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Experimental Study on Hardness of AA5059 Reinforced Kaolinite Composite Subjected to Novel Encapsulate Technique

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Abstract

This study aimed to compare as-cast AA5059 to composites reinforced with 10% kaolinite and made using a novel encapsulation technique that determines their hardness level. Using a novel encapsulation technique, the stir-casting method generated the samples for both groups. The mixture of kaolinite (10%) and AA5059 was exploited as a composite for group 1, while AA5059 as-cast was employed for group 2. ASTM E92 standards produced the samples, and a Vickers hardness machine was deployed to measure the hardness of the samples. There were 20 samples in each group. The sample size calculation was done using a G-power of 80%, $\alpha = 0.05$ per set, and a total sample size of 40. The (10%) kaolinite-filled material had the maximum hardness, 48% harder than the as-cast AA5059. According to statistical analysis of the t-test, it is observed that there is a significant $p = 0.00$ ($p < 0.05$) difference in the mean variance of hardness between group 1 and group 2. Within the limitations of this study, it was observed that the hardness of the AA5059 composite is immensely enhanced by adding the 10% kaolinite reinforcement.

Keywords

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

Introduction

Due to the severe energy crisis and environmental pollution, all governments are now focusing globally more on energy conservation, pollution reduction, and performance improvement. Choosing and developing light materials (such as aluminum) can considerably decrease the vehicle's weight [1]. Therefore, lightweight materials are essential for the long-term growth of the sustainable sector. AA5059 aluminum alloy is a lightweight structural alloy with excellent corrosion resistance, outstanding formability, and significant hardness. The complex AA5059 aluminum alloy offers significant strength improvements over the conventional AA5083 aluminum alloy. In addition to more zinc (Zn) and zirconium (Zr) for grain refining, AA5059 has higher Mg (magnesium) concentrations than AA5083. It is a non-heat treatable alloy with Mg and manufactured in Koblenz, Germany, by Aleris International, Inc. $Al_2Si_2O_5(OH)_4$ is the formula for kaolinite, which is made up of silicate sheets (Si_2O_5) connected to layers of aluminum oxide/hydroxide ($Al_2(OH)_4$) by the arrangement of tetrahedral and octahedral sheets [2]. AA5059 is reinforced with kaolinite which leads to higher strength. It is toughened by mechanical strain hardening. Aluminum alloy is frequently used to combine structural components due to its high weldability. Because of its enhanced performance, aluminum alloy is employed in several industries, including marine, aerospace, automotive, and defense. It is used extensively in the construction of ships, the aviation industry, and other sectors that deal with electronics. Therefore, this composite material will drastically increase its strength and can be applied to various industries to manufacture its products [3-6].

Recently, several articles were published about the AA5059 and its hardness level. There are 171 research articles in Google Scholar whereas 41 research articles were in Science Direct based on the AA5059 and hardness level. Effect of low cast-rolling speeds on the microstructure and mechanical properties of twin-roll casting high Mg AA5059 alloy sheets. Evaluating mechanical and metallurgical properties of gas tungsten arc welded AA 5059 aluminum alloy joints. Influence of nano graphite on dry sliding wear behavior of novel encapsulated squeeze cast Al-Cu-Mg metal matrix composite using artificial neural network. 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 [7]. The work on the hybrid composites prepared by the novel encapsulation feeding technique is considered the best article narrating the novel encapsulation technique [8-11]. This paper optimized the composite with more than one reinforcement and added to this. They also implemented the artificial neural network method with a novel encapsulation feeding technique for casting, showing the combination of mechanical and computer science fields.

This research has noticed that relatively limited studies have been done on developing composites with novel encapsulation techniques. This study aimed to develop a novel encapsulating stir-casting method to fabricate the AA5059/10% kaolinite composite. The study has been conducted to compare the hardness properties of the as-cast and composite materials.

Materials and Method

The Institute of Mechanical Engineering, Saveetha Industries, Saveetha School of Engineering, and Saveetha Institute of Medical and Technical Sciences, Chennai (Tamil Nadu, India), served as the study location for this study. The as-cast and composite material were the two groups that contributed to this study to examine hardness. The 8 - 10 mm thick as-cast and composite samples were utilized in the research to compare the hardness properties. There are two groupings with a total of 40 sizes. G-power was determined to be 80% while carrying out samples on each group of 20 sizes [12].

This research considers the as-cast material as group 1 to prepare the 20 samples. Initially, a 20 mm diameter AA5059 rod is taken to the lathe operations to perform the machining on the surface of the alloy. It leads to obtaining a suitable surface finishing on the material to get a smooth surface and ride out the unnecessary burs or material on the surface of the metal [13]. After machining, 1 kg of AA5059 has been kept inside the crucible which has a capacity of 1 kg. Then, the crucible is placed inside the furnace along which the temperature of the furnace is gradually increased up to the range of 700 °C to start melting the alloy inside the crucible. Followed by the melting process, the molten metal is allowed to pour into the mould under gravity and let to cool down the temperature. Finally, the casting metal has to be removed from the mold and remove the excess material. The casting metal is cut into 8 - 10 mm pieces for hardness testing [14].

These research works were carried out in two groups, each with 20 samples. First, a 20 mm diameter AA5059 rod has to be machined with a lathe machine to get the smooth bur-free material. Using a 2 mm drill bit, a hole is drilled at the center of one end of the rod. With the help of 4 mm, 6 mm, and 12 mm drill bits, a drill has to be made up to 50 mm in the rod one by one. In figure 1, kaolinite (10%) is weighed at 10 g. In figure 2, 10% kaolinite is filled in the depth of the drilled rod and covered using a 15 mm thick cup made using a lathe machine [15]. The crucible is placed inside the furnace after being filled with the rod and gradually increases the temperature to melt down the rod. In figure 3, molten AA5059 alloy is mixed with the 10% kaolinite and poured into the mould using the stir-casting method. After cooling, the composite is removed

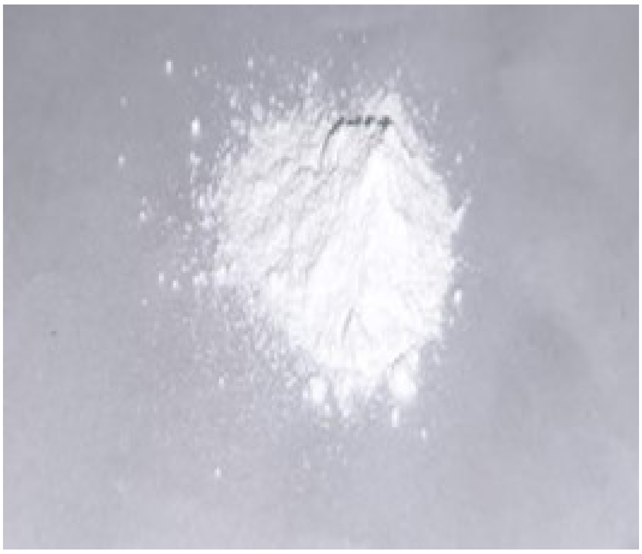

Figure 1: Kaolinite (10% reinforcement).

Figure 2: Feeding kaolinite to novel encapsulated AA5059.

Figure 3: Stir casting.

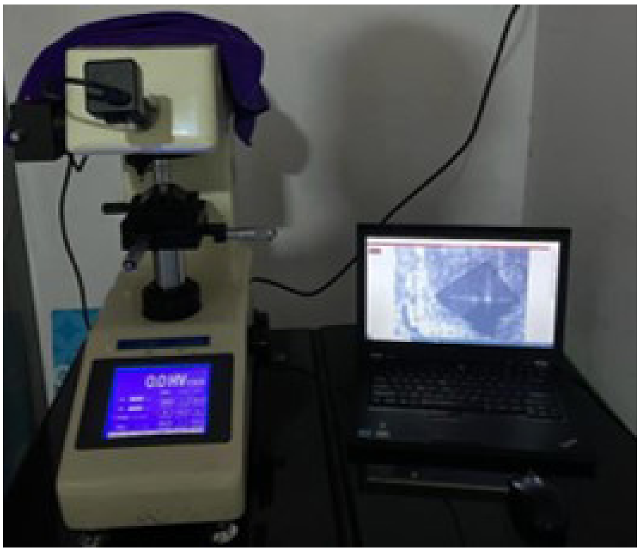

Figure 4: Hardness test.

from the mold, and excess material is removed from the composite [16]. For hardness testing, the composite material is cut into 8 - 10 mm pieces.

A Vickers hardness tester machine conducts the hardness test for both as-cast and composite material. As per the ASTM E92 standard, each of the 20 samples per group is sliced using the dimension of 10 x 10 mm for hardness testing. In figure 4, a sample is placed at the working table and start the machine for the hardness test. A force is applied to the sample using the diamond indenter to obtain an indentation. The applied force is 0.5 kgf and the hardness test's dwell time is 10 s. Using the microscope, the depth of indentation is evaluated by the readings on the three locations on the sample. After evaluating the hardness of the sample, the reading has displayed on the screen [17-20].

The above process is repeated 3 times for every 20 samples per group. The hardness value of all 20 samples of as-cast material is entered in the 2nd column of table 1 and the hardness value of all 20 samples of composite material is entered in the 3rd column of table 1.

Statistical analysis

SPSS (Statistical Package for the Social Sciences) is a software developed by IBM for data management, data analysis, mathematical modeling, etc. Using the SPSS statistical software, the T-test is conducted to the hardness measurements generated for the research samples. The descriptive and independent sample tests are performed using the statistical software SPSS. In This research, stir speed and reinforcement weight percentage are independent variables, while hardness is the dependent variable. Additionally, the study provides the mean data, significance, and standard deviation [20].

Results

Table 1 shows the hardness of as-cast AA5059 without reinforcement and AA5059 with reinforcement kaolinite. Table 2 shows group statistics of hardness in as-cast AA5059 and AA5059 with reinforcement kaolinite.Table 3 shows the independent samples test of the hardness. Table 4 shows the descriptive of the hardness as-cast AA5059 without reinforcement and AA5059 with reinforcement kaolinite. As a result, the hardness data are recorded in the two group's tables.

Discussion

The data show that the as-cast AA5059 with reinforce-

Table 1: Hardness of as-cast AA5059 and AA5059 with kaolinite.

Sample number	As-cast AA4032	AA5059 with reinforced kaolinite
1	31.09	57.41
2	30.94	57.26
3	30.03	56.35
4	31	57.32
5	28.8	55.12
6	28	54.32
7	28.66	54.98
8	26.88	53.2
9	28.23	54.55
10	29.33	55.65
11	27.89	54.21
12	27.24	53.56
13	25.92	52.24
14	25.54	51.86
15	23.78	50.1
16	25.14	51.46
17	26.94	53.26
18	27.94	54.26
19	29.54	55.86
20	29.93	56.25

Table 2: Group statistics of hardness in as-cast AA5059 and AA5059 with reinforcement kaolinite.

Group statistics		N	Mean	Std. deviation	Std. error mean
Hardness	As-cast AA5059 without reinforcement	20	28.1410	2.04227	0.45666
	AA5059 without reinforcement kaolinite	20	54.4610	2.04227	0.45666

Table 3: Independent samples test of the hardness in as-cast AA5059 and AA5059 with kaolinite.

		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
Hardness	Equal variances assumed	0.000	1.000	-40.75	38	0.000	-26.32	0.645	-27.62740	-25.01260
	Equal variances not assumed			-40.75	38	0.000	-26.32	0.645	-27.62740	-25.01260

Table 4: Descriptive of the hardness of as-cast AA5059 and AA5059 with kaolinite.

	N	Mean	Std. deviation	Std. error	95% CI for mean		Minimum	Maximum
					Lower bound	Upper bound		
As-cast AA5059 without reinforcement	20	28.1410	2.0422	0.45666	27.185	29.096	23.78	31.09
AA5059 without reinforcement kaolinite	20	54.4610	2.0422	0.45666	53.505	55.416	50.10	57.41
Total	40	41.3010	13.479	2.1312	36.990	45.611	23.78	57.41

ment kaolinite significantly improves hardness than the as-cast AA5059 without reinforcement. To simplify the process, the descriptive and independent sample test table results also show us the mean, standard deviation, standard mean error, etc. data. It enables readily determining both materials' hardness for analysis. Previously, the study on the gas tungsten arc welded AA5059 aluminum alloy joints provided 38% less hardness than the base material in a welded zone. Another work on friction stir welded AA5059 aluminum alloy joints gives 15% less hardness than the base metal at welded zone [21]. This study uses Al_2O_3 and graphite as hybrid reinforcement for aluminum alloy, which provides 15% more hardness than the stock material. But in our research, in figure 5, this research got 48% more hardness than the as-cast AA5059 for AA5059/10% kaolinite composite. The aluminum alloy had also been cast using a novel encapsulation technique that this research developed, and it has a better hardness than the other AA5059 alloy in earlier studies [22]. It is accomplished using both the stir-casting and novel encapsulation techniques, which leads to evenly spreading the reinforcement to all metals during casting. As an outcome, this research generated a composite with a substantially higher hardness employing a novel encapsulation technique and kaolinite as reinforcement.

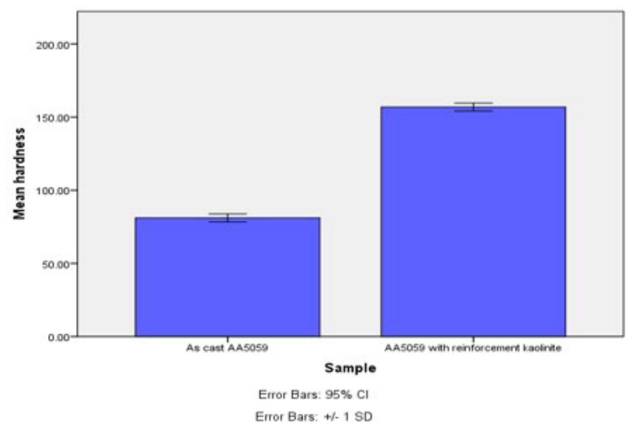

Figure 5: Mean hardness in comparison with and without reinforcement. The mean value shows that the hardness of composite metal with reinforcement had a maximum value of 48% more than the as-cast metal in hardness value.

The stirrer and pouring technique are two aspects that are affecting our research. Due to the molten metal flowing to the die under gravity, this research occasionally discovered shrinkage cavities, pinholes, and blow holes in castings. This research recognized that this casting defect had limited our study. The goal of this study's future research is to use squeeze casting to prevent the production of air bubbles from preventing such casting defects.

Conclusion

Within the limitations of this study, concluded that the novel encapsulation technique increases the hardness of the composite material (AA5059 with 10% kaolinite). A 10% kaolinite reinforcement added to the AA5059 alloy increased its hardness by around 48% compared to the as-cast AA5059 material. An essential factor in the hardness of AA5059 with 10% kaolinite was a novel encapsulation technique combined with stir casting. Since AA5059 with 10% kaolinite has increased hardness, it may be utilized to create vehicle armor that can withstand enough hardness application. It can also produce various ship designs and cryogenic propellant tanks.

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Conflict of Interest

There is no conflict of interest in this manuscript.

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