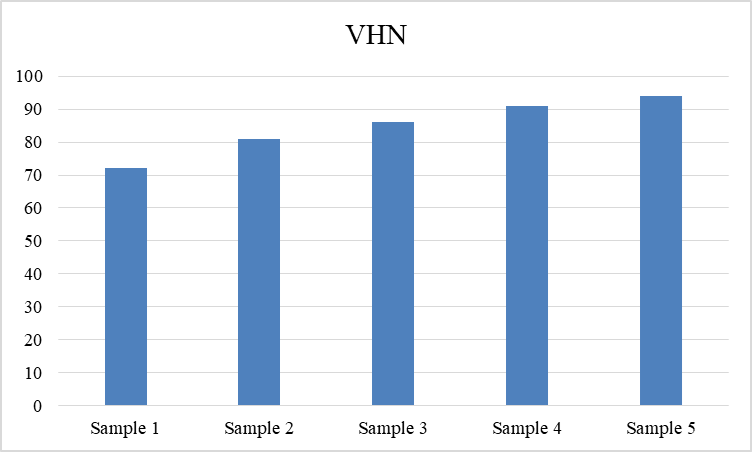
# Results and Discussion

## Vickers Hardness Number (VHN)

An upward trend in the hardness of the composites based on AZ91D was observed and this tendency was commensurate with an increase in the reinforcing content. Not only can nano-sized SiC and Al2O3 particles operate as strong load-bearing elements, but they also contribute to grain refinement by effectively pinning grain boundaries during the solidification process. This enhancement can be due to the dual impact of these particles. Sample 5 with greatest Al2O3 concentration (six weight percent) recorded the highest VHN of 94. This indicates that it has greater resistance to surface deformation and has the potential to improve wear life which is essential for components such as brake pads that are subjected to repetitive frictional loads [49-51].

**TABLE 2** Vickers Hardness Number

|  |  |
| --- | --- |
| **Sample** | **VHN** |
| Sample 1 | 72 |
| Sample 2 | 81 |
| Sample 3 | 86 |
| Sample 4 | 91 |
| Sample 5 | 94 |



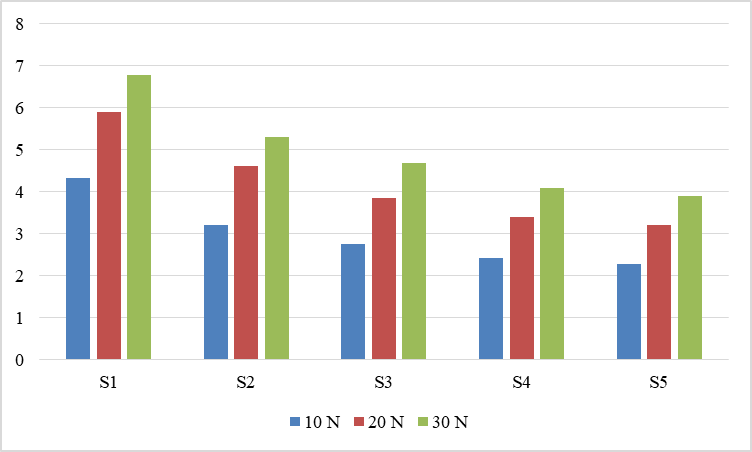
**Figure 1.** Shore D Hardness

## Wear Rate (mm³/N·m) at Sliding Speed = 1 m/s

Because SiC and alumina nanoparticles work together to harden materials the wear resistance of AZ91D composites significantly improved as the AlO₃ content increased. Under sliding conditions the composites showed reduced material loss as reinforcement levels rose. The advantages of improved surface hardness and uniform particle dispersion were highlighted by Sample 5 had the lowest wear rate across all applied loads (10, 20 and 30 N) with 1.5 weight % SiC and 6 weight % AlO₃. Brake pad systems and other applications involving constant friction benefit most from these advancements.

**TABLE 3.** Wear Rate

|  |  |  |  |
| --- | --- | --- | --- |
| **Load (N)** | **10 N** | **20 N** | **30 N** |
| S1 | 4.32 | 5.89 | 6.78 |
| S2 | 3.2 | 4.62 | 5.3 |
| S3 | 2.76 | 3.85 | 4.69 |
| S4 | 2.42 | 3.41 | 4.1 |
| S5 | 2.28 | 3.22 | 3.91 |



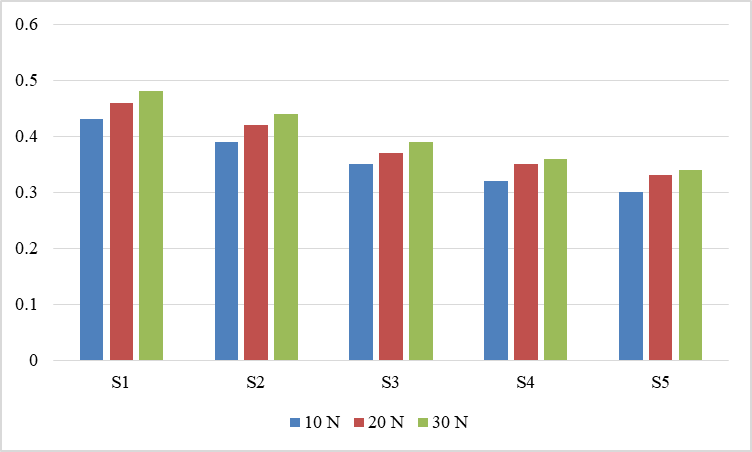
**Figure 2.** Wear Rate

## Coefficient of Friction (COF)

When nano SiC and AlO₃ particles were added, the coefficient of friction gradually dropped. The increased tribo-layer formation and the solid lubricant-like behavior of hard ceramic particles reduced adhesive and abrasive interactions during sliding, are mainly responsible for this reduction. Well placed reinforcements reduced ploughing forces and surface adhesion by suppressing metal-to-metal contact. The composites ability to absorb energy improved as well, reaching its maximum at Sample 4. The sample with the highest value (36.9 MJ/m2) reinforced with 1.5 weight % SiC and 4 weight % AlO₃ demonstrated the best possible balance between strength and ductility. .

**TABLE 4.** Coefficient of Friction (COF)

|  |  |  |  |
| --- | --- | --- | --- |
| **Load (N)** | **10 N** | **20 N** | **30 N** |
| S1 | 0.43 | 0.46 | 0.48 |
| S2 | 0.39 | 0.42 | 0.44 |
| S3 | 0.35 | 0.37 | 0.39 |
| S4 | 0.32 | 0.35 | 0.36 |
| S5 | 0.3 | 0.33 | 0.34 |



**Figure 3.** Coefficient of Friction (COF)

# Applications in Brake Pads

In contemporary automobiles, brake pad systems endure high levels of frictional heat, cyclic mechanical stress and frequent start-stop operations. Excellent wear resistance, dimensional stability and a constant coefficient of friction across a broad range of loads are requirements under such harsh conditions and by reducing material loss from abrasive wear, the AZ91D based composites supplemented with nanosized silicon carbide and alumina showed a notable improvement in surface hardness. The COF was stabilized and dependable and predictable braking performance was ensured by uniformly distributed hard ceramic phases. These composites with improved tribological behavior and magnesium alloy low density make them ideal for lightweight vehicle brake pad applications where fuel economy and performance are crucial [52-54].

# Conclusion

The present investigation demonstrated the noteworthy benefits of hybrid nano reinforcements namely silicon carbide and alumina in increasing the mechanical and tribological properties of composites made of magnesium alloy AZ91D. The composites were designed to produce uniform dispersion of ceramic fillers using a two step stir casting technique leading to improvements in hardness, wear resistance, and frictional behavior. Sample 5 of AZ91D + 1.5 wt% SiC + 6 wt% Al₂O₃ outperformed all other manufactured samples in terms of overall performance showing the highest Vickers hardness, the lowest wear rate and a stable COF under various load situations (10 N to 30 N). These results demonstrate the promise of these nano-engineered magnesium matrix composites as a practical and long term solution for lightweight, high performance brake pad components in the transportation and automotive sectors.

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