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Research Article

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# Enrichment of Tensile Properties for AA7178/Nano $ZrO_2$/ Fly Ash Metal-matrix Composite via Novel Encapsulate Stir Casting Technique by Drilling Process

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## Abstract

The main motto of this research is to investigate the tensile property of AA7178 reinforced with 5% fly ash and 5% nano zirconium oxide ($ZrO_2$) hybrid composites fabricated by a novel encapsulate technique and comparison with as-cast AA7178 alloy. The samples for both groups were prepared using a novel encapsulation technique employing the stir-casting method. While preparing group 2 samples, a hybrid composite of fly ash (5%), nano $ZrO_2$ (5%), and AA7178 was used to prepare metal matrix composite, whereas AA7178 as-cast was used for group 1. The samples were made per ASTM E92 standards, and their tensile strength was measured using a universal testing machine (UTM-Auto instrument). 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 sum of the two groups sample size is 40. The maximum tensile strength of hybrid metal matrix composite material, AA7178 with (5% and 5%) fly ash and nano $ZrO_2$ is found to be 35.61% higher than that of as-cast AA7178 without reinforcement. Based on the t-test statistical analysis, there is a significant $p = 0.00$ ($p < 0.05$) difference in the mean-variance of tensile strength between groups 1 and 2. Within the confines of this investigation, it is noticeable that adding reinforcement made of 5% fly ash and 5% nano $ZrO_2$ dramatically increases tensile strength in the AA7178 composite.

## Keywords

AA7178, Fly ash, Energy, Hybrid composite, Novel encapsulate, sustainability, Safe work, Stir casting, Tensile strength

## Introduction

To meet human requirements, sea transportation is used more extensively. Over 10 billion tons of containers are transported by ships annually across the world's seas due to marine transportation, which accounts for 80 - 90% of global trade [1]. An aluminum base metal and its alloys are used to build these ships. Even though quicker and lighter ships have been developed recently, aluminum has long been utilized extensively in maritime applications [2]. As a result, there is now a more significant need for corrosion-resistant aluminum alloys [3]. Due to its anti-corrosive and lightweight qualities, which have been proven to add value to ships by enabling them to go faster, quicker, with more cargo capacity, superior stability, and better fuel efficiency [4], hence aluminum has consequently become a crucial material for shipbuilders [5]. To enhance aluminum's properties, so much research is going on aluminum and its metal matrix composites. Metal matrix composites are metals reinforced with other metal, ceramic, or organic compounds to enhance the superior qualities of base metal. These reinforcements increase the base metal's qualities such as tensile strength, hardness, stiffness, conductivity, wear resistance, corrosion resistance, and durability, and so on compared to conventional engineering materials [6]. With the advent of reinforcement technology, the usage of aluminum developed and became one of the leading metals in various engineering applications such as automobile, marine, and aerospace manufacturing [7].

Several publications have been published in the last five years regarding the Al7178 metal and its tensile strength. There are 340 research publications in Google Scholar and 1 article in Science Direct about the AA7178 and its tensile strength. Effect of $ZrB_2$ on microstructural, mechanical, and corrosion behavior of aluminum (AA7178) alloy matrix composite prepared by the stir casting route [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 a novel encapsulation feeding technique [9]. A review of aluminum matrix composites' fabrication methods, reinforcements, and mechanical properties [10]. Synthesis of zinc oxide and CNT in AA7178 aluminum alloy composite impression on characteristics [11]. Mechanical properties and characterization of nano $ZrO_2$ and coconut shell ash reinforced aluminum (Al 6082) matrix hybrid composite [12]. Preparation and properties of Al6061/fly ash/nano $ZrO_2$ metal matrix composites processed by stir casting method [13]. From the above four research papers, the study of the novel encapsulation feeding technique is considered one of the best studies. This study involves innovative techniques of feeding the hybrid reinforcement which enhances the metal more than other studies. In this study, they also implemented the integrated artificial neural network and Taguchi approach with a novel encapsulation feeding methodology for casting [14]. Efforts have revealed few studies on aluminum fabrication with hybrid reinforcements using novel encapsulation feeding techniques.

Full of efforts found that relatively limited studies on aluminum fabrication with hybrid reinforcements employ novel encapsulation feeding techniques. The primary purpose of this study was to create an AA7178/5% fly ash/5% nano $ZrO_2$ hybrid composite using a novel encapsulating stir-casting process. The tensile strength of as-cast AA7178 and cast AA7178 metal with hybrid composites were compared.

## 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 Sciences, Chennai (Tamil Nadu, India). Two sets of 40 samples each, for a total of two groups of 20 samples, have been collected for this investigation. To compare the tensile strength of the two groups, group 1 (base metal without any composite material) and group 2 (hybrid composites reinforced with base metal), tensile strength tests were conducted on each group [15]. The investigation employed a sample of 8 - 10 mm thick cast metal with reinforcements and base metal to compare the tensile strength property. An estimate of 80% G-power was made.

The material utilized in this study is a 20 mm diameter rod of as-cast AA7178, used to make 20 samples in group 1. The rod is first machined on a lathe to achieve a better surface quality and remove metallic debris from the rod's ends [16]. 1 kg of AA7178 rods are put inside the graphite crucible once the machining process is finished, and the crucible is then placed into the furnace and allowed to heat up to 700 °C [17]. The melting aluminum metal is poured into the die by gravity once the crucible is taken out of the furnace, which causes the temperature to decrease [18]. The aluminum is then split into 8 - 10 mm pieces and removed from the die for tensile strength testing. The as-cast AA7178 pieces are machined into cylindrical sections for tensile strength testing [19].

While moving on to group 2, 20 samples were made using 5% fly ash and 5% $ZrO_2$ reinforcing material, as indicated in figure 1. A 20 mm diameter AA7178 rod must first be turned on a lathe to remove metallic burrs from the ends of the rod. A 2 mm drill bit is used to create the center of one end of the rod. The size of the hole created by the 2 mm drill bit is then expanded by using the other drill bits with a depth of 50 mm on all of the rods by using the next size drill bit, which is a 4 mm, 6 mm, and 10 mm drill bit. These drilled holes are filled with 5% fly ash and 5% nano $ZrO_2$ before being sealed with a lathe-made, 15 mm-thick cap [20]. As seen in figure 2, this technique is known as novel encapsulation. All AA7178 rods are placed inside the graphite crucible, which is then placed into the furnace and heated to 700 °C. At this temperature, the AA7178 rods containing composite material melt into a molten state. This molten aluminum is then poured into the die and allowed time to cool after being thoroughly mixed with the stirrer as seen in figure 3. The reinforced metal is then cut into cylindrical sections of 8 mm in diameter and 30 mm in length for the tensile strength test, as illustrated in figure 4.

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

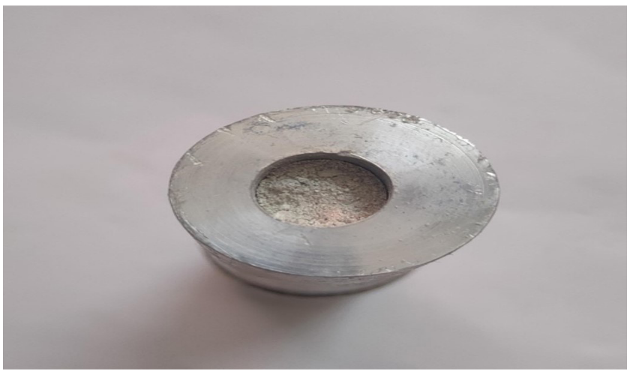

**Figure 2:** Feeding of 5% fly ash and 5% nano $ZrO_2$ to novel encapsulated AA7178.

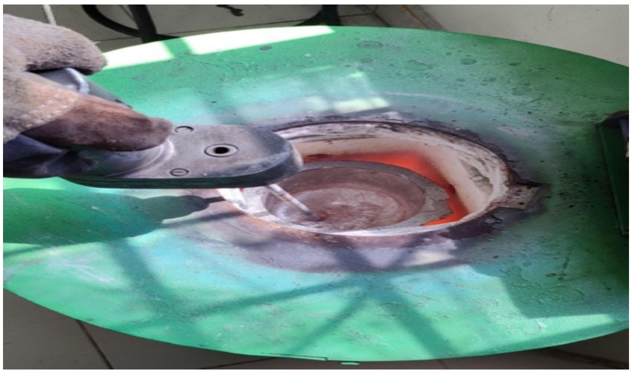

**Figure 3:** Stir casting setup.

The tensile strength test is performed on both as-cast AA7178 alloy and reinforced AA7178 MMC materials by using a UTM-Auto instrument, as shown in figure 4. According to the ASTM E92 norms the sample specimens for both groups are made as cylindrical rods to perform tensile strength testing. Initially, the testing samples were polished using 1200-grit SiC grinding paper to reduce machining scratches. The tensile test was carried out on the UTM loaded with a 10 kN load cell as shown in figure 4. A crosshead speed of 2.5 mm/min was employed to examine the tensile strength. The sample is fixed and appropriately positioned in between two jaws of UTM. Tension is introduced on the sample to perform the tensile test on the samples as shown in figure 5. When the sample is perfectly fitted, the upper jaw is dragged upward to create tension until the fracture point is reached. When the force applied to the specimen reaches the fracture point as shown in figure 5, the tensile strength of the specimen is noted.

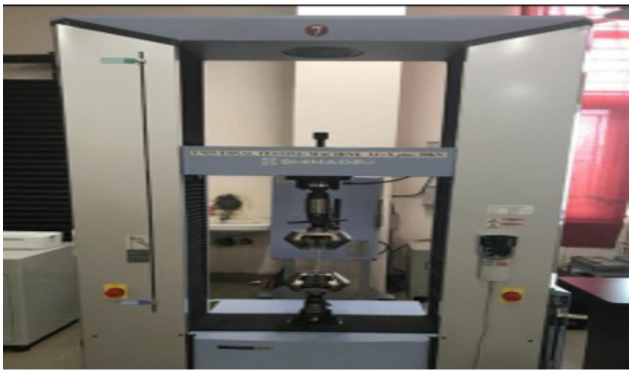

**Figure 4:** UTM.

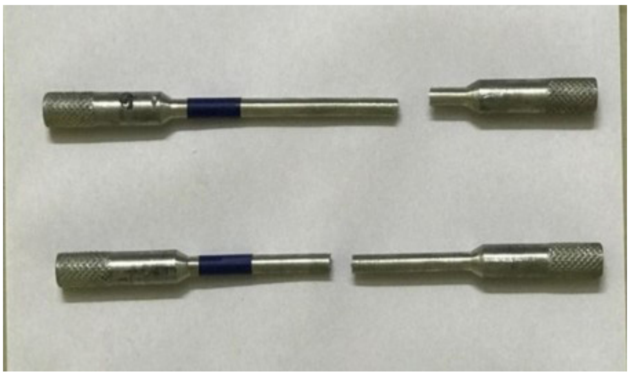

**Figure 5:** Samples of both groups are tested for tensile strength by a UTM.

The above procedure will be applied to all 20 samples in each group. The tensile strength values of all 20 as-cast material samples are represented in column 1 of table 1. In comparison, the tensile strength values of all 20 samples fabricated with 5% of fly ash and 5% of nano $ZrO_2$ are represented in column 2.

### Statistical analysis

Based on obtained tensile strength values, a t-test is performed using IBM's statistical software, SPSS (Statistical Package for the Social Sciences). The descriptive and as well as the Bonferroni tests are produced using SPSS software. Tensile strength is the dependent variable in this experiment, whereas stirring speed and the % of reinforcement weight are the independent factors. Additionally, the standard deviation, significance, and mean values are produced using this method. This technique also yields mean data, significance, and standard deviation.

## Results

Table 1 compares the tensile strength (MPa) of AA7178 alloy with and without reinforcement. It also compares the tensile strength of AA7178 alloy with and without reinforcement with 5% fly ash and 5% nano $ZrO_2$ (MPa). Table 2 shows the aggregate data for the tensile strength (MPa) of the AA7178 as-cast without reinforcement and the AA7178 with reinforcing material made of 5% fly ash and 5% nano $ZrO_2$. Tensile strength measurements for both materials with and without reinforcements are shown in table 3 as independent samples tests (MPa). Table 4 shows the description of the tensile strength (MPa) for the AA7178 as-cast without

**Table 1:** Tensile strength 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 nano $ZrO_2$ and 5% of fly ash |
|---|---|---|
| 1 | 204.42 | 312.83 |
| 2 | 203.99 | 312.39 |
| 3 | 201.37 | 309.77 |
| 4 | 204.16 | 312.57 |
| 5 | 197.83 | 306.23 |
| 6 | 195.52 | 303.93 |
| 7 | 197.42 | 305.83 |
| 8 | 192.30 | 300.70 |
| 9 | 196.19 | 304.59 |
| 10 | 199.35 | 307.76 |
| 11 | 195.21 | 303.61 |
| 12 | 193.33 | 301.74 |
| 13 | 189.53 | 297.94 |
| 14 | 188.44 | 296.84 |
| 15 | 183.37 | 291.77 |
| 16 | 187.29 | 295.69 |
| 17 | 192.47 | 300.87 |
| 18 | 195.35 | 303.75 |
| 19 | 199.96 | 308.36 |
| 20 | 201.08 | 309.48 |

**Table 2:** Group statistics of tensile strength (MPa) 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 |
|---|---|---|---|---|---|
| Tensile strength (MPa) | As-cast AA7178 without reinforcement | 20 | 195.9290 | 5.88093 | 1.31502 |
| | AA7178 with 5% of nano $ZrO_2$ and 5% of fly ash | 20 | 304.3325 | 5.88203 | 1.31526 |

reinforcement and the AA7178 with reinforcement of 5% fly ash and 5% nano $ZrO_2$.

When the tensile strength values of both metals with and without additional reinforcements are compared, the reinforced (AA7178/fly ash/nano $ZrO_2$) metal matrix composite has a higher and enhanced value of tensile strength by 35.61% compared to as-cast AA7178, as shown in figure 6. The mean value tensile strength for metal with reinforcement shows 35.61% more tensile strength than as-cast metal. The X-axis represents two groups: as-cast AA7178 vs AA7178 with 5% fly ash and 5% nano $ZrO_2$. The Y-axis shows the mean tensile strength with a standard deviation error of +/-1 and a 95% confidence interval (CI).

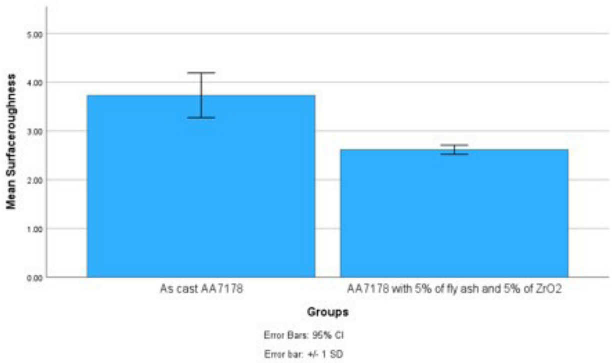


**Figure 6:** Comparison of the mean surface roughness with and without reinforcement material.

# Discussion

Based on the tensile test outcomes, the hybrid reinforced aluminum metal made from 5% fly ash and 5% nano $ZrO_2$ performs better with higher tensile strength than the cast AA7178 alloy with no added reinforcements. The SPSS software was utilized to draw group statistics, descriptives, ANOVA test, and independent samples test also allows us to find mean, standard error, standard mean error, mean-variance, and standard error difference, which allows us to compare tensile strength between and without reinforcement metals more efficiently. And compared this research results with recent studies on tensile strength, Effect of $ZrB_2$ on the microstructural, mechanical, and corrosion behavior of aluminum (AA7178) alloy matrix composite prepared by the stir casting route. In this study only 15% of tensile strength were improved. Microstructure and mechanical properties of friction stir welded SiC/$TiB_2$ reinforced aluminum hybrid composites, in this research only 2.5% of tensile strength was improved for weld specimens. Mechanical properties of aluminum metal matrix composites – a review, in this study, the specimen fabricated by stir casting equipment yields maximum tensile strength at 15% SiC reinforcement. evaluation of microstructure, hardness, and tensile properties: a comparative study of stir cast and extruded Al7005/glass-/fly ash-reinforced hybrid metal matrix composites, in this study only 11.05% of tensile strength were improved. 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, in this study only 27.29% of tensile strength were increased. However, compared to other recent research on AA7178 metal matrix composite and its characteristics, The study conducted on AA7178 with 5% nano $ZrO_2$ and 5% fly ash cast by novel encapsulate feeding technique exhibits excellent outcomes with 35.61% higher tensile strength. This research employed stirs casting and novel encapsulation feeding techniques of reinforcements to ensure similar distribution of reinforcement material in molten metal during casting. The research demonstrates higher tensile strength in a

**Table 3:** Independent samples test of the tensile strength (MPa) in as-cast AA7178 without reinforcement and AA7178 with reinforcement of 5% of fly ash and 5% of nano $ZrO_2$.

| Tensile strength (MPa) | 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 | -58.282 | 38 | 0.000 | -108.4035 | 1.85989 | -112.16865 | -104.63835 |
| Equal variances not assumed | | | -58.282 | 38 | 0.000 | -108.4035 | 1.85989 | -112.16865 | -104.63835 |

**Table 4:** Descriptive of the tensile strength (MPa) 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 | 195.9290 | 5.88093 | 1.31502 | 193.1766 | 198.6814 | 183.37 | 204.42 |
| AA7178 with 5% of nano $ZrO_2$ and 5% of fly ash | 20 | 304.3325 | 5.88203 | 1.31526 | 301.5796 | 307.0854 | 291.77 | 312.83 |
| Total | 40 | 250.1308 | 55.19840 | 8.72763 | 232.4774 | 267.7841 | 183.37 | 312.83 |

metal matrix composite created through a novel encapsulating process.

The critical parameters that affect the research are the pouring technique of molten metal in the die, the stirrer impeller, the impeller's size, and the impeller's position. The major limitation of this research is that the flow of molten metal into the casting die under gravity may generate casting defects such as blow holes, misrun, and shrinkage cavities. The primary focus of future research in this work is to use squeeze casting to eliminate such casting faults.

# Conclusion

Within the constraints of this study, it was discovered that unique encapsulating feeding of reinforcements through stir casting enhances the tensile strength of AA7178 metal matrix composites, which comprise hybrid composites of 5% fly ash and 5% nano $ZrO_2$. The tensile strength of AA7178 metals with and without composite materials was measured. The AA7178 with hybrid composites improved tensile strength by 35.61% when compared to the AA7178 alloy without composite material, as depicted in figure 6. The tensile strength of AA7178 alloy with hybrid composites has dramatically increased, allowing for its application in the fabrication of agricultural farm machinery, electrical transmission lines, and parts for vehicle engines.

# Acknowledgements

None.

# Conflict of Interest

None.

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