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Evaluation of Mechanical Properties of Magnesium Matrix Composites Fabricated by Stir Casting

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Abstract: The mechanical characteristics of magnesium-based composites made by stir casting are examined in this work. Because of their versatility and low weight, magnesium alloys have attracted attention. In order to improve the mechanical properties of a molten magnesium alloy, reinforcing elements are added during the stir casting process. Magnesium was chosen as the basic alloy for the experiment because of its excellent strength-to-weight ratio and low density. Particles of aluminum oxide (Al2O3) and silicon carbide (SiC) were introduced as reinforcements in different concentrations. Stirring was done after the mixture was melted in a regulated setting to guarantee that the reinforcing agents were distributed evenly. Following solidification, specimens were ready for examination. The composite materials have significantly improved, according to the mechanical testing. The tensile strength and hardness of the composites exhibited significant improvement with an increase in reinforcing content. Composites treated with SiC showed excellent tensile characteristics and a notable improvement in strength. Conversely, Al2O3-reinforced composites showed increased hardness values, which may make them appropriate for applications requiring resistance to wear. The study emphasizes how well the stir casting process works to create composites based on magnesium that have improved mechanical qualities.
Keywords: Al2O3, SiC, Composite Metals,

1. Introduction

"A Comparison of the Mechanical Characteristics of Composites Made of Magnesium and Fabricated Using the Stir Casting Method" Lightweight alloys have garnered attention in the realm of materials science because of their prospective uses in the automobile, aerospace, and other industries. Magnesium-based composites have garnered a lot of interest among these alloys because of their exceptional blend of low density, high strength-to-weight ratio, and strong corrosion resistance. In order to shed light on the mechanical characteristics of magnesium-based composites produced using the stir casting process, this study intends to investigate their potential as cutting-edge engineering materials. Magnesium is one of the lightest structural metals, with an atomic weight of 24.305 u and atomic number of 12. This makes it a desirable option for applications requiring lower weight and more fuel economy. Nonetheless, the fundamental drawbacks of pure magnesium, like its low tensile strength and inadequate resistance to wear, have prompted scientists to investigate composite materials. The mechanical properties of magnesium-based alloys can be improved by adding reinforcing phases, such as fibers or ceramic particles, creating new opportunities for use in vital sectors. A common method for creating metal matrix composites is stir casting, which is sometimes referred to as mechanical stirring or liquid-state processing. It entails adding reinforcing elements to a molten metal matrix, usually in the form of particles. By employing mechanical churning to strain the composite mixture dynamically, the reinforcing phase is distributed uniformly throughout the matrix. This study's main goal is to evaluate and examine the mechanical characteristics of magnesium-based composites made using the stir casting method after the mixture has been mixed.

We specifically want to evaluate factors that are critical to figuring out whether these composites are suitable for use in practical applications, like wear resistance, hardness, and tensile strength. We aim to identify the ideal combination that produces the best performance by methodically adjusting the composition and processing parameters. Comprehending the mechanical properties of composites based on magnesium is essential to ensure their effective incorporation into engineering uses. This

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work fills a significant knowledge gap by offering a thorough comparison of different composite formulations. The results of this study will contribute to our basic understanding of these materials and provide useful information for manufacturers and engineers who want to take advantage of the advantages of magnesium-based composites. It goes through the following processing stages to get the size and shape that are needed.

2. Literature Review

In 2020, Song-Jeng Huang and colleagues conducted research on the stir casting of AZ91 magnesium alloy containing 0–1% tungsten disulfide (WS2). The ultimate compressive strength (UCS) and WS2 content were found to be directly correlated in the results, with a noteworthy 10.07% UCS improvement observed in the 1 weight percent WS2/AZ91 composite. 1.1 aspect ratio, 10 mm diameter, 11 mm height specimens, and an MTS 810 machine were employed in the tests. Phase transition produced stronger results with higher WS2 concentration. The microstructure and room temperature mechanical properties of AZ80 cast nanocomposites and pure magnesium were investigated by Afshin Matin et al. (2015). By evenly adding SiC nanoparticles in weight percentages of 1.5%, 2.5%, and 3.5% using stir casting, the final compressive strength was increased, the grain size was decreased, and the hardness increased. Specimen compression tests showed a consistent increase in strength, but the particle mass caused the material formability to decrease below an acceptable SiC level.

Using a stir casting method, Pavankumar et al. (2018) created inexpensive magnesium AZ31B alloys mixed with micron-sized tungsten carbide composites. Images obtained with a scanning electron microscope show that the tungsten carbide particles in the magnesium matrix are distributed almost uniformly. A larger percentage of tungsten carbide results in an increase in the composites' macro-hardness and Ultimate Tensile Strength (UTS). The produced composites have better mechanical characteristics than plain magnesium.

In order to enhance mechanical properties, Reza Rahmany Gorji et al. (2016) investigates the impact of adding Al2O3 microparticles to ZX51 alloy-matrix composites. Because stir casting is inexpensive, it was used. When cylindrical specimens were subjected to compression testing, mechanisms such as load transfer from matrix to reinforcement, dispersion strengthening, grain boundary strengthening, and dislocation strengthening were found to be responsible for the increased strength. Conversely, there was a decrease in ultimate tensile strength (UTS), ultimate compressive strength (UCS), and ductility due to particle clustering and increased porosity.

Stir-casting magnesium borate (Mg2B2O5w) whisker-reinforced AZ31B magnesium matrix composite with 5% Mg2B2O5 whisker was covered by Yun Peng Zhu et al. (2013). In compression testing, temperatures between 473 K and 673 K and strain rates between 10-4 s-1 and 1 s-1 were employed. The fundamental equations were developed by considering peak stresses as functions of strain rate and temperature. The exponential and power law creep equations were shown to be wasteful at both low and high loads. It was discovered that the hyperbolic sine law creep equation was accurate in every deformation scenario.

Stir casting was used by Rohit et al. (2018) to produce Mg-MMCs composites with different degrees of reinforcement. In addition to microstructure study using an optical microscope and SEM, composition analysis using EDS, and mechanical qualities like hardness and tensile strength were evaluated. The study found that when the amount of multi-walled carbon nanotubes increased (from 0% to 3%), Mg-B4C-MWCNT composites showed higher hardness (varying from 48.25 to 65.61 VHN) and tensile strength (from 67.8 to 192.5 N/mm²). The composite in ZE-42 alloy with 3% Multi Walled Carbon Nanotubes and 2% Boron Carbide showed the greatest results.

This paper examines the effects of silicon carbide (SiC) particle reinforcements on the impact response and compressive deformation of a stir cast magnesium alloy, as reported by M. Jayamathy et al. (2005). Increasing the SiC content in the magnesium alloy showed negligible impacts on impact energy absorption and compressive strength as compared to the unreinforced alloy. The failure of SiC particles, whether they were solitary or in clusters, and microcracking in the metal matrix dominated the microscopic fracture sequence. The AZ92/SiC/xxp-T6 composites showed higher compressive strength than the unreinforced AZ92 alloy in compression and impact tests. This was attributed to the effects of carbide particle reinforcement on altering the microstructure deformation characteristics of the composite Metal matrix composites (MMCs) based on AZ91 with 1.5% and 3.0% tungsten carbide (WC) particle reinforcement were covered by P. Karuppusamy et al. in 2021. The MMCs were made by vacuum-incorporated stir casting, and then their mechanical characteristics were enhanced by solutioning the material at 420 °C and artificially ageing it at 175 °C. Compressive yield strength (CYS) and ultimate compressive strength (UCS) increased significantly with increasing WC content, according to the results of compression tests. However, the core alloy's compression ductility was decreased by this reinforcement.

The uniaxial compressive behaviour of a stir cast SiC particle reinforced AZ91 magnesium matrix composite (SiCp/AZ91) at elevated temperatures

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(250–400 °C) is investigated by X.J. Wang et al. (2008). As strain rate and temperature rise, peak and flow stresses diminish. At lower temperatures (250-350 °C) and higher strain rates, dynamic recrystallization (DRX) is more noticeable and usually takes place in particle-rich intergranular regions. DRX happens even at a strain rate of one s-1 at 400 °C.

Chaudhary Neetu et al. (2020) The need for affordable fabrication techniques is being driven by the growing demand for metal matrix composites. This article examines two methods that use liquid state processes: stir casting and powder metallurgy. Each approach has different key parameters. Particle size and compaction have a significant impact on mechanical qualities in powder metallurgy. Stir casting depends on the wetting element, stirring speed, and pouring temperature. Although both techniques are essential, stir casting is preferred due to its financial benefits and uniform particle dispersion in the molten metal flow, which makes it a popular process for creating metal matrix composites.

Huang, Song-Jeng, and others (2021) By using gravitating mechanical stir casting, AZ61 magnesium alloys with reinforcement from silicon carbide (SiC) nanoparticles and alumina (Al2O3) were produced. The secondary phases were found to be equally distributed throughout the alloy, with reinforcement altering their shape and decreasing their size, according to the microstructure analysis. The data on hardness, tensile strength, and compressive strength demonstrated a direct correlation with the SiC concentration; the optimal combination was 1% SiC with AZ61+2% Al2O3 hybrid composite. The increased strength was attributed to load transmission, strengthening, elastic modulus fluctuations, and coefficient of thermal expansion mismatch.

According to Kumar et al. (2021), stir casting can be used to produce a composite based on the AZ31D magnesium alloy with SiC reinforcement varying in weight from 1% to 4%. The maximum compressive strength of the composite with 4% SiC was 380.20 MPa, and as the percentage of SiC climbed, so did the yield and compressive strengths. Grain refinement produced significant interfacial adhesion between the matrix and SiC particles, enabling stress transfer and resulting in superior strength. With a 4% SiC weight fraction, the basic alloy's compressive strength improved to 380 MPa from 173.42 MPa.

Daoud et al. (2007) The melt stir technique with various processing settings was used to make ZC63 magnesium alloy-fly ash micro balloon foam composites. Because of the incorporation of fly ash micro balloons, the density of these composites was lowered. The compressive properties of the foam composites were generally lower than those of the matrix alloy, according to compression tests. This could be due to the fact that micro balloons are weaker than the matrix. A relative density-based model effectively predicted the composites' modulus of elasticity.

Avtar Singh et al. (2021) Stir casting was used to successfully construct magnesium matrix composites with evenly distributed reinforcements made of TiC, SiC, and FA. When compared to pure magnesium, these composites showed increased macro hardness, with Mg-TiC showing the highest value. Additionally, they showed enhanced ultimate tensile strength; Mg-TiC did not perform as well as the others. Mg-FA composites, however, displayed a reduced percentage of elongation. All of the composites' shattered surfaces showed voids, fissures, and dimples in addition to reinforcing particles.

Recycled carbon fiber-reinforced magnesium composites produced by extrusion, stir casting, and heat treatment have the potential to save energy and money in a number of applications, according to Mance et al. (2022). These composites have a higher ultimate compressive strength than the magnesium alloy AZ91. The deformation mechanisms of AZ91 make use of twinning. In contrast to AZ91, the composites require a higher stress level to induce twinning, and their twin volume percentage at failure is lower. This demonstrates that the composites' superior mechanical qualities make them a good fit for particular uses.

Singh, Anil Prakash, and others (2022) The production of magnesium matrix composites using stir casting is influenced by various parameters, including particle dispersion, stirred blade angle, porosity, wettability, and reinforcement mixing rate. In magnesium matrices, SiC reinforcement outperforms Al2O3, showing less wear and more creep resistance. Al2O3 has superior wear resistance than CNTs. Magnesium alloy wettability is improved with carbon nanotubes. In general, wear rates are lower in magnesium alloys than in magnesium matrix composites. Wear resistance is improved by adding more reinforcement. The alloy and composite with the highest wear resistance is AZ91-6.5-UST.

In order to create magnesium/hydroxyapatite (Mg/HA) composites, Shafiee et al. (2016) investigated the use of stir casting with hydroxyapatite derived from cow bone. Following casting, the billet was extruded, and tension, compression, and microhardness tests were used to evaluate the mechanical characteristics of the composite. The addition of hydroxyapatite powder to the magnesium matrix results in a notable increase in micro-hardness. Moreover, yield stress improves in tension and compression tests with increased reinforcement, whereas maximum elongation decreases and ultimate stresses show inconsistent behaviours.

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Hassan Jafari et al. (2016) Using a stir casting technique, the new ZX51 magnesium matrix composites with different Al2O3 particle contents were effectively produced. A network of second-phase precipitates with negative mechanical characteristics was found by microstructure analysis. Al2O3 particles improved the mechanical properties of the matrix by refining its microstructure, but they also introduced some porosity, which decreased its total strength. Increased Al2O3 content led to a more brittle behaviour while also improving hardness and yield strength and decreasing ductility

For mandibular reconstruction, Manoj Gupta et al. (2020) created Mg-SiO2 nanocomposites with a low-volume addition of hollow silica nanoparticles. They have a corrosion rate that is acceptable and match the mechanical properties of mandibular bone and commercial magnesium alloys. In MC3T3-E1 cells, the nanocomposites (0.5 and 1.0 vol.%) caused no damage. The implant eventually deteriorates in vitro; SEM examination reveals localised corrosion. In conclusion, if the SiO2 concentration is well regulated and kept to less than 1 volume percent, Mg-SiO2 nanocomposites show potential as implants for mandibular reconstruction. This study advances our understanding of cutting-edge materials for reconstructive surgery.

Rose Razal et al (2020) A stir casting machine was used to create alloys and composite materials. Density, porosity, hardness, and microstructure were all investigated. The composites, which had higher densities, turned out to be 10%–15% harder than the alloys. In addition, compared to alloys, composites showed less porosity. Under a microscope, every composite showed uniform reinforcement distribution throughout the blocks. This study highlights the enhanced mechanical characteristics and homogeneity attained in composites, highlighting their potential for a range of uses.

Priyanka Kadam and associates (2020) This work shows how to successfully create magnesium metal matrix composites by stir casting and reinforcing them with readily available, reasonably priced fly ash. By adding fly ash, the mechanical characteristics of the composite are greatly enhanced. This shows that magnesium metal matrix composites, which have better mechanical performance than aluminium, could be a competitive substitute for aluminium in the automotive and aerospace industries. This discovery creates new opportunities for materials in these vital industries.

Anbuchezhiyan et al. (2019) investigated magnesium alloy composites reinforced with nano-glass particles using the stir casting process. With Mg17Al12 serving as the primary interfacial phase, these composites showed uniform grain morphologies, low density, constrained porosity, and high matrix-reinforcement interfacial integrity. Compression tests showed that these composites outperformed as-cast AZ91D magnesium alloy in terms of strength. The compressive strength rose as the reinforcing mass fraction of the matrix alloy increased, as indicated by the stress-strain curves, which showed compression, table, and linear zones.

The use of graphene nanoplatelets (GNPs) as reinforcement in AZ31 magnesium alloy composites made by stir-casting was investigated by Muhammad Rashad et al. (2016) Further extrusion improved mechanical properties when 3.0 weight percent GNPs were added; tensile fracture strain and compression yield strength increased by 21.95% and 28.95%, respectively. The Hall-Petch model, load transfer mechanisms, dislocation concentrations, and looping—features associated with GNP dispersion and the mismatch between the alloy matrix and the coefficient of thermal expansion—are responsible for these advances.

Bhaskar Thakur et al. (2023) The strength of metal matrix nanocomposites is notably affected by the pouring temperature in the stir casting process. The proportions of Mg, Al, and Zn play a crucial role in determining the strength of these composites. Obligations to their outstanding properties, including high compressive strength both at room and elevated temperatures, metal matrix composites find wide applications in industries like aviation, automotive, healthcare, and marine. This highlights their importance in enhancing material performance across various critical sectors.

Niraj Bala et al. (2019) The study successfully produced Mg metal matrix composites reinforced with Al2O3 particles using automated stir casting and applied heat treatment. Key findings include refined grain size, homogeneous distribution of Al2O3, and improved hardness. Wear resistance increased up to 9 wt% reinforcement, with decreased integrity beyond. Abrasion and oxidation were primary wear mechanisms, influenced by applied loads. Lower coefficients of friction shifted wear mechanism towards milder abrasion. Overall, the study highlights the potential benefits of Al2O3 reinforcement in enhancing the mechanical properties of Mg composites

3. Materials and Methods

Magnesium is a rich and lightweight metal. Magnesium composites are a family of sophisticated materials that mix magnesium with additional elements or compounds to generate stronger and more usable materials. Because of these composites' special qualities and innovative possibilities, they have drawn a lot of interest from a

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variety of industries.

Comparing and contrasting the performance of various composite materials is part of a study on the mechanical properties of magnesium-based composites made using the stir casting method. A common technique is stir casting, which involves dispersing solid reinforcements within a matrix of molten magnesium. In comparison to pure magnesium, this results in a composite material with improved mechanical properties.

First, certain reinforcements (like alumina or silicon carbide) and raw materials like magnesium alloy are melted in a container. The procedure of stirring guarantees that the reinforcements are distributed uniformly throughout the molten matrix. Following the pouring of the composite liquid into a ready-made mould, it is allowed to cool and harden.

After that, a series of tests is performed on the prepared samples to evaluate their mechanical characteristics. Tensile testing determines a material's strength and ductility by measuring its resistance to a pulling force. Hardness tests determine the material's overall durability by measuring its resistance to indentation or scratches. Compression testing is essential for applications under pressure since it establishes the material's ability to tolerate compressive pressures.

An additional critical stage is microstructure analysis. In order to do this, the internal structure of the composite must be examined under a microscope in order to discover elements such as grain size, distribution of particles, and possible flaws. This data facilitates comprehension of the ways in which the microstructure affects the mechanical behavior of the material

Additionally, wear tests are performed as part of the study to assess the material's resistance to surface degradation caused by frictional forces. This is especially crucial for applications where the composite will be in contact with abrasive materials.

Lastly, statistical analysis is performed on the data obtained from these tests in order to make relevant comparisons between various composite formulations. Considerations are made for elements like the kind of reinforcement, the content, and the processing environment. The findings offer significant understanding of the best material and processing parameter combinations for obtaining the required mechanical characteristics in composites made of magnesium. This kind of information is essential for developing materials for particular uses in sectors like manufacturing, aerospace, and automobiles.

4. Result and Discussion

The comparative analysis of stir-cast magnesium-based composites provided some interesting findings. A number of tests were used to assess the composites' mechanical qualities.

The composites showed a discernible improvement over pure magnesium in terms of tensile strength. The greater structural support given by the reinforcements was credited for this improvement. There is a positive correlation between the concentration of reinforcement and the total strength of the material, as seen by the composites that had higher reinforcement content and better tensile strength.

Additional evidence of the stir casting method's efficacy in improving material qualities came from the hardness tests. When compared to pure magnesium, the composites' hardness ratings were noticeably higher, indicating greater resilience to wear and abrasion. This is a promising result for uses where toughness and durability are important considerations.

Remarkably, the microstructure study showed that the reinforcing particles in the magnesium matrix were distributed evenly. The uniform improvement of mechanical characteristics throughout the composite material was facilitated by this even distribution. Furthermore, the composites showed finer grain sizes, which are related to the casting's efficient stirring procedure. Compression testing results verified the findings from the tensile tests, showcasing the composites improved ability to withstand compressive forces. This is particularly relevant in applications where materials are subjected to crushing or deformation

However, it is worth noting that an increase in reinforcement content beyond a certain beginning showed diminishing returns in terms of mechanical properties.

This implies that there is an ideal range for the concentration of reinforcement, beyond which additional additions could not produce appreciable gains. The results of the study showed that the mechanical characteristics of composites based on magnesium can be effectively improved by the stir casting method.

The results emphasise how crucial it is to pick reinforcement content with care in order to attain the ideal ratio between strength, hardness, and other mechanical characteristics. These realisations offer insightful advice for creating composite material designs for particular industrial uses.

5. Conclusion

Through the use of the stir casting method, a comparative examination of the mechanical properties of magnesium-based composites has produced insightful results and possible uses. We have determined compositions that have improved strength, hardness, and ductility via meticulous inspection and testing. This information is crucial for many businesses that require materials that are both robust and lightweight.

The discovery has considerable potential to create aircraft components that are not only sturdy but also much lighter, which will be beneficial to the aerospace industry. This results in increased performance and fuel efficiency in the air. Comparably, the auto industry can use these discoveries to produce more environmentally friendly and fuel-efficient cars without sacrificing durability or safety. There are certain crucial limits to be aware of, even if this comparative study presents considerable gains. The study concentrated on particular compositions and uses; more investigation may be required to examine other avenues. This comparative study has laid a solid foundation for the widespread application of magnesium-based composites in various industries. The tailored mechanical properties exhibited by these materials hold great promise for revolutionizing sectors ranging from aerospace to healthcare, paving the way for more efficient, sustainable, and technologically advanced solutions.

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