Nano World Journal

https://doi.org/10.17756/nwj.2023-s3-072

Research Article

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Experimental Investigation on Tensile Strength of AA4032 Reinforced Nano Si_3N_4 Composite Subjected to Novel Encapsulate Technique

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Received: July 28, 2023
Accepted: October 12, 2023
Published: October 16, 2023

Citation: Ram HB, Natrayan L, Richard T. 2023. Experimental Investigation on Tensile Strength of AA4032 Reinforced Nano Si_3N_4 Composite Subjected to Novel Encapsulate Technique. *NanoWorld J* 9(S3): S400-S404.

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Abstract

This study evaluated the tensile strength of AA4032, both in its as-cast form and when reinforced with 10% nano Si_3N_4 (Silicon nitride), using a unique encapsulation technique alongside the stir-casting method. Two groups were formed: Group 1 used as-cast AA4032, while Group 2 utilized a composite of AA4032 and 10% nano Si_3N_4. The production of 20 samples per group adhered to ASTM E08-8 standards, and their tensile strengths were assessed using a universal testing machine (UTM-Auto instrument). With a total sample size of 40, determined by a G-power of 80% and $\alpha = 0.05$, the nano Si_3N_4-reinforced composite exhibited a tensile strength increase of 48% compared to the as-cast AA4032. Statistical analysis using the t-test highlighted a significant difference in tensile strength between the groups ($p < 0.05$), with a p-value of 0.00. The results underscore that reinforcing AA4032 with 10% nano Si_3N_4 significantly augments its tensile strength.

Keywords

AA4032, Nano silicon nitride, Innovation, Stir casting, Composite, Sustainability, Novel encapsulation, Energy, Tensile strength

Introduction

All states are paying strong attention to lowering emissions, pollution control, and quality enhancement due to acute energy consumption and environmental degradation. The vehicle's weight may be significantly lowered by selecting and manufacturing lightweight materials [1]. Therefore, lightweight materials are essential for the sustainable industry's long-term growth. AA4032 is an aluminum alloy with high hardness, excellent formability, and high corrosion resistance [2]. It is a structural alloy with low weight. The complex AA4032 aluminum alloy offers substantial strength increases over the more popular AA5083 alloy. For grain refining, AA4032 has bigger magnesium (Mg) amounts than AA5083 and also includes more zinc and zirconium; made in Koblenz, Germany, by Aleris International, Inc., it is a Mg alloy that cannot be heated. In AA4032, nano Si_3N_4 is employed as reinforcement to boost its tensile strength. It becomes more challenging due to mechanical strain hardening. Aluminum alloy is widely used to unite structural components due to its superior weldability. Numerous industries, like marine, aviation, automotive, and defense, utilize aluminum alloy for better performance. It is employed extensively in the shipbuilding business, the aviation sector, and other electronic-related areas [3]. This composite material will therefore become significantly more robust and be suited for making products across various sectors.

Eventually, various articles regarding the AA4032 and its tensile strength were issued. Science Direct published 23 research publications based on the

AA4032 and tensile strength, while about 148 were published in Google Scholar. The study on metal matrix composite innovative encapsulated squeeze cast best describes the novel encapsulation process thoroughly. This study exemplifies the combination of mechanical and computer science domains by optimizing the composite well with several reinforcements. They also used an artificial neural network approach with a novel encapsulation feeding methodology for casting. We discovered a few works on the manufacture of composites using innovative encapsulating approaches [4]. This research aimed to develop a novel encapsulating stir-casting technology for producing the AA4032/10% nano Si_3N_4 composite. The goal of the research was to examine the as-cast materials.

Materials and Method

The research was conducted at Saveetha Industries, Saveetha School of Engineering, and Saveetha Institute of Medical and Technical Sciences (Chennai, Tamil Nadu, India). The primary investigation compared two distinct material groups: As-cast and composite materials. Both sets of samples were crafted into cylindrical shapes to facilitate the tensile strength comparison [5]. The study classified these materials into two groups with 40 samples—20 per category. These sample sizes were determined based on a G-power of 80%.

The as-cast material was the focal point of group 1. A 20 mm diameter rod of AA4032 alloy was machined using lathe operations to initiate the process, ensuring a smooth, burr-free finish on the metal's surface. Post this operation, the AA4032 alloy was melted in a crucible with a 1 kg capacity. The melting was done by placing the crucible inside a furnace and gradually increasing the temperature to around 700 °C [6]. Once melted, the molten alloy was allowed to solidify within a mold. After solidification, extraneous material was removed, and the resultant cast metal was sectioned into various cylindrical pieces ready for tensile strength assessment.

The focus of group 2 was the composite material. An AA4032 rod, 20 mm in diameter, underwent lathe operations to ensure a smooth surface. Subsequently, increasing in diameter, a series of drill holes were made into one end of the rod [7]. After preparing the rod, it was filled with 10% nano Si_3N_4 (Figure 1) and sealed with a 15 mm thick cup (Figure 2). This rod was then placed in a crucible and subjected to furnace heat until molten. The stir-casting process (Figure 3) was employed at this stage to mix the molten AA4032 alloy with 10% nano Si_3N_4. Once mixed and poured into a mold, the composite cooled and segmented into cylindrical sections, analogous to group 1 [8].

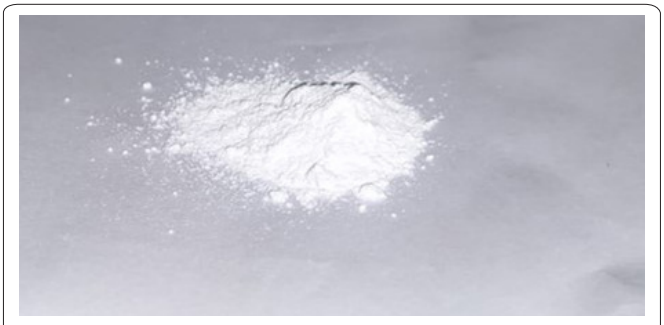

Figure 1: Nano Si_3N_4 (10% reinforcement).

Both material groups were subjected to tensile strength (Figure 4) testing using a UTM-Auto instrument (Figure 5). Before testing, each sample was polished with 1200-grit SiC (Silicon carbide) grinding paper to minimize surface imperfections [9]. During the testing, each sample was securely clamped between the jaws of the UTM, which applied tension until the sample reached its fracture point [10]. This method determined the tensile strength of the specimen. Each group's respective tensile values were illustrated in distinct figures, enabling visual comparisons [11].

Statistical analysis

IBM created the statistical software program SPSS (Statistical Package for the Social Sciences) [11] for data management, data processing, mathematical analysis, and other

Figure 2: Feeding nano Si_3N_4 to novel encapsulated AA4032.

Figure 3: Stir casting process.

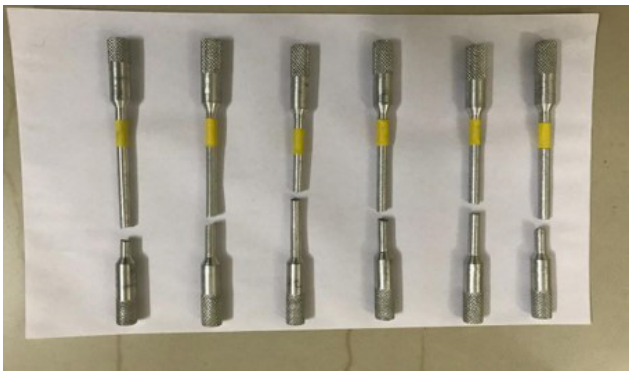

Figure 4: Material for tensile strength.

Figure 5: Tensile strength test.

purposes. The t-test is applied to the experimental specimens' tensile strength values using SPSS statistical software [12]. The descriptive table, as well as the Bonferroni analyses, are run using the statistical application SPSS. While tensile strength is the dependent variable, stir speed and reinforcement weight % are considered independent factors.

Results

In the presented research, a series of tables meticulously document the tensile strength characteristics of the AA4032 alloy. Table 1 straightforwardly contrasts the tensile strength, in megapascals (MPa), of the unaltered as-cast AA4032 and its enhanced version reinforced with nano Si_3N_4. Building on this foundational data, table 2 delves deeper by showcasing tensile strength group data, possibly segmented by certain variables or conditions. This detailed perspective, indicated by reference [13], might be informed by a particular study or previous research. Adding another layer of depth, table 3 introduces results from the tensile strength independent samples test, hinting at a distinct methodology or sample set used to evaluate the tensile strength, potentially to validate or cross-reference earlier findings. Finally, table 4 returns to the main theme but with a more intricate focus, exploring the finer tensile strength characteristics of the two AA4032 versions. The mention of

Table 1: Tensile strength of as-cast AA4032 and AA4032 with reinforcement nano Si_3N_4.

Sample number	As-cast AA4032	AA4032/Nano Si_3N_4
1	308.54	353.85
2	308.20	353.52
3	306.18	351.50
4	308.34	353.65
5	303.45	348.77
6	301.68	346.99
7	303.14	348.46
8	299.19	344.50
9	302.19	347.50
10	304.63	349.94
11	301.43	346.75
12	299.99	345.30
13	297.06	342.37
14	296.21	341.53
15	292.31	343.70
16	295.33	412.10
17	299.32	344.64
18	301.54	346.86
19	305.09	350.41
20	305.96	351.28

Table 2: Group statistics of tensile strength in as-cast AA4032 without reinforcement and AA4032 with reinforcement nano Si_3N_4.

Group statistics	N	Mean	Std. deviation	Std. error mean
As-cast AA4032	20	301.9890	4.53369	1.01376
AA4032/Nano Si_3N_4	20	351.1810	14.80299	3.31005

Table 3: Independent samples test of the tensile strength (MPa) in as-cast AA4032 without reinforcement and AA4032 with reinforcement nano Si_3N_4.

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	1.234	0.274	-14.210	38	0.000	-49.1920	3.46181	-56.20007	-42.18393
Equal variances not assumed			-14.210	22.533	0.000	-49.1920	3.46181	-56.36152	-42.02248

Table 4: Descriptive of the tensile strength (MPa) of as-cast AA4032 without reinforcement and AA4032 with reinforcement nano Si_3N_4.

Tensile strength (MPa)	N	Mean	Std. deviation	Std. error	95% CI for mean		Minimum	Maximum
					Lower bound	Upper bound		
As-cast AA4032	20	301.9890	4.53369	1.01376	299.8672	304.1108	292.31	308.54
AA4032/Nano Si_3N_4	20	351.1810	14.80299	3.31005	344.2530	358.1090	341.53	412.10
Total	40	326.5850	27.15223	4.29314	317.9013	335.2687	292.31	412.10

citation [13] suggests this data-driven approach might draw from, or be benchmarked against, external research. Collectively, these tables provide a layered and comprehensive insight into the tensile strength dynamics of AA4032, both in its pure form and when enhanced with nano Si_3N_4 reinforcement.

Discussion

The findings show that the tensile strength (MPa) of AA4032 with nano Si_3N_4 reinforcement is higher than as-cast AA4032 without reinforcement. To make things easier, the descriptive table data includes mean, standard deviation, standard mean error, and other statistics. It facilitates determining the tensile strength of both materials for easy assessment. Previously, a study on the AA4032 with SiC found that it had 5% higher tensile strength than the basic metal. Another study on twin-roll casting high Mg AA4032 to alloy sheets yields 4.6% and 7.6% higher tensile strength than the basic metal. In figure 6, however, composite had about 14% higher tensile strength in our tests than as-cast metal [14].

Furthermore, we devised a revolutionary encapsulating approach to cast the aluminum alloy, which resulted in better tensile strength than the other AA4032 alloy in prior studies. It is accomplished by the use of the stir-casting process as well as evenly spreading the reinforcement to the overall metals during casting [15]. As a result, we used a unique encapsulating technology and reinforcing nano Si_3N_4 to create a composite with higher tensile strength.

The stirrer and pouring technique are two aspects impacting our study. We discovered several casting flaws such as pinholes, blow holes, and, on rare occasions, shrinkage cavities caused by molten metal flowing under gravity to the die [16]. This casting flaw was regarded as the research's limitation. As a result, the future goal of this research is to eliminate such casting flaws by using the squeeze casting process to prevent the creation of air bubbles.

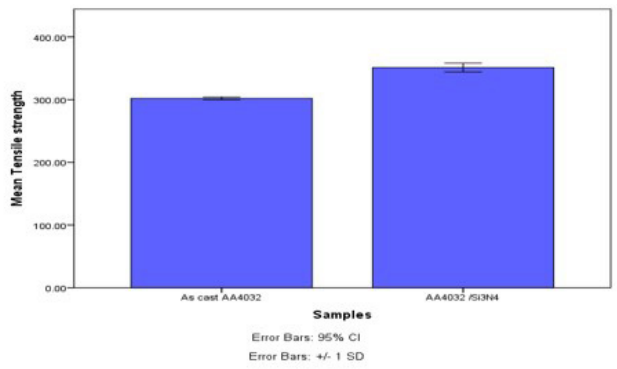

Figure 6: The AA4032 with 10% nano Si_3N_4 reinforcement has about 48% higher tensile strength than the as-cast AA4032 material without reinforcement.

Conclusion

The research primarily focuses on the mechanical properties, specifically the tensile strength, of a composite material made from the AA4032 alloy reinforced with 10% nano Si_3N_4. The AA4032 alloy, in its pure form without any reinforcements, already possesses certain intrinsic strength and other mechanical attributes. However, by introducing 10% Si_3N_4, a known reinforcement agent, the tensile strength of this composite material has been significantly enhanced. When comparing the reinforced version of AA4032 with the as-cast, or pure, AA4032 alloy, there's a noticeable 48% increase in tensile strength in the former. This impressive enhancement in tensile strength is not solely due to the addition of Si_3N_4; a novel encapsulating process using the stir casting method played a pivotal role. Such an increase in tensile strength opens up new avenues for the application of this composite material. For instance, it can be considered as a potential material for constructing vehicle armor, ensuring that it can withstand significant impact and stress. Beyond this, the reinforced AA4032 holds promise for use in cryogenic propellant tanks, vital components in rocketry where the material needs to withstand extreme conditions. Furthermore, there's potential for its application in the maritime industry, especially in ship development, given its enhanced strength and durability.

Acknowledgements

None.

Conflict of Interest

None.

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