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Research Article

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Improvement of Surface Roughness on AA7178/Nano ZrO_2/Fly Ash Metal-matrix Composite via Novel Encapsulate Stir Casting Technique by Drilling Process

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Abstract

This research aims to compare the surface roughness of AA7178 reinforced with 5% fly ash and 5% nano zirconium oxide (ZrO_2) hybrid composites fabricated using a novel encapsulation process to that of as-cast AA7178 alloy. Group 1 consists of AA7178 as-cast samples without any composite material, whereas group 2 comprises AA7178 metal matrix composite prepared using a hybrid composite of fly ash (5%), nano ZrO_2 (5%), and AA7178. The samples for both groups are fabricated by stir casting using a novel encapsulation technique. The samples of both groups were created by following the ASTM E92 guidelines, and a Mitutoyo surface roughness tester (SJ-410) was used to measure the sample's surface roughness. The G-power used for this process is 80%, $\alpha = 0.05$ per set for calculating sample size and the total sample size is 40; each group contains 20 samples. The samples filled with reinforcement of (5% and 5%) fly ash and nano ZrO_2 exhibit a more excellent surface finish than samples of as-cast AA7178 without any reinforcement. Based on t-test statistical analysis, it is obtained that there is a significant $p = 0.00$ ($p < 0.05$) difference between group 1 and group 2 in the mean variance of surface roughness. Within the limitations of this study, it proves that the reinforcement of AA7178 with 5% fly ash and 5% nano ZrO_2 considerably decreases 29.90% of surface roughness compared to as-cast AA7178 alloy.

Keywords

AA7178, Energy, Fly ash, Hybrid composite, Innovation, Novel encapsulate, Sustainability, Stir casting, Surface roughness

Introduction

Increasing the world's population leads to an impact tremendously on environmental changes resulting in the degradation of natural resources in the earth's crust. Over-extraction of limited natural resources and minerals from the earth significantly affects and leads to an energy crisis [1]. To address the depletion of natural resources, it is crucial to embrace sustainable development that utilizes abundant materials without significant environmental impact [2]. Aluminum, the third most abundant element that covers 8.1% of the earth's crust, is a promising material for such purposes. However, without any alloy, pure aluminum offers limited properties other than corrosion resistance [3-5]. Aluminum with alloys like copper, zinc, silicon, magnesium, and manganese improves many more properties of aluminum such as low density, nontoxic, durability, malleable, high strength-to-weight ratio, hardness, corrosion-resistant, good electrical and thermal conductivity, easily machined and excellent recycling characteristics so on. This aluminum and its alloys properties can be enhanced by adding reinforcements materials into the as-cast aluminum alloy, which becomes an aluminum metal matrix composite. Aluminum metal matrix composites are a family of materials that have proven effectiveness in satisfying most of the rigorous standards in applications requiring lightweight, high stiffness, and moderate strength [6]. With a wide range of reinforcing materials and manufacturing flexibility, aluminum metal matrix composites offer higher potential for the development of composites with the desired qualities for specific applications such as aircraft components, spacecraft components, ships, trains, automobile engines, powerlines, consumer electronics, construction of high-rise buildings, window frames, food packing, etc.

Numerous publications on Al7178 and its surface roughness have been published during the last five years. Two hundred research papers were published in Google Scholar, while ten research articles were published in Science Direct. These are some of the papers mentioned in this research, such as aluminum economy for sustainable development: aluminum as core material for energy storage and energy saving products: low cost, high performance, and easy processing in developing countries [7]. Effect of ZrB_2 on microstructural, mechanical, and corrosion behavior of aluminum (AA7178) alloy matrix composite prepared by the stir casting route [8]. The preparation of hybrid reinforced aluminum metal matrix composite using ZrB_2: a systematic review [9]. A novel feeding technique in squeeze casting to improve reinforcement mixing ratio [10]. Influence of B_4C and industrial waste fly ash reinforcement particles on the microstructural characteristics and mechanical behavior of aluminum (Al-Mg-Si-T6) hybrid metal matrix composite. Machining behavior of aluminum 6063 with strengthened aluminum oxide and chicken bone ash produced by modern technique [11]. From the study described above, the one on novel feeding methods in squeeze casting is regarded as one of the outstanding articles. In this study, new approaches for feeding reinforcement were employed to enhance the qualities of aluminum by eliminating casting defects, and good results also were obtained when compared to the outcomes of the other studies. This study of the new feeding approach also enhances metal matrix composite with a superior surface finish compared to previous studies that utilize the same reinforcement material and produce a lower surface finish than the study that employs the novel feeding technique. The team members' profound experience and knowledge of this particular encapsulation technology have provided more helpful information in this research. Our team has extensive knowledge and research experience that has translated into high-quality publications [12].

Based on research, there is a shortage of studies on the fabrication of hybrid metal matrix composites using novel encapsulation techniques. This research aims to fabricate AA7178 alloy with hybrid composites of 5% fly ash and 5% nano ZrO_2 (Figure 1) by employing a novel encapsulate feeding with a stir-casting technique (Figure 2). The central vision of the study is to compare the surface roughness properties between as-cast AA7178 and AA7178 metal matrix composite.

Materials and Method

This research was conducted in the Institute of Mechanical Engineering, Saveetha Industries, Saveetha School of Engineering, and Saveetha Institute of Medical and Technical

Figure 1: Reinforcements of 5% fly ash and 5% nano ZrO_2.

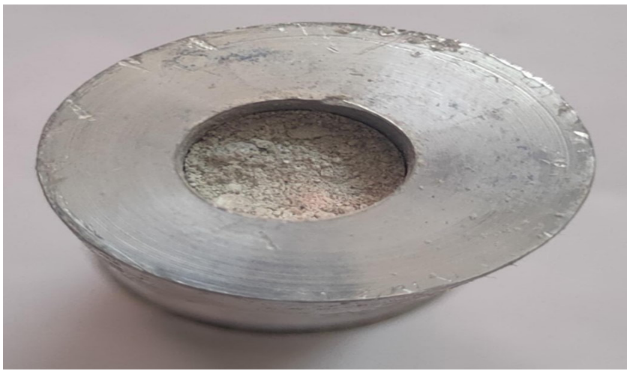

Figure 2: Feeding of 5% fly ash and 5% nano ZrO_2 to novel encapsulated AA7178.

Sciences, Chennai (Tamil Nadu, India). This work compared the surface roughness of as-cast metal and reinforced metal. The sample utilized in the study is a 10 mm thick as-cast metal sample, and the surface roughness property was examined using composite metal. There are two groups of 20 samples each, for 40 samples. G-power was determined to be 80%.

To prepare the samples in group 1, a 20 mm diameter rod of as-cast AA7178 is used for this research. Initially, the rod is machined to provide a superior surface quality and to eliminate metallic rough edges from the rod's ends. After finishing this lathe operation on all AA7178 alloy rod ends. These machined AA7178 alloy rods of 1 kg are placed inside the graphite crucible, which is then placed within the furnace and allowed to heat up to 700 °C, at which point the AA7178 alloy rods inside the furnace melt into the liquid state, as seen in figure 3. The crucible is picked out from the furnace. The molten

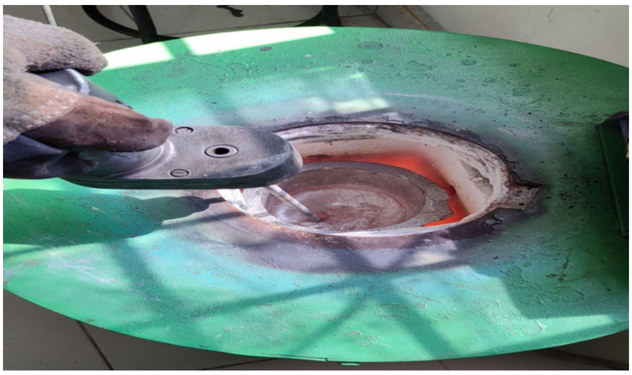

Figure 3: Stir casting setup.

aluminum metal is poured into the die under gravity, allowing the temperature to drop. Finally, the cast aluminum is removed from the die, and a drilling operation is carried out on the cast metal. A total of 20 holes are drilled with an 8 mm drill bit to perform a surface roughness test as shown in figure 4.

To prepare the 20 samples in group 2 made with hybrid composite materials of 5% fly ash and 5% of ZrO_2 as shown in figure 1. To begin, a 20 mm diameter AA7178 rod must be machined on a lathe to erase metallic burrs from the rod's ends. A hole is drilled on the center of one end of the rod using a 2 mm drill bit, and then the size made by the 2 mm drill bit is expanded by using the next size drill bit that is 4 mm, 6 mm, and 10 mm drill bits with the depth of 50 mm on all the rods. These holes are filled with hybrid composite materials of 5% fly ash and 5% nano ZrO_2 then these holes are enclosed by caps with a thickness of 15 mm that are prepared on a lathe known as novel encapsulate feeding as shown in figure 2. All encapsulated rods are kept inside the furnace with the crucible for melting at 700 ˚C as shown in figure 3. Next the molten metal undergoes a moving process to mix composite materials properly. Then molten AA7178 metal matrix composite is poured into the die. At last reinforced metal of 10 mm thickness is removed from the die and then 20 holes are drilled with an 8 mm drill bit to carry a surface roughness test as shown in figure 4.

The surface roughness of as-cast AA7178 alloy and AA7178 alloy with hybrid composites were tested by using a Mitutoyo surface roughness tester (SJ-410) as shown in figure 5. According to ASTM E92 standards, holes are produced consistently on both metals of 10 mm thickness using an 8 mm drill bit for surface roughness test as shown in figure 4. The sample metal is then fixed on the working bench and holes are faced towards the vertical adjustment unit. Height is adjusted by the knob perpendicularly towards the drilled holes, and a skid's fulcrum point is adjusted in the traverse direction of the detector [13]. The skid and stylus parts of the detector testing machine make contact with the sample hole, then the stylus part skids entirely around the hole with the measuring speeds of 0.05, 0.1, 0.2, 0.5, and 1.0 mm/s. At last, results are displayed on the screen, and then a high-speed in-built printer prints out surface roughness measurement results on site as shown in figure 5.

Figure 4: Material is drilled by CNC for surface roughness testing.

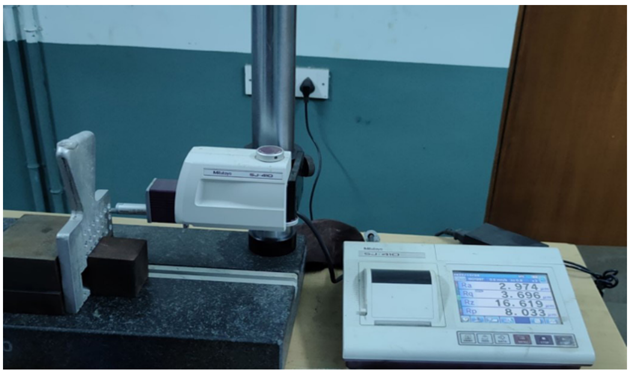

Figure 5: Mitutoyo surface roughness tester (SJ-410).

The above procedure was carried out on both groups of 40 samples. In column 1 of table 1, the surface roughness values of all 20 samples made with cast AA7178 are recorded [14]. Similarly, the surface roughness values of AA7178 reinforced with hybrid composites are given in column 2.

Statistical analysis

With the help of a statistical software program, SPSS (Statistical Package for the Social Sciences) developed by IBM is utilized to perform a t-test based on surface roughness values obtained. The descriptive and Bonferroni studies are done by using SPSS software. In this experiment, the independent variables are stirring speed and reinforcement weight percentage, whereas the dependent variable is surface roughness. In addition, this analysis also produces mean data, significance, and standard deviation [15].

Results

Table 1 presents the surface roughness (microns) of AA7178 alloy with 0% reinforcement and AA7178 alloy with 5% fly ash and 5% nano ZrO_2 reinforcements with a good

Table 1: Surface roughness of as-cast AA7178 and AA7178 reinforced with 5% of nano ZrO_2 and 5% of fly ash.

Sample number	As-cast AA7178	AA7178 with 5% of fly ash and 5% of nano ZrO_2
1	4.416	2.957
2	4.005	2.546
3	3.756	2.297
4	3.541	2.455
5	3.182	2.723
6	3.096	2.637
7	3.182	2.723
8	3.547	2.488
9	4.415	2.656
10	5.614	2.882
11	6.692	2.233
12	4.090	2.631
13	3.679	2.520
14	3.430	2.971
15	3.188	2.680
16	2.856	2.435
17	2.770	2.389
18	2.856	2.697
19	3.221	2.762
20	3.089	2.630

surface finish by minimizing surface roughness. Table 2 displays the surface roughness (microns) group statistics of both as-cast AA7178 without reinforcements and AA7178 with reinforcement material of 5% fly ash and 5% nano ZrO_2. The independent samples test comparing surface roughness (in microns) with and without reinforcements is presented in table 3. Descriptive statistics for surface roughness (in microns) of as-cast AA7178 without reinforcements and with 5% fly ash and 5% nano ZrO_2 reinforcements are shown in table 4.

When the surface roughness values with and without reinforcements are compared, the reinforced metal with fly ash and nano ZrO_2 matrix composite has a lower surface roughness (microns) value of 29.90%, as shown in figure 6 [16]. The mean surface roughness value for metal with reinforcement of 5% fly ash and 5% nano ZrO_2 shows a 29.90% lesser value than as-cast AA7178 [17]. The X-axis depicts two categories: as-cast AA7178 and AA7178 with 5% fly ash and 5% nano ZrO_2. The Y-axis shows the mean surface roughness, a standard deviation error of +/-1 and a confidence interval (CI) of 95% [18].

Discussion

The recent study on the hybrid reinforced aluminum metal matrix composite offers insightful results, mainly when fabricated with a 5% inclusion of fly ash and 5% nano ZrO_2. It was observed that this composite demonstrated a significantly improved surface quality, primarily characterized by reduced surface roughness. This was especially evident when compared against the cast AA7178 alloy, both in its pure form and when integrated with various reinforcements. For context and a broader understanding, this research also juxtaposed its findings against multiple recent studies that delved into surface roughness aspects. Notable among these were research that explored the impacts of ZrB_2 on the microstructural, mechanical, and corrosion behavior of aluminum (AA7178) alloy matrix composite, the study on the surface roughness of aluminum metal matrix composites when exposed to abrasive waterjet cutting, efforts to estimate surface roughness in aluminum-reinforced metal matrix composites, and an analysis on machining characteristics about surface roughness of the Al6061-SiC-Al_2O_3 hybrid aluminum metal matrix composite. Interestingly, all these referenced studies displayed minimal variations in surface roughness when juxtaposed against the base metal [19]. This contrasts with the current research, where a distinct reduction of 29.90% in surface roughness was recorded for the AA7178 alloy with 5% nano ZrO_2 and 5% fly ash. This marked improvement was attributed to deploying a unique encapsulate stir casting method, ensuring a uniform distribution of the reinforcing materials within the molten metal during casting. It's important to highlight that the success of this novel technique in producing metal

Table 2: Group statistics of surface roughness (microns) in as-cast AA7178 without reinforcement and AA7178 with reinforcement of 5% of fly ash and 5% of nano ZrO_2.

Group statistics		N	Mean	Std. deviation	Std. error mean
Surface roughness (Microns)	As-cast AA7178 without reinforcement	20	3.7313	0.97763	0.21860
	AA7178 with 5% of fly ash and 5% of nano ZrO_2	20	2.6156	0.19994	0.04471

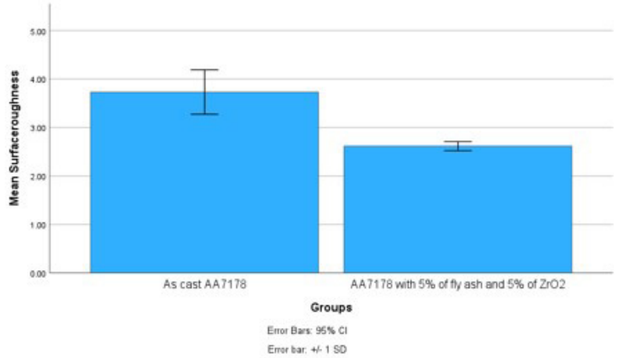

Figure 6: Comparison of the mean surface roughness with and without reinforcement material.

Table 3: Independent samples test of the surface roughness (microns) in as-cast AA7178 without reinforcement and AA7178 with reinforcement of 5% of fly ash and 5% of nano ZrO_2.

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	12.123	0.001	5.000	38	0.000	1.11565	0.22313	0.66395	1.56735
Equal variances not assumed			5.000	20.587	0.000	1.11565	0.22313	0.65106	1.58024

Table 4: Descriptive of the surface roughness (microns) of as-cast AA7178 without reinforcement and AA7178 with reinforcement of 5% fly ash and 5% of nano ZrO_2.

	N	Mean	Std. deviation	Std. error	95% CI for mean		Minimum	Maximum
					Lower bound	Upper bound		
As-cast AA7178 without reinforcement	20	3.7313	0.97763	0.21860	3.2737	4.1888	2.77	6.69
AA7178 with 5% of fly ash and 5% of nano ZrO_2	20	2.6156	0.19994	0.04471	2.5220	2.7092	2.23	2.97
Total	40	3.1734	0.89680	0.14180	2.8866	3.4602	2.23	6.69

matrix composites with lower surface roughness was a pivotal discovery of this investigation. However, like all research, this study wasn't without its limitations. Casting methods heavily influenced the results and introducing molten metal into the casting die purely under gravitational forces posed challenges. It sometimes led to casting defects, including blow holes, misrun, and shrinkage cavities. Given these constraints, the research envisions its next step to incorporate squeeze casting methodologies, which promises to overcome these identified casting imperfections.

Conclusion

In the scope of this particular study, a significant innovation was the introduction of the encapsulation feeding technique during the reinforcement and stir-casting process. This method played a pivotal role in the observed reduction of surface roughness for the AA7178 metal matrix composite when integrated with a hybrid composite of 5% fly ash and 5% nano ZrO_2. The comparative analysis revealed noteworthy results. When juxtaposed against the AA7178 metal, both in its pure form and when blended with composite materials, the hybrid composite-enriched aluminum alloy AA7178 exhibited a commendable reduction in surface roughness by 29.90%. This distinction becomes evident when one observes. Such a marked improvement in surface finish opens many application possibilities. Given the reduced surface roughness and improved structural integrity, the AA7178 metal matrix composite infused with hybrid materials becomes an attractive option for industries prioritizing strength and finish. Specifically, this composite offers promising potential for manufacturing automobile bodies, aircraft components, and even parts that are essential in marine applications.

Acknowledgements

None.

Conflict of Interest

None.

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