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Research Article

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Improvement of Surface Roughness on AA5059 Reinforced Novel Encapsulated Nano Kaolinite Metal Matrix Composite by the Drilling Process

Annadurai Kaviarasu[1], Lakshmaiya Natrayan[1*] and Sivakumar Vidhya Lakshmi[2]

[1]Department of Mechanical Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu, India
[2]Department of Civil Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu, India

[*]Correspondence to:
Lakshmaiya Natrayan
Department of Mechanical Engineering,
Saveetha School of Engineering,
Saveetha Institute of Medical and
Technical Sciences,
Chennai, Tamil Nadu, India.
E-mail: natrayanl.sse@saveetha.com

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Abstract

This study compared the surface roughness of composites with 10% nano kaolinite and manufactured them with a novel encapsulation technique to the as-cast AA5059. Utilizing a novel encapsulation technique, the stir-casting process was employed to create samples for both groups. For group 1, AA5059 was used as cast, while for group 2, a composite comprised of nano kaolinite (10%) and AA5059 was used. The samples were made following ASTM E92 specifications, and the surface roughness was assessed using a Mitutoyo surface roughness tester (SJ-410). Each group contained 20 samples. The sample size calculation was performed using a G-power of 80%, α per set = 0.05, and a total sample size of 40. The material containing 10% nano kaolinite filler exhibits the highest surface finish, which is 39% lesser than AA5059 in its as-cast state. The statistical t-test research demonstrates that there could be a significant p = 0.00 ($p < 0.05$) difference between group 1 and group 2's mean variance of surface finish. Within the limitations of this study, it is manifest that the 10% nano kaolinite reinforcement significantly reduces the AA5059 composite's surface roughness.

Keywords

AA5059, Kaolinite, Stir casting, Composite, Energy, Novel encapsulation, Surface roughness, Substantiality

Introduction

As a result of the severe climate change and energy pollution, all nations are now placing a greater emphasis on energy efficiency, pollution reduction, and performance enhancement [1]. In reality, using and creating light materials (like aluminum) can cause a significant reduction in the weight of the vehicle. For the sustainable industry to thrive over time, lightweight materials are crucial. The aluminum alloy AA5059 has a large amount of hardness, good formability, and high corrosion resistance. Compared to the standard AA5083 aluminum alloy, the complex AA5059 aluminum alloy offers a substantial increase in strength [2]. AA5059 contains greater magnesium (Mg) concentrations than AA5083 and more zinc and zirconium for grain refinement. It is a Mg alloy that cannot be heated and is produced in Koblenz, Germany, by Aleris International, Inc. The chemical formula for nano kaolinite is $Al_2Si_2O_5(OH)_4$, and it is made up of silicate sheets (Si_2O_5) that are connected to layers of aluminum oxide/hydroxide ($Al_2(OH)_4$) by the arrangement of tetrahedral and octahedral sheets. To increase its wear resistance, nano kaolinite is utilized as reinforcement in AA5059. Mechanical strain hardening makes it more durable [3]. Because of its excellent weldability, many structural components are joined together using aluminum alloy. Due to its superior performance, aluminum alloy is employed in various industries, including marine, aviation, automotive, and defense [4]. The construction of ships, the aviation sector, and other fields involving electronics all make extensive use of it. Therefore, this composite material's strength will significantly increase, and it might be utilized to make products across various industries.

AA5059's surface roughness has recently been discussed in several articles. Related to the AA5059 and surface roughness, there are 171 research papers published in Google Scholar, while 41 research articles were published in Science Direct. Study on mechanical and wear properties of Al 7075/Al_2O_3/graphite hybrid composites [5]. Ballistic performance testing of aluminum alloy 5059-H131 and 5059-H136 for armor applications [6, 7]. Experimental investigation on mechanical behaviour, modelling, and optimization of wear parameters of B_4C and graphite reinforced aluminum hybrid composites [8]. 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 [9]. The publication on the hybrid composites prepared by novel encapsulation feeding technique that most thoroughly described the novel encapsulation technique is regarded as the finest effort [10]. The merging of mechanical and computer science disciplines is demonstrated in this paper's optimization of the composite well with several reinforcements and the addition of the artificial neural network approach with a novel encapsulation feeding casting technology [11].

This research found that research on the development of composites using novel encapsulation techniques has been conducted a limited number of times. To generate the AA5059/10% nano kaolinite composite, this study attempted to establish a novel encapsulating stir-casting technique. The study's objective was to compare the surface roughness characteristics of the composite material with the as-cast material.

Materials and Method

This comprehensive study was carried out across multiple institutions: the Institute of Mechanical Engineering, Saveetha Industries, Saveetha School of Engineering, and Saveetha Institute of Medical and Technical Sciences, Chennai (Tamil Nadu, India). The research aimed to analyze the surface roughness of two groups: as-cast and composite materials. Specifically, these materials had a thickness of 10 mm. A total of 40 samples were examined, equally split between the two categories, ensuring a solid sample size with G-power at 80%.

For the as-cast group, labeled as group 1, 20 samples were prepared. The procedure began with a 20 mm AA5059 rod subjected to lathe operations to ensure a polished surface finish and eliminate extraneous material or burrs. Once polished, 1 kg of AA5059 was placed in a crucible and then heated to 700 °C until the alloy melted. Post-melting, the alloy was transferred into a mold and allowed to solidify. The solidified metal was then extracted from the mold and any excess material was discarded. Subsequently, the metal was converted into a 10 mm thick plate, with surface roughness being assessed for all 20 samples.

On the other hand, for the composite materials labeled as group 2, a similar 20 mm diameter AA5059 rod underwent lathe operations. This rod was then drilled at one end and further holes of varying diameters were added along its length. This rod was then filled with 10% kaolinite, followed by a sealing process using a specially crafted cup. The entire assembly was then melted in a furnace. Upon melting, the molten AA5059 alloy was amalgamated with the 10% nano kaolinite through a stir-casting method. This mixture was poured into a mold and once solidified, excess material was removed. The composite was then fashioned into a 10 mm thick plate, ready for surface roughness assessment for all 20 samples.

A specialized Mitutoyo surface roughness tester (SJ-410) was employed to test surface roughness. This testing adhered to the ASTM standard, wherein each 40 samples was fashioned into a 10 mm thick plate. The tester's methodology involved aligning the metal sample's drill hole with the tester's needle. A visual inspection was then carried out before activating the tester. The device's needle traverses the sample's surface, discerning if the metal surface is regular or irregular. Depending on the findings, appropriate measurements were taken. The tester operated at various speeds, ranging from 0.002 to 0.04 in/s.

All collected data was systematically cataloged. Surface roughness values for the as-cast samples were documented in the 2nd column of table 1, while those for the composite samples were recorded in the 3rd column of table 1.

Statistical analysis

IBM corporation's statistical software program SPSS (Statistical Package for the Social Sciences) is utilized for data administration, data analysis, mathematical modelling, etc. The t-test has been done on the surface roughness value obtained for this article using the SPSS software. The descriptive, independent sample test and independent sample

Table 1: Surface roughness of as-cast AA5059 and AA5059 reinforced with kaolinite.

Sample number	As-cast AA5059	AA5059 with reinforcement 10% kaolinite
1	9.041	5.757
2	8.630	5.346
3	8.381	5.097
4	8.139	4.855
5	7.807	4.523
6	7.721	4.437
7	7.807	4.523
8	8.172	4.888
9	9.040	5.756
10	10.266	6.982
11	11.317	8.033
12	8.715	5.431
13	8.304	5.020
14	8.055	4.771
15	7.813	4.529
16	7.481	4.197
17	7.395	4.111
18	7.481	4.197
19	7.846	4.562
20	8.714	5.430

test tables are obtained using the SPSS application. In this article, the dependent variable is surface roughness, while the independent variables are considered to be stir speed and the weight percentage of reinforcement. The standard deviation, significance, and mean statistics are also obtained for our study [12].

Results

Table 1 provides an overview of the surface roughness, measured in microns, for both the as-cast AA5059 metal without any reinforcement and the AA5059 metal that has been reinforced with 10% kaolinite. Following this, table 2 presents group statistics detailing the distribution and measures of surface roughness in both aforementioned metal types. Moving on, table 3 delves deeper by offering the results of the independent samples test. This test compares the surface roughness of the non-reinforced as-cast AA5059 metal with its counterpart that has been reinforced with 10% kaolinite. Lastly, table 4 furnishes descriptives, which likely include measures such as mean, median, and standard deviation, pertaining to the surface roughness of both metal categories. Therefore, it's evident from these tables that comprehensive data regarding surface roughness has been meticulously recorded and presented for both groups of metals.

Figure 1 presents nano kaolinite (10% reinforcement). Figure 2 presents feeding nano kaolinite to novel encapsulated AA5059. Figure 3 presents stir casting process. Figure 4 presents material for surface roughness. Figure 5 presents surface roughness test.

Discussion

The outcome of our research clearly shows that the surface

Figure 1: Nano kaolinite (10% reinforcement).

Figure 2: Feeding nano kaolinite to novel encapsulated AA5059.

Figure 3: Stir casting process.

Table 2: Group statistics of surface roughness in as-cast AA5059 metal without reinforcement and AA5059 with reinforcement of 10% kaolinite.

Group statistics		N	Mean	Std. deviation	Std. error mean
Surface roughness (Microns)	As-cast AA5059 without reinforcement	20	8.4063	0.96858	0.21658
	AA5059 without reinforcement kaolinite	20	5.1223	0.96858	0.21658

Table 3: Independent samples test of the surface roughness in as-cast AA5059 metal without reinforcement and AA5059 with reinforcement of 10% kaolinite.

Surface roughness (Microns)	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	10.722	38	0.000	3.28400	0.30629	2.66394	3.90406
Equal variances not assumed			10.722	38	0.000	3.28400	0.30629	2.66394	3.90406

Table 4: Descriptive of the surface roughness in as-cast AA5059 metal without reinforcement and AA5059 with reinforcement of 10% kaolinite.

	N	Mean	Std. deviation	Std. error	95% CI for mean		Minimum	Maximum
					Lower bound	Upper bound		
As-cast AA5059 without reinforcement	20	8.4063	0.96858	0.21658	7.9529	8.8596	7.40	11.32
AA5059 without reinforcement kaolinite	20	5.1223	0.96858	0.21658	4.6689	5.5756	4.11	8.03
Total	40	6.7643	1.91818	0.30329	6.1508	7.3777	4.11	11.32

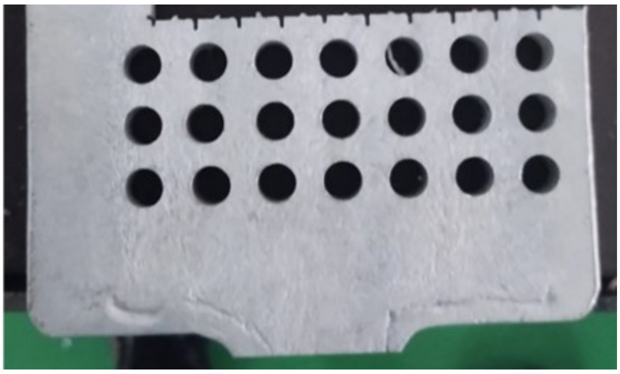

Figure 4: Material for surface roughness.

Figure 5: Surface roughness test.

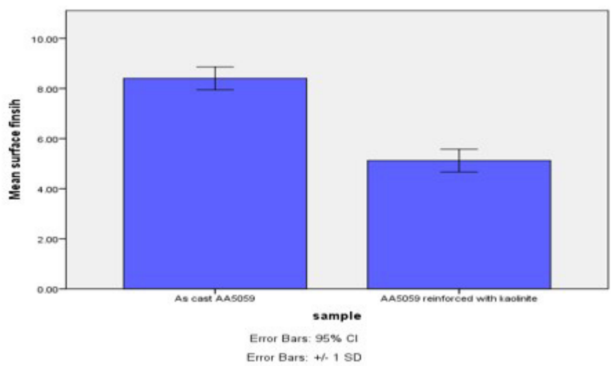

Figure 6: Mean surface roughness value comparison without and with 10% kaolinite.

roughness value of AA5059 with reinforcement of 10% nano kaolinite is reduced more when compared to as-cast AA5059 metal without reinforcement. Using the values of standard deviation, significance, and mean statistics from descriptive and independent sample test tables are also obtained for our study and it leads us to make it simpler to compare the value of surface roughness for both metals. Evaluating mechanical and metallurgical properties of gas tungsten arc welded AA 5059 aluminum alloy joints [13]. This paper utilized the gas tungsten arc welding for the aluminum alloy to produce a stronger alloy than the base metal. Friction stir welding process for AA5059 metal to improve its property more than the base metal [14]. Microstructure-property characterization of a friction-stir welded joint between AA5059 aluminum alloy and high-density polyethylene [15]. It describes the microstructure property of friction stirs welding with polyethylene. Few researchers mentioned that composite materials have better material properties than the base metal, especially in surface roughness [16]. This research introduced a new concept of a novel encapsulation technique that helps the reinforcement mix with the metal equally during casting [17]. It leads to a better surface finish on the AA5059 with 10% nano kaolinite than the as-cast metal. Therefore, in figure 6, this research showed a 39% lesser surface finish value than the as-cast metal compared to composite metal.

The mean result indicates that the AA5059 with nano kaolinite achieved 39% lower than the as-cast metal in surface roughness [18]. The stirrer blade and pouring method are the factors that have affected our research work. The limitations of our work are found in casting defects like blow holes, pin holes and sometimes shrinkage cavities. This is caused by pouring the molten metal under gravity into the die [19]. So, this is taken into account as the limitations of our work. Thus, the future scope is to diminish air bubbles generated while pouring the molten metal into the die by replacing the squeeze casting method.

Conclusion

In this study, a new encapsulation technique was employed to explore the surface finish of the AA5059 metal when reinforced with 10% kaolinite. The findings revealed a noticeable decline in the surface finish of the AA5059 metal combined with this percentage of kaolinite. Specifically, when juxtaposed with the original as-cast AA5059 metal, the reinforced alloy demonstrated a surface finish value that was approximately 39% lower. This decline in surface roughness for the AA5059 metal, when combined with 10% kaolinite, was significantly achieved using the innovative encapsulation approach and the stir casting process. Such a reduction in surface roughness suggests potential applications for the reinforced AA5059 metal. For instance, it may be ideal for creating smoother vehicle armor. Its properties make it suitable for constructing cryogenic propellant tanks and various maritime building projects.

Acknowledgements

None.

Conflict of Interest

None.

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