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Research Article

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Effect of Nano ZrO_2/Fly Ash Particles on Hardness of AA7178 Metal Matrix Composites Using Novel Encapsulate Stir Casting Technique

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Abstract

This study compares the hardness level of as-cast AA7178 with a reinforced hybrid metal matrix composite fabricated with fly ash (5%) and nano zirconium oxide (ZrO_2) (5%) hybrid composites using a novel encapsulation technique. The samples for both groups were created using a novel encapsulating process employing the stir-casting method. For group 2, a hybrid composite of fly ash (5%), nano ZrO_2 (5%), and AA7178 was used, whereas AA7178 as-cast was used for group 1. The samples were made following ASTM E92 criteria, and their hardness was measured using a Vickers hardness machine. Each group with 20 samples was fabricated. 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. The maximum hardness of the (5% and 5%) fly ash and nano ZrO_2 filled material is 35.61% greater than the as-cast AA7178. T-test statistical analysis reveals a significant $p = 0.00$ ($p < 0.05$) difference in the mean-variance of hardness between groups 1 and 2. Within the constraints of this study, it was observed that adding 5% fly ash and 5% nano ZrO_2 reinforcement with AA7178 composite significantly enhances hardness.

Keywords

AA7178, Fly ash, Nano zirconium oxide, Energy, Hybrid composite, Hardness, Novel encapsulate, Productivity, Stir casting

Introduction

In the aerospace sector, countless studies are being conducted to improve efficiency, minimize fuel burn, reduce carbon emissions, and maximize aircraft payload capacity. Only using modern materials in aerospace manufacturing makes it feasible to conduct one such study on lowering aircraft weight while increasing their strength [1]. According to recent technical advancements, these superior material qualities are frequently refined to fulfill safety and operating norms [2]. Due to present industrial needs and customer expectations for systems and machines that are more energy efficient, stronger, lighter, and more accessible, etc., the need for new and innovative materials will always be of interest [3]. Aluminum metal matrix composites are known as more sophisticated materials in several industries, including automotive, shipbuilding, aviation, structural applications, electrical appliances [4], food packaging, and transportation, due to their superior strength-to-weight ratio, corrosion resistance, and excellent mechanical characteristics gained by thermal treatments [5]. In the aerospace industry, aluminum is graded as the top metal of choice for building airplanes [6]. This is because of its corrosion resistance, high strength, and low density [7]. Aluminum metal matrix composites are metals that have been reinforced with other metals, ceramics, or organic compounds to achieve superior performance over the parent metal of aluminum [8]. They are made by distributing reinforcements all over the metal.

Reinforcements are frequently used to boost the base metal's properties—such as hardness, strength, stiffness, conductivity, corrosion resistance, wear resistance, and so on while reducing the metal's weight [9].

Over the past five years, several studies have been published about Al7178 metal and its hardness properties. 118 research articles are published in Google Scholar and 62 in Science Direct related to the AA7178 and its hardness properties such as the synthesis of zinc oxide and CNT in AA7178 aluminum alloy composite impression on characteristics [10]. Machinability studies on hybrid nano SiC and nano ZrO_2 reinforced aluminum hybrid composite by wire-cut electrical discharge machining [11]. The effect of ZrB_2 on the microstructure, mechanical properties, and corrosion behavior of an aluminum (AA7178) alloy matrix composite prepared by stir casting [12]. 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 a novel encapsulation feeding technique [13]. Synthesis and characterization of AL6061/fly ash/nano ZrO_2 metal matrix composites processed by stir casting method [14]. The study of mechanical properties of fly ash reinforced aluminum matrix composites. The study on hybrid composites produced by a novel encapsulation feeding approach is recognized as one of the finest publications that thoroughly explains the innovative encapsulation process. This paper demonstrated the fusion of mechanical and computer science fields by upgrading the metal matrix composite well with hybrid composite and using an integrated artificial neural network, Taguchi technique, and novel encapsulating feeding system for casting.

It was observed that there had been relatively very few studies on hybrid composite fabrication employing novel encapsulation processes. This study aimed to create an AA7178/5% fly ash/5% nano ZrO_2 hybrid composite using a novel encapsulating stir-casting process. The hardness properties of as-cast AA7178 and AA7178 alloy with hybrid composites were compared.

Materials and Method

The research was conducted at Saveetha Industries, housed within the larger umbrella of the Saveetha School of Engineering and the Saveetha Institute of Medical and Technical Sciences, Chennai (Tamil Nadu, India). At the heart of this study, a comparative analysis was undertaken between two distinct metal groupings: the as-cast metal, in its raw, unaltered state, and its counterpart, which was reinforced with specific materials. Specifically, the hardness values of these metals were pitted against each other. For this purpose, the chosen samples were metal casts measuring 8 - 10 mm thick [15]. For statistical assurance and accuracy, the study employed a G-power of 80% for the samples collected in groups of 20.

For group 1, a 20 mm diameter rod of the as-cast aluminum alloy 7178 was used. These rods underwent an initial lathe operation to smoothen the surface and remove unwanted burrs at the ends. Following this, the rods were subjected to a melting process: 1 kg of these rods were placed inside a graphite crucible, then heated to 700 °C in a furnace. Once melted into a molten state, the molten metal was transferred into a die and allowed to solidify. The cast aluminum was then sectioned into 8 - 10 mm pieces for subsequent hardness testing [16].

Group 2, on the other hand, was a bit more intricate. Here, the samples were made from AA7178 rods reinforced with 5% fly ash and 5% nano ZrO_2 (visually represented in figure 1). These rods, like those in group 1, were initially machined to rid them of end burrs. Subsequently, a central hole was drilled into one end, progressively enlarging the hole through a sequence of drill bits. These hollowed sections were filled with reinforcement materials and sealed using specially crafted 15 mm thick caps. This unique method of introducing reinforcements is termed "novel encapsulation feeding". It is showcased in figure 2. Following this preparation, these rods were melted at 700 °C, stirred, and poured into dies for solidification. Once solidified, they were sectioned into 8 - 10 mm pieces, mirroring the process followed for group 1 [17]. Figure 3 presents stir casting setup.

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

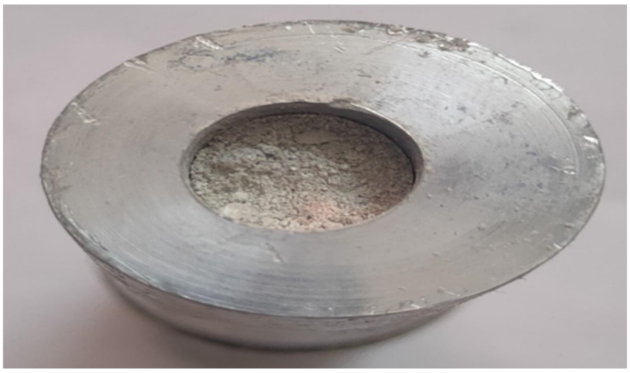

Figure 2: Feeding of 5% fly ash and 5% nano ZrO_2 to novel encapsulated AA7178.

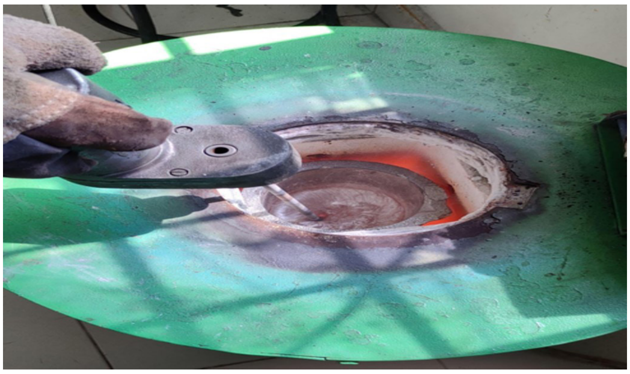

Figure 3: Stir casting setup.

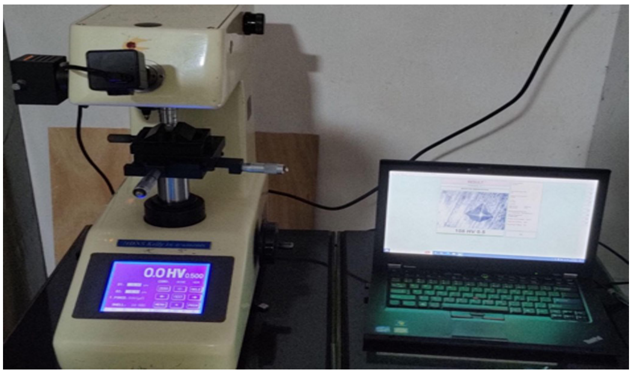

Figure 4: Hardness testing equipment.

For the actual hardness testing, a Vickers hardness testing apparatus was employed, as depicted in figure 4. Each of the 20 samples from both groups was trimmed down to 10 x 10 mm dimensions and tested under the guidelines set by ASTM E92. During testing, a diamond-shaped indenter was pressed into the sample with a force of 0.5 kgf, leaving it for 10 s. The depth of this indentation was then measured microscopically at three different locations on the sample, ensuring a comprehensive reading. These readings were then displayed and documented for further analysis.

The data gathered from this rigorous testing process was then tabulated. Specifically, table 1 first column showcased the hardness values of the 20 as-cast material samples, while its second column depicted the hardness readings for the 20 composite material samples.

Statistical analysis

The hardness observations obtained from the samples are tested only through a t-test using the statistical package for the social sciences (SPSS) software. The SPSS software generates descriptive and Bonferroni tests. In this experiment, the independent variables are stirring speed and reinforcement weight %, while hardness is the dependent variable. The technique calculates mean data, significance, and standard deviation.

Results

Table 1 delivers a straightforward comparison of the hardness values (measured in HV) of the AA7178 alloy in two distinct states: the pristine state without any material reinforcement and its counterpart that's been bolstered with a 5% infusion of both fly ash and nano ZrO_2. The juxtaposition of these values elucidates the tangible improvement in hardness achieved by incorporating these reinforcing materials.

Table 2 takes this data analysis a step further by presenting group statistics. It details the hardness of the as-cast AA7178 alloy in its unaltered state alongside its reinforced variant. This reinforced version contains 5% fly ash and 5% nano ZrO_2. The statistics offer a comprehensive view of how each sample set fares in hardness and what the introduction of these reinforcements does to the inherent hardness of the AA7178 alloy. Diving deeper into the analytical realm, table 3 showcases the independent samples test, comparing the hardness values of the AA7178 alloy with and without reinforcements. Table 3 establishes the statistical significance and differences between the two sample sets.

Table 1: The hardness of as-cast AA7178 and AA7178 was reinforced with 5% of nano ZrO_2 and 5%of fly ash.

Sample number	As-cast AA7178	AA7178 with 5% of nano ZrO_2 and 5% of fly ash
1	70.98	108.62
2	70.83	108.47
3	69.92	107.56
4	70.89	108.53
5	68.69	106.33
6	67.89	105.53
7	68.55	106.19
8	66.77	104.41
9	68.12	105.76
10	69.22	106.86
11	67.78	105.42
12	67.13	104.77
13	65.81	103.45
14	65.43	103.07
15	63.67	101.31
16	65.03	102.67
17	66.83	104.47
18	67.83	105.47
19	69.43	107.07
20	69.82	107.46

Table 2: Group statistics of hardness in as-cast AA7178 without reinforcement and AA7178 with reinforcement of 5% of flash and 5% of nano ZrO_2.

Group statistics		N	Mean	Std. deviation	Std. error mean
Hardness	As-cast AA7178 without reinforcement	20	68.0310	2.04227	0.45666
	AA7178 with 5% of flash and 5% of nano ZrO_2	20	105.6710	2.04227	0.45666

Table 4, on the other hand, provides a detailed descriptive analysis of the hardness. It distinguishes between the as-cast AA7178 alloy that has remained untouched by reinforcements and its modified version, enhanced with 5% fly ash and 5% nano ZrO_2. This table encapsulates the average hardness values, distribution, and variability across both sets [18].

The crux of the data is visually captured in figure 5, which

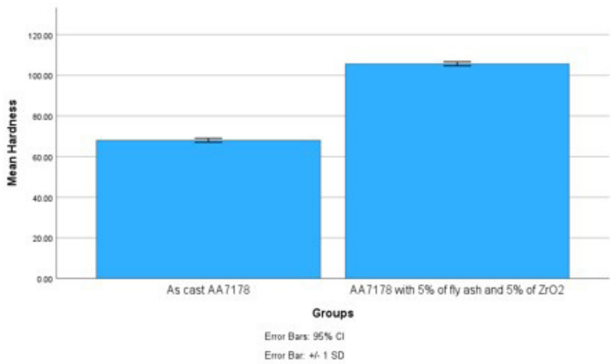

Figure 5: Comparison of the mean hardness with and without reinforcement material.

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

Hardness	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	95% CI of the difference: Upper
Equal variances assumed	0.000	1.000	-58.282	38	0.000	-37.640	0.645	-38.94740	-36.33260
Equal variances not assumed			-58.282	38	0.000	-37.640	0.645	-38.94740	-36.33260

Table 4: Descriptive of the hardness 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: Lower bound	95% CI for mean: Upper bound	Minimum	Maximum
As-cast AA7178 without reinforcement	20	68.0310	2.04227	0.45666	67.0752	68.9868	63.67	70.98
AA7178 with reinforcement of 5% fly ash and 5% of nano ZrO_2	20	105.6710	2.04227	0.45666	104.7152	106.6268	101.31	108.62
Total	40	86.8510	19.16607	3.03042	80.7214	92.9806	63.67	108.62

graphically compares the hardness values of the two alloy states. The reinforced AA7178/fly ash/nano ZrO_2 metal matrix composite outperforms its as-cast counterpart when the two are placed side-by-side. The numeric magnitude of this performance differential is a staggering 35.61% increase in hardness for the reinforced alloy. The reinforced alloy's mean hardness value showcases this 35.61% enhancement over its as-cast equivalent. This superiority in hardness is further illustrated through a graphical representation, where the X-axis categorizes the two distinct groups: the as-cast AA7178 and the enhanced AA7178 with a 5% mix of fly ash and nano ZrO_2. The Y-axis, conversely, plots the mean hardness values. To account for potential variations and discrepancies, the graph also factors in the standard deviation error at +/- 1 and operates within a confidence interval (CI) of 95%. This ensures that the data presented is accurate, statistically valid, and significant.

Discussion

The comprehensive analysis of the hardness test unveiled that the hybrid reinforced aluminum metal, which incorporated 5% fly ash and 5% nano ZrO_2, demonstrated superior hardness compared to the as-cast AA7178 alloy with no reinforcement. Utilizing the SPSS software for data analysis, this research was able to extract intricate details such as the group statistics, descriptive values, ANOVA test results, and independent samples test results. Moreover, this software facilitated data acquisition, including mean, standard deviation, standard mean error, mean difference, and standard error difference. Such detailed analysis significantly streamlined discerning the hardness differential between the reinforced and non-reinforced metals.

Viewing these findings in the larger context of previous research is essential. When juxtaposed with studies like the one focused on the effect of ZrB_2 on AA7178 alloy, where a mere 26% improvement in hardness was observed, the results of this research stand out. Likewise, the study using an integrated artificial neural network and Taguchi approach on AA6061 alloy reported a hardness increase of 27.48%, and other researchers recorded improvements of 2.43%, 11%, and 8.67%, respectively. In stark contrast, this current research, focusing on AA7178 alloy incorporated with 5% of nano ZrO_2 and 5% fly ash and utilizing the novel encapsulation technique, witnessed a significant spike in hardness by 35.61%, as graphically depicted in figure 5. This enhancement in hardness notably surpasses the results from the referenced studies on AA7178 metal matrix composite and its various properties.

A crucial aspect that potentially underpins these enhanced results is the unique method employed: stir casting combined with novel encapsulate feeding. This combination ensures a homogeneous dispersion of the reinforcement material within the molten metal during the casting phase, an observation captured in figure 3. Thus, by leveraging this innovative technique, the study successfully achieved a metal matrix composite characterized by amplified hardness, a feature depicted in figure 2.

Every research has its challenges. While the novel encapsulation feeding and stir-casting methods have revolutionized the results of this study, it's essential to acknowledge their subtle limitations. Propelled by gravity, the natural flow of molten metal into the casting die can sometimes give rise to casting anomalies such as blow holes, misrun, and shrinkage cavities. These imperfections, albeit minor, form the primary constraint of this study. To circumvent these casting irregularities, future research aims are clear: explore alternative methods like squeeze casting to achieve even more precise and flawless results.

Conclusion

The research undertaken within this framework primarily aimed to understand the impact of introducing hybrid composites on the hardness of the AA7178 metal matrix composite. Specifically, the study employed a novel approach of feeding reinforcements through encapsulations during the stir casting. This innovative technique had a marked effect on the hardness of the composite material. The main focal point was to assess the hardness of the AA7178 metal both in its natural state and when it's merged with composite materials. The findings of this research, vividly illustrated in figure 5, were significant. The data demonstrated that the resultant material showed a substantial hardness improvement when the AA7178 aluminum alloy was incorporated with hybrid composites, specifically 5% fly ash and 5% nano ZrO_2. In concrete numbers, there was a 35.61% enhancement in hardness when comparing the reinforced AA7178 alloy to its pure, unreinforced counterpart. Such a remarkable improvement in hardness can have numerous practical implications. The enhanced hardness means the composite can withstand greater pressures and resist deformation better than its pure counterpart. Consequently, given its increased hardness and likely enhanced durability, this reinforced alloy is perfectly suited for applications where structural rigidity and resistance to wear, and tear is paramount. One can easily envisage its applications in the automotive and aerospace industries. Specifically, the AA7178 alloy with improved hardness due to hybrid composites can be an excellent choice for crafting sturdy vehicle body panels that can resist minor dings and impacts better. Likewise, this material can be used in the aviation sector to create aircraft parts requiring higher rigidity and resistance to mechanical stresses.

Acknowledgements

None.

Conflict of Interest

None.

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