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Investigation on Tribological Properties of AA5059 Reinforced Nano Kaolinite Metal Matrix Composite Using Novel Encapsulate Technique

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Abstract

In this work, the wear behaviour of composite with reinforcement of 10% nano kaolinite fabricated utilizing a novel encapsulating technique will be compared to those of as-cast AA5059. The samples for every group were produced using the stir-casting technique and a novel encapsulating technique. For group 1, AA5059 was used as cast, while for group 2, a composition of nano kaolinite (10%) and AA5059 was used as a composite. ASTM E92 standards created the samples, and their wear behavior was assessed using a pin-on-disc apparatus. In each group, there were 20 samples. This study produces the G-power as 80% where $\alpha = 0.05$ for every set, and the total sample size is 40. The material with 10% nano kaolinite filler received the highest wear resistance properties, which is 58% lesser than the AA5059 as-cast. The t-test's statistical analysis reveals a $p = 0.00$ ($p < 0.05$) effectively in the difference between both groups' mean-variance of wear. Considering the inherent limitations of this study, it is noticeable that the composite with 10% nano kaolinite significantly increases the AA5059 composite's wear resistance.

Keywords

Wear, AA5059, Kaolinite, Energy, Stir casting, Composite, Novel encapsulation

Introduction

All governments are now placing more of a worldwide emphasis on emission reduction, pollution reduction, and performance enhancement due to the pressing issues of the energy crisis and environmental degradation. Choosing and using light materials (like aluminum) can significantly reduce the vehicle's weight. Consequently, lightweight materials are crucial for sustainably expanding the sustainable industry [1]. An aluminum alloy is a lightweight structural alloy with high corrosion resistance, exceptional formability, and substantial hardness (AA5059). Comparing the AA5059 aluminum alloy to the traditional AA5083 alloy, considerable strength gains are offered. In addition to having greater magnesium (Mg) concentrations than AA5083, AA5059 has more zinc and zirconium for processing grains. It is a Mg non-heat treatable alloy made in Koblenz, Germany, from Aleris International, Inc. [2]. Kaolinite, which is composed of silicate sheets (Si_2O_5) joined to layers of aluminum oxide/hydroxide ($Al_2(OH)_4$) by the arrangement of tetrahedral and octahedral sheets, has the chemical formula $Al_2Si_2O_5(OH)_4$. Nano kaolinite is used as reinforcement in AA5059, increasing its wear resistance [3]. It becomes more challenging by mechanical strain hardening. Due to its excellent weldability, aluminum alloy is widely utilized to join structural components. Due to its improved performance, aluminum alloy is used in various sectors, including marine, aviation, automotive, and defense. It is widely utilized in manufacturing ships, aviation, and other electronic-related industries [4]. As a result, the strength of this composite material will significantly rise, and it may be used to produce goods in various sectors.

Several articles concerning AA5059's wear resistance were recently released. Based on the AA5059 and wear behaviour, there are 171 research papers published in Google Scholar, compared to 41 research articles published in Science Direct. A statistical analysis of optimization of wear behavior of Al-Al_2O_3 composites using Taguchi technique [5]. Wear and mechanical characteristics of Al 7075/graphite composites [6]. Experimental investigation on mechanical behaviour, modelling, and optimization of wear parameters of B_4C and graphite reinforced aluminium hybrid composites [7]. An integrated artificial neural network and Taguchi approach to optimize the squeeze cast process parameters of AA6061/Al_2O_3/SiC/Gr hybrid composites prepared by novel encapsulation feeding technique [8]. The paper on the hybrid composites prepared by the novel encapsulation feeding technique is regarded as the finest since it described the novel encapsulation technique in detail. This research exhibits the fusion of the mechanical and computer science domains by optimizing the composite well with more than one reinforcement and adding to this, they also applied the artificial neural network approach with a unique encapsulation feeding methodology for casting.

This research discovered that there had been very few investigations on the fabrication of composites using novel encapsulation methods. This study aimed to create a novel encapsulating stir-casting technique for the AA5059/10% nano kaolinite composite. The purpose of the study was to compare the wear characteristics of the composite material with the as-cast material.

Materials and Method

The research in focus was carried out in Saveetha Industries, Saveetha School of Engineering, and Saveetha Institute of Medical and Technical Sciences, Chennai (Tamil Nadu, India). This study examined the wear resistance of two distinct material groups: the as-cast and the composite. To facilitate a comprehensive analysis, samples were crafted, each measuring 8 mm in diameter and 30 mm in height. These samples were essential in comparing wear behavior across the two materials. Cumulatively, there were forty such samples neatly divided into two groups. A sample size check revealed a G-power of 80% when analyzing each set of 20 samples.

The meticulous preparation process for the as-cast samples, which form group 1, began with procuring a 20 mm diameter AA5059 rod [9]. This rod underwent lathe operations, ensuring the alloy's surface was accurately machined. The resultant finish was impeccably smooth, devoid of any additional or unwanted material that might have existed on the metal's surface. The subsequent phase of the preparation involved melting the alloy. A 1 kg quantity of AA5059 was placed in a crucible with an equivalent capacity. Upon positioning this crucible in a furnace, the temperature gradually ramped up, reaching a peak of 700 ˚C [10]. The alloy is liquefied at this temperature, ready to be poured into a mold. Using gravity as the guiding force, the molten metal was poured and then allowed to cool. Once solidified and extracted from the mold, any superfluous material was discarded. The resultant casting metal was then meticulously sectioned into samples, each measuring 8 mm in diameter and 30 mm in height. These samples were subsequently set aside for wear resistance testing, setting the stage for the pivotal part of the research [11].

The second research phase, about the composite material samples, categorizes them as group 2. The inception of the preparation process involves an AA5059 rod, 20 mm in diameter, which is meticulously machined on a lathe. This process ensures that the rod's surface is impeccably smooth and devoid of any surface irregularities or burs [12]. The rod then undergoes a specialized drilling process. Initially, a 2 mm drill bit creates a central hole on one end of the rod. Subsequently, a series of holes, each 50 mm deep, are drilled into the rod using progressively larger drill bits with diameters of 4 mm, 6 mm, and 12 mm [13].

In a subsequent step, depicted in figure 1, the rod is integrated with 10% nano kaolinite, translating to a weight of 10 g. This composite mixture is visually represented in figure 2. To contain this mixture, a specialized 15 mm thick cup, precisely manufactured on a lathe, is used. Once the drilled rod has been adequately filled with the nano kaolinite, the cup is positioned to seal the rod's depth. The encapsulated rod is then placed in a crucible and introduced to a furnace. The furnace's temperature is incrementally raised to facilitate the melting of the rod. As illustrated in figure 3, the liquid state of the AA5059 alloy is meticulously blended with the 10% nano kaolinite using the stir-casting method before being poured into a mold. Post solidification and cooling, the composite is extracted, and any excess or superfluous material is meticulously removed. As

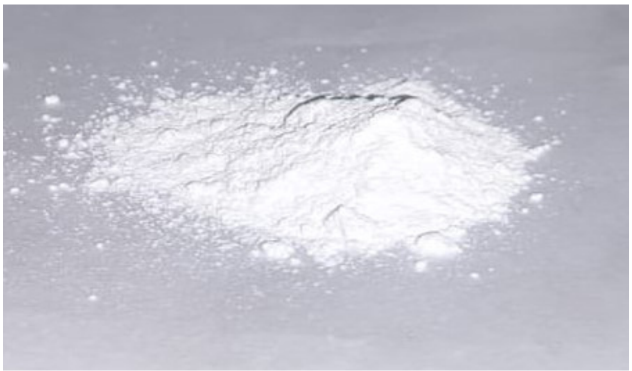
Figure 1: Nano kaolinite (10% reinforcement).


Figure 2: Feeding nano kaolinite to novel encapsulated AA5059.

Figure 3: Stir casting.

represented in figure 4, the composite casting is subsequently segmented into samples, each measuring 8 mm in diameter and 30 mm in height, for wear resistance tests [14].

A pin-on-disc apparatus is employed for both the as-cast and composite material samples for wear resistance testing. Adhering to ASTM E92 standards, each of the 20 samples per group is segmented into slices, maintaining the dimensions of 8 mm in diameter and 30 mm in height. As showcased in figure 5, the counter surface for this test comprises an oil hardened nickel steel disc, 55 mm in diameter, boasting a hardness of 60 HRc. The testing variables include loads of 20 N, 40 N, and 60 N, with sliding speeds ranging from 0.6 m/s to 1.0 m/s across a consistent sliding distance of 2000 m [15]. The test environment is maintained at a relative humidity of 60 - 65% and a room temperature of 30 °C.

It is pivotal to note that the above-stipulated procedure is rigorously adhered to for each group of 20 samples and is repeated thrice. For clarity and reference, the wear resistance values of the as-cast samples are depicted in figure 1, while the composite material samples are showcased in figure 2.

Figure 4: Material for wear test.

Figure 5: Wear rate test.

Statistical analysis

IBM developed robust statistical software known as SPSS (Statistical Package for the Social Sciences). This program is designed to handle data management, detailed analysis, mathematical modeling, and other computational tasks. In the context of this research, the SPSS software was pivotal in processing the wear resistance measurements garnered from the samples. One of the critical statistical tests executed using SPSS was the t-test, which analyzed the variances in wear resistance across the samples [16].

Further diving into the functionalities of SPSS, the software is adept at running both descriptive and independent sample test tables. Beyond this, the Bonferroni analysis, which is crucial for multiple comparison tests, ensuring a rigorous and accurate statistical evaluation, is also facilitated through this versatile application. Within the framework of this research, the wear resistance value is identified as the dependent variable. This means that other factors in the study influence or determine this variable. On the other hand, the independent variables, which act as influencers, are identified as the stir speed and the proportion of reinforcement weight. These variables are considered foundational as they directly impact the outcome of the wear resistance value [17].

Moreover, the study doesn't stop identifying these variables; it dives deeper into statistical metrics. Utilizing the capabilities of SPSS, the research provides a comprehensive understanding of the data's distribution through metrics like standard deviation, which provides insights into the variability or dispersion of the data set. Furthermore, the mean statistics, representing the average value, aid in understanding the central tendency of the wear resistance values. Lastly, the significance level is critical, as it provides a statistical measure to determine the likelihood that the observed difference between groups occurred by random chance [18]. This aids in confirming or refuting the hypotheses set at the beginning of the research.

Results

In the presented research, a meticulous exploration of wear rates has been undertaken, and the data has been systematically tabulated across multiple tables. Table 1 provides a straightforward representation of the wear rate for two distinct materials: the as-cast AA5059 and its counterpart, the AA5059 that's been fortified with a 10% kaolinite reinforcement. This allows for an immediate comparison between the untreated and reinforced alloy.

Diving deeper into the statistical intricacies, table 2 offers an analytical perspective by presenting group statistics related to wear rates. Here, we find a detailed breakdown comparing the as-cast AA5059 against the AA5059 enhanced with 10% nano kaolinite reinforcement. This table is an important data source, likely detailing mean values, standard deviations, and other pertinent statistical metrics [19]. Table 3 provides

Table 1: Wear rate of as-cast AA5059 and AA5059 with reinforcement of 10% nano kaolinite.

Sample number	As-cast AA5059 (x 10^{-5})	AA5059 with reinforced nano kaolinite (x 10^{-5})
1	4.217	1.801
2	4.179	1.763
3	4.192	1.776
4	4.158	1.742
5	4.169	1.753
6	4.183	1.767
7	4.160	1.744
8	4.154	1.738
9	4.151	1.735
10	4.108	1.692
11	4.118	1.702
12	4.080	1.664
13	4.093	1.677
14	4.059	1.643
15	4.070	1.654
16	4.084	1.668
17	4.061	1.645
18	4.055	1.639
19	4.052	1.636
20	4.009	1.593

Table 2: Group statistics of wear rate in as-cast AA5059 and AA5059 with reinforcement of 10% nano kaolinite.

Group statistics		N	Mean	Std. deviation	Std. error mean
Wear rate	As-cast AA5059 without reinforcement	20	4.1176	0.05810	0.01299
	AA5059 without reinforcement kaolinite	20	1.7016	0.05810	0.01299

an even more rigorous statistical analysis, focusing on the independent samples test related to wear rates. Such a test is instrumental in understanding if the differences in wear rates between the two materials are statistically significant, thereby offering more weight to any conclusions drawn from the raw data. Lastly, table 4 offers a descriptive overview detailing the wear rates of both the as-cast AA5059 and the version reinforced with 10% kaolinite. Table 4 provides a summary of the data, highlighting key values, ranges, and perhaps confidence intervals, which give a clearer understanding of the range within which true population values might lie.

Overall, the wear rate data is concisely yet comprehensively represented across these tables, segmenting the information into two primary groups - the untreated As-cast AA5059 and its reinforced counterpart. This systematic presentation ensures clarity and ease of interpretation for anyone reviewing the research findings.

Discussion

The study found that the as-cast AA5059 with reinforcement of 10% nano kaolinite has a greater enhancement in wear rate than the as-cast AA5059. To simplify things better, the descriptive and independent sample test table outcomes also give us the mean, standard deviation, standard mean error, etc. It facilitates quickly determining both material's tensile strengths for testing. Previously, the study on a hybrid composite provided a 30% lower wear rate than the base metal for all several wt.% of Al_2O_3. Another work on composite with reinforcement of graphite had used to reduce the wear rate while increasing the value of graphite content which has a minimum of 5 wt.%, whereas, in our study, in figure 6, this research achieved nearly 58% lesser wear rate than the as-cast AA5059 material over AA5059 with 10% nano kaolinite. It can be reached by the novel encapsulation technique used to spread the nano kaolinite reinforcement to the overall aluminium alloy equally during the stir-casting method. Hence, this research achieved a lower wear strength than the as-cast material by the composite material fabricated by stir-casting and novel encapsulation technique.

Two factors that are impacting our research are the stirrer and pouring technique. This research rarely encountered shrinkage cavities, pinholes, and blow holes in castings because the molten metal ran to the die under gravity. This research acknowledged that this casting defect had limited our research. To avoid such casting defects, this report's future research aims to utilize squeeze casting to stop the generation of air bubbles.

Table 3: Independent samples test of the wear rate in as-cast AA5059 and AA5059 with reinforcement of 10% nano kaolinite.

Wear rate	Levene's test for equality of variances		T-test for equality of means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean difference	Std. error difference	95% CI of the difference	
								Lower	Upper
Equal variances assumed	0.000	1.000	131.500	38	0.000	2.41600	0.01837	2.37881	2.45319
Equal variances not assumed			131.500	38	0.000	2.41600	0.01837	2.37881	2.45319

Table 4: Descriptive of the wear rate in as-cast AA5059 and AA5059 with reinforcement of 10% nano kaolinite.

	N	Mean	Std. deviation	Std. error	95% CI for mean		Minimum	Maximum
					Lower bound	Upper bound		
As-cast AA5059 without reinforcement	20	4.1176	0.05810	0.01299	4.0904	4.1448	4.01	4.22
AA5059 without reinforcement kaolinite	20	1.7016	0.05810	0.01299	1.6744	1.7288	1.59	1.80
Total	40	2.9096	1.22473	0.19365	2.5179	3.3013	1.59	4.22

Figure 6: Mean wear rate of comparison with 10% nano kaolinite and without kaolinite. The mean output shows that the as-cast without nano kaolinite got 58% less than the AA5059 with 10% nano kaolinite in wear resistance.

Conclusion

Within the defined scope of this investigation, we've arrived at some significant findings. Central to these discoveries was the realization that the innovative encapsulation process has a tangible effect on the wear rate of the composite material, specifically AA5059 when reinforced with 10% nano kaolinite. A remarkable decrease, around 58% in the wear rate, was observed when the AA5059 alloy underwent reinforcement with 10% nano kaolinite, compared to its counterpart, the as-cast AA5059 material, without any reinforcement. The encapsulation technique, particularly when combined with stir casting, emerged as a pivotal factor in augmenting the wear resistance of the AA5059 material reinforced with 10% kaolinite. The practical implications of these findings are vast and quite promising. Given the enhanced wear resistance, the AA5059 alloy, reinforced with 10% nano kaolinite, becomes a prime candidate for applications where wear resistance is paramount. One such application is in vehicle armor; the alloy's improved wear resistance makes it ideally suited to withstand the rigors of corrosion or erosion, thereby promising longevity, and durability. Furthermore, considering its resistance to wear, this material could also find significant applications in aerospace and marine industries, particularly in the fabrication of cryogenic propellant tanks and innovative ship designs. These use cases demonstrate the material's potential and the importance of wear resistance in diverse fields.

Acknowledgements

None.

Conflict of Interest

None.

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