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An Experimental Investigation on Surface Roughness of AA4032 Reinforced Si_3N_4 Novel Encapsulated Metal Matrix Composite by Drilling Process

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Abstract

This study compared the surface roughness of composites with 10% Si_3N_4 and manufactured them with a novel encapsulation technique to the as-cast AA4032. Utilizing a novel encapsulation technique, the stir-casting process was employed to create samples for both groups. For group 1, AA4032 was used as cast, while for group 2, a composite comprised of Si_3N_4 (10%) and AA4032 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% Si_3N_4 filler exhibits the highest surface finish, which is 39% lesser than AA4032 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% Si_3N_4 reinforcement significantly reduces the AA4032 composite's surface roughness.

Keywords

AA4032, Si_3N_4, Productivity, Energy, Stir casting, Composite, Sustainability, Novel encapsulate, Surface roughness

Introduction

As a result of severe climate change and energy pollution, all nations are now focusing more on energy efficiency, pollution reduction, and performance enhancement. Using and developing light materials (such as aluminum) can significantly reduce vehicle weight [1]. For the sustainable sector to thrive over time, lightweight materials are essential. The aluminum alloy AA4032 offers high hardness, formability, and corrosion resistance. Compared to the conventional AA5083 aluminum alloy, the complex AA4032 aluminum alloy significantly improves strength. As a result, lightweight materials are especially vital for the long-term growth of sustainable businesses. AA4032 is an aluminum alloy with excellent formability and high corrosion resistance. Because of its exceptional weldability, aluminum alloy is commonly utilized to join structural components [2]. Because of its superior performance, aluminum alloy is used in various industries, including marine, aviation, automotive, and defense. It is widely used in the shipbuilding industry, the aviation industry, and other electronic-related fields. This composite material will become substantially stronger and be appropriate for creating items across various sectors.

Eventually, many publications describing the AA4032 and its surface roughness were produced. Science Direct has 56 research papers based on the AA4032

and surface roughness, whereas Google Scholar has around 259 papers. This project shows the merging of mechanical and computer science fields by optimizing the composite well with multiple reinforcements [3]. They also used an artificial neural network approach with a novel encapsulation feeding process for casting. Our group members have a wealth of knowledge and a complete understanding of this revolutionary capsule [4].

We noticed few works on the fabrication of composites utilizing novel encapsulating techniques. This research aimed to create a novel encapsulating stir-casting process for creating the AA4032/10% Si_3N_4 composite. The study's purpose was to look at the properties of as-cast material.

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 two groups that contributed to this study's investigation of surface roughness were as-cast material and composite material [5]. The as-cast and composite samples were machined to be cylindrical shapes, which was employed in the study to compare the surface roughness. There are two classes and a total of 40 sizes. G-power was discovered to be 80%, with each classification having 20 sizes [6].

We consider the material cast as group 1 to produce the 20 samples. To begin machining on the alloy's surface, a rod of AA4032 20 mm diameter is initially inserted into the lathe operations. A smooth surface and removing any extra material or burs on the metal's surface result in a more excellent surface polish. After the machining, the crucible, which has a capacity of 1 kg, still retains 1 kg of AA4032. The crucible is placed in the furnace, and the temperature is gradually raised to around 700 °C to begin melting the alloy inside the crucible. Following melting, the molten metal can flow against gravity into the mold and cool. Finally, the excess material must be removed after extracting the casting metal from the mold. The casting metal is then divided into numerous cylindrical parts for surface roughness [7-10].

We regard the material in its as-cast form as group 1 to prepare the 20 samples. The lathe operations begin with the introduction of a 20 mm diameter AA4032 rod for the aim of machining the alloy's surface. It results in a smooth surface and eliminates any extra material or burs on the metal's surface. Following the machining operation, a 1 kg capacity crucible now held 1 kg of AA4032. The alloy inside the crucible begins to melt as soon as it is placed in the furnace, which is gradually heated to a temperature of 700 °C. Once melted, the metal is allowed to fall into the mold by gravity and then relaxed. The casting metal is withdrawn from the mold, and the excess material is removed. The casting metal is then drilled 20 times into a 10 mm thick plate to determine its surface roughness.

We treat the composite material as group 2 while preparing the 20 samples. To begin, a smooth, bur-free AA4032 rod of 20 mm diameter must be turned on a lathe. A 2 mm drill bit is used to make a hole in the center of one end of the rod. One by one, drill holes up to 50 mm must be made in the rod using drill bits with 4 mm, 6 mm, and 12 mm diameters [9-11]. In figure 1, a 15 mm thick cup created on a lathe is used to cover the drilled rod after it has been filled with 10% Si_3N_4 and filled to the depth of the rod. In figure 2, after being filled with the rod, the crucible is inserted into the furnace, progressively raising the temperature to melt the rod. In figure 3, molten AA4032 alloy is mixed with 10% Si_3N_4 using the stir-casting technique and then poured into the mold. After cooling, the composite is removed from the mold, and excess material is removed. In figure 4, the composite material is then drilled into a 10 mm thick metal for 20 drills to determine surface roughness.

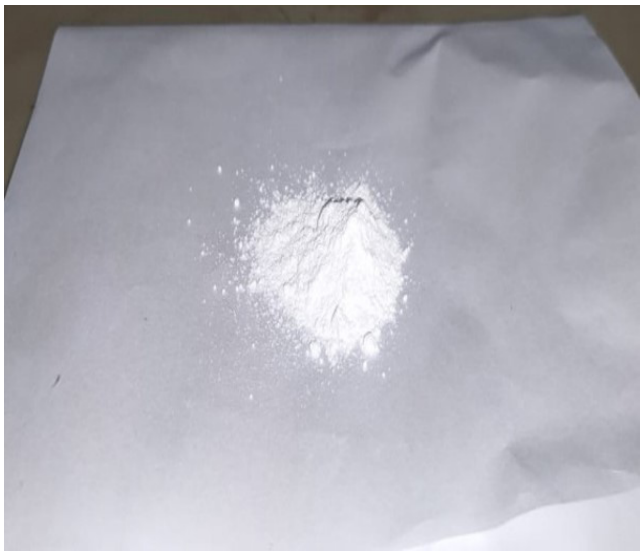

Figure 1: Si_3N_4 (10% reinforcement).



Figure 2: Feeding Si_3N_4 to novel encapsulated AA4032.

As-cast and composite metal surface roughness is tested using a Mitutoyo surface roughness tester (SJ-410). Every 20 drills per group are drilled into a 10 mm thickness plate by ASTM standard for surface roughness. In figure 5, we must align the drill hole in the metal with the tester's needle. The surface of the metal has to be visually examined and turned



Figure 3: Stir casting.

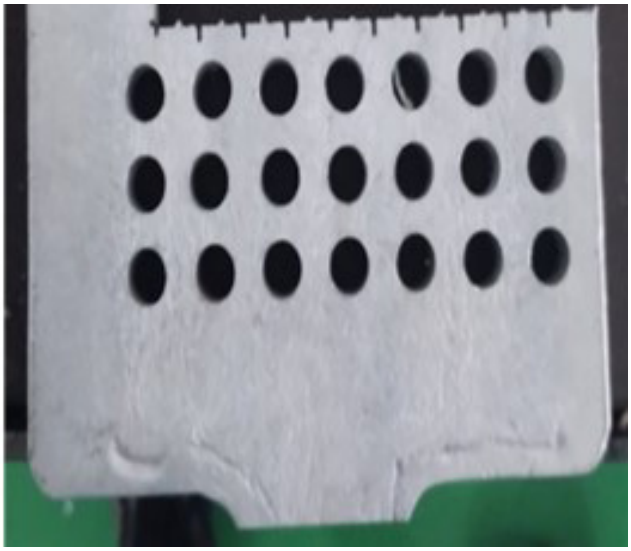

Figure 4: Material for surface roughness.



Figure 5: Surface roughness test.

on by the tester. The needle skids the surface of the drill hole to determine whether the surface of the Mitutoyo surface roughness metal is periodic or non-periodic. The corresponding sampling length is determined, and the measurements are carried out. Finally, the threshold value has to be evaluated for the parameters from the measured values displayed on the screen. This tester measures speeds of 0.002, 0.004, 0.008, 0.02, and 0.04 mm/s.

This technique must be followed for each group of 20 drills. The surface roughness values of all 20 drills of as-cast material are recorded in the 2nd column of table 1, and those of all 20 samples of composite material are reported in the 3rd column of table 1.

Table 1: Surface roughness of as-cast AA4032 and AA4032 reinforced with Si_3N_4.

Sample number	As-cast AA4032	AA4032/Si_3N_4
1	8.172	6.506
2	7.761	6.095
3	7.512	5.846
4	7.270	5.604
5	6.938	5.272
6	6.852	5.186
7	6.938	5.272
8	7.303	5.637
9	8.171	6.505
10	9.397	7.731
11	10.448	8.782
12	7.846	6.180
13	7.435	5.769
14	7.186	5.520
15	6.944	5.278
16	6.612	4.946
17	6.526	4.860
18	6.612	4.946
19	6.977	5.311
20	7.845	6.179

Statistical analysis

IBM Corporation's statistical software application SPSS (Statistical Package for the Social Sciences) [12], is used for data administration, data analysis, mathematical modelling, and other purposes. Using the SPSS software, the t-test was performed on the surface roughness value obtained for this research. The descriptive, independent sample test table is obtained using the SPSS application. In this article, the dependent variable is surface roughness, whereas the independent variables are the stirring speed and the weight percentage of reinforcement. We also collected our investigation's standard deviation, significance, and mean statistics.

Results

Table 1 shows the surface roughness (micron) of as-cast AA4032 metal without reinforcement and AA4032 with 10% Si_3N_4 reinforcement. Table 2 displays the group statistics of surface roughness (micron) in as-cast AA4032 metal without reinforcement and AA4032 with 10% Si_3N_4 reinforcement. Table 3 displays the independent samples test of surface

Table 2: Group statistics of surface roughness in as-cast AA4032 metal without reinforcement and AA4032 with reinforcement of 10% Si_3N_4.

Group statistics		N	Mean	Std. deviation	Std. error mean
Surface roughness (micron)	As-cast AA4032	20	7.5373	0.96858	0.21658
	AA4032/ Si_3N_4	20	5.8713	0.96858	0.21658

roughness (micron) in as-cast AA4032 metal without reinforcement and AA4032 with 10% Si_3N_4 reinforcement. Table 4 displays the surface roughness (micron) characteristics of as-cast AA4032 metal without reinforcement and AA4032 with 10% Si_3N_4 reinforcement. The term "responsibility" refers to the act of determining whether or not a person is responsible for their actions. As a result, the surface roughness data for both groups are listed in the table.

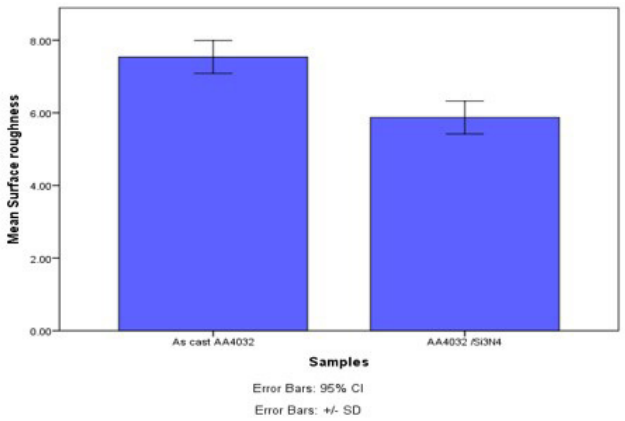

Figure 6: Mean surface roughness value of comparison without and with 10% Si_3N_4.

Discussion

Our findings clearly show that the surface roughness value of AA4032 with 10% Si_3N_4 reinforcement is reduced more than as-cast AA4032 metal without reinforcement. Using the standard deviation, significance, and mean statistics from the descriptive table are also obtained for our study. It leads us to make it simpler to compare the value of surface roughness for both metals. This paper utilizes kerf width and surface roughness studies using the response surface methodology in AA 4032-TiC composites [13-14]. Performance analysis of conventional and DMLS copper electrode during EDM process in AA4032-TiC composite. Studies on friction behavior of aluminum AA4032 alloy during forging using ring compression test. Reducing in-cylinder parasitic losses through surface modification and coating. A numerical study of the direct-chill co-casting of aluminum ingots via Fusion™ technology [11, 15]. We presented a novel encapsulation technique that allows the reinforcement to mix evenly with the metal during casting. The AA4032 with 10% Si_3N_4 has a better surface finish than the as-cast metal. In figure 6, As a result, when comparing as-cast metal to composite metal, we obtained a 22% lower surface finish value. Similarly, the past investigation proved their enhancement.

The mean result indicates that the AA4032 with 10% Si_3N_4 got a 22% lower surface finish value than the as-cast metal without Si_3N_4 in wear resistance. The stirrer blade and pouring method are the factors that have influenced our research. Our work is limited by casting flaws such as blow holes, pin holes, and sometimes shrinkage cavities. This is caused by pouring the molten metal under gravity into the die. Thus, by replacing the squeeze casting method, the future scope is to reduce the generation of air bubbles while pouring the molten metal into the die.

Conclusion

Within the constraints of this study, we concluded that the surface finish of the AA4032 metal reinforced with 10% Si_3N_4 is reduced using a novel encapsulation technique. Compared to the as-cast AA4032 metal, the AA4032 alloy with 10% Si_3N_4 reinforcement has a 39% lower surface finish value. The surface roughness of AA4032 with 10% Si_3N_4 was significantly reduced using a novel encapsulation technique and stir casting method. Because AA4032 with 10% Si_3N_4 has

Table 3: Independent samples test of the surface roughness in as-cast AA4032 metal without reinforcement and AA4032 with reinforcement of 10% Si_3N_4.

		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
Surface roughness (micron)	Equal variances assumed	0.00	1.000	5.439	38	0.000	1.66600	0.30629	1.045	2.286
	Equal variances not assumed			5.439	38.00	0.000	1.66600	0.30629	1.045	2.286

Table 4: Descriptive of the surface roughness in as-cast AA4032 metal without reinforcement and AA4032 with reinforcement of 10% Si_3N_4.

	N	Mean	Std. deviation	Std. error	95% CI for mean		Minimum	Maximum
					Lower bound	Upper bound		
As-cast AA4032	20	7.5373	0.96858	0.21658	7.0839	7.9906	6.53	10.45
AA4032/Si_3N_4	20	5.8713	0.96858	0.21658	5.4179	6.3246	4.86	8.78
Total	40	6.7043	1.27506	0.20160	6.2965	7.1120	4.86	10.45

a lower surface roughness, it can be used to make vehicle armor with a smoother application. It is also suitable for cryogenic propellant tanks and various shipbuilding projects.

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Conflict of Interest

There is no conflict of interest in this manuscript.

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