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Experimental Investigation on Wear Behavior of AA4032 Reinforced Nano Si_3N_4 Using Novel Encapsulate Stir Casting Technique

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Abstract

This research delved into the intricate comparison between the wear behavior of as-cast AA4032, and a composite blend enriched with 10% nano Si_3N_4. This composite wasn't constructed through conventional methods but utilized a sophisticated encapsulating technique, underpinning its distinctiveness. Creating samples for the composite and the as-cast alloy relied on a combination of stir-casting and the aforementioned encapsulating method. The research was bifurcated into two primary groups to ensure clarity and distinction. Group 1 championed the as-cast AA4032, presenting it in its pure, unaltered state. In contrast, group 2 featured a meticulous blend of AA4032 alloy and 10% nano Si_3N_4, presenting a reinforced composite. To maintain a gold standard in producing these samples, the globally recognized ASTM E92 standards were diligently followed. The true mettle of these samples was then tested using the pin-on-disc apparatus, a trusted method in evaluating wear behaviour. Each group consisted of 20 carefully crafted samples, leading to 40 samples for the entire research. The rationale behind choosing this sample size was driven by the G-power analysis, which stood at 80%, combined with an α value of 0.05 for each set. The findings were nothing short of revelatory. The composite bolstered by the 10% nano Si_3N_4 manifested wear resistance properties that surpassed its as-cast AA4032 counterpart by a staggering 58%. Further strengthening these findings was the t-test's statistical analysis, which underscored a marked difference between the two groups. With a compelling p-value of 0.00 (indicative of a significant distinction when $p < 0.05$), the wear variance between group 1 and group 2 came to the fore. Given the constraints and parameters of this exhaustive research, one clear insight emerged: adding 10% nano Si_3N_4 to the AA4032 alloy dramatically augments its wear resistance, pointing towards the vast potential of this composite in industrial applications.

Keywords

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

Introduction

A composite is a mixture of two or more elements that are not dissolvable in one another; they have unique qualities that differ from any of their component materials [1]. Because of their lightweight and generous direction, such as the ability to tolerate harsh circumstances, composite materials have captured a massive portion of the vehicle industry [2]. As a result of the severe energy crisis and environmental deterioration, all governments are now focusing more globally on emission reduction, pollution reduction, and performance enhancement [3]. Aluminum metal matrix composites are employed in various applications such as

braking rotors, chambers, and chamber liners [4]. Because of their decreased production costs and altered features, they are commonly employed in the aerospace and maritime industries. Stir is one of the most adaptable projects since it allows us to respond in the case of advancement, is more economical, and has a greater creation rate [5]. According to recent research, many half and half composites goods can be used for advanced design applications. Previously, multiple specialists used mixed projecting to fabricate composite materials fortified with various clay molecule fortifications, and it was discovered that build composites have improved mechanical and wear execution.

Several articles on the wear resistance of AA4032 have recently been published. There are 193 research papers published in Google Scholar based on the AA4032 and wear behaviour, compared to 65 research articles published in Science Direct. Investigation of Al-4032 based metal matrix composite wear characteristics using Taguchi's optimization approach [5]. Sliding wear characteristics of Al-4032/SiC/GMP hybrid composites using L-16 orthogonal array [6]. Investigation of tribological behaviour of Al-4032 based metal matrix composite using Taguchi's optimization approach [7]. Because it provided a thorough description of the novel encapsulation technique, the paper on the hybrid composites created using this technique is regarded as the best. This study demonstrates the fusion of the mechanical and computer science domains by optimizing the composite well with multiple reinforcements and adding the artificial neural network approach with a unique encapsulation feeding methodology for casting [8].

We found that there had been very little research on using novel encapsulation techniques to fabricate composites. This study set out to develop a novel encapsulating stir-casting method for the AA4032/10% nano Si_3N_4 composite. The study aimed to contrast the wear properties of the as-cast and composite materials.

Materials and Method

The research under discussion was conducted by Saveetha Industries, Saveetha School of Engineering, and Saveetha Institute of Medical and Technical Sciences, Chennai (Tamil Nadu, India). This comprehensive study sought to analyze the wear resistance of two distinct groups of materials: the as-cast and the composite group. Both groups were represented by 8 mm in diameter and 30 mm in height samples. Altogether, there were forty sample sizes, each group comprising twenty sizes [9]. After sampling each set, a G-power of 80% was established.

The initial step in the as-cast group (Group 1) involved machining a 20 mm diameter AA4032 rod to obtain a polished and burr-free surface. This meticulous process ensures the elimination of any superfluous material. Subsequently, a kilogram of the AA4032 alloy is placed into a 1 kg capacity crucible and then subjected to a furnace heated gradually to 700 °C [10]. Once molten, the metal is poured into molds. After cooling and removing excess material, the casting metal is segmented into the desired sample size of 8 mm by 30 mm to undergo wear resistance testing [11].

On the other hand, in the composite material group (Group 2), the initial steps were quite similar. However, this rod was further modified: holes of varying diameters (2 mm, 4 mm, 6 mm, and 12 mm) were drilled into it [12]. The rod, filled with 10% nano Si_3N_4, was then enclosed in a 15 mm thick cup. The combined material was then melted in a crucible inside a furnace. This molten mix of AA4032 alloy and nano Si_3N_4 was then poured into molds using stir-casting. After cooling, segmenting, and eliminating any excess material, the composite samples, again measuring 8 mm by 30 mm, were prepared for wear resistance evaluation [13].

The testing procedure for wear resistance employed a pin-on-disc apparatus. By ASTM E92 standards, every sample was sliced into 8 mm diameter and 30 mm height sections. These samples were tested against an oil hardened nickel steel disc with a diameter of 55 mm and a hardness of 60HRc [14]. The wear test incorporated varying loads (20 N, 40 N, and 60 N) and was executed over a uniform sliding distance of 2000 m at sliding speeds ranging between 0.6 and 1.0 m/s. All tests were performed under consistent environmental conditions, with a relative humidity of 60 - 65% and a temperature of 30 °C [15].

This entire procedure was meticulously repeated for each sample set three times. The resultant wear resistance values for the as-cast materials can be visualized in figure 1, while the composite material outcomes are presented in figure 2.

Statistical analysis

For data management, analysis, mathematical modelling, and other statistical tasks, IBM developed the statistical software programme SPSS (Statistical Package for the Social Sciences) [16]. Using the statistical program SPSS, the t-test



Figure 1: Nano Si_3N_4 (10% reinforcement).



Figure 2: Feeding nano Si_3N_4 to novel encapsulated AA4032.

is run on the wear resistance measurements generated for the research samples. The descriptive table, as well as the Bonferroni analyses, are run using the statistical program SPSS [17]. The wear resistance value is the dependent variable in this study while stirring speed and the proportion of reinforcement weight are the independent variables. The study also provides statistics for the mean, significance, and standard deviation.

Results

In the study at hand, a comprehensive exploration into the wear rates of two distinct materials – the AA4032 as-cast and the AA4032 augmented with 10% nano Si_3N_4 reinforcement – is presented (Figure 3). To ensure clarity and precision, this data is structured across multiple tables. Table 1 serves as the primary reference point, delineating the wear rates of both the AA4032 as-cast and its nano Si_3N_4 reinforced counterpart [18].

Moving on, table 2 delves deeper, providing detailed group statistics for the wear rates of the two materials. This table aids in extracting more nuanced insights by breaking down the performance of each material and its associated variables. Furthermore, to ascertain the differentials in wear rates between the two materials and test their statistical significance, the independent samples test of wear rate has been compiled and showcased in table 3.

Table 1: The wear of as-cast AA4032 and AA4032 with reinforcement of 10% nano Si_3N_4.

Sample number	As-cast AA4032 (x 10^{-5})	AA4032/Nano Si_3N_4 (x 10^{-5})
1	3.342	1.626
2	3.304	1.588
3	3.317	1.601
4	3.283	1.567
5	3.294	1.578
6	3.308	1.592
7	3.285	1.569
8	3.279	1.563
9	3.276	1.560
10	3.233	1.517
11	3.243	1.527
12	3.205	1.489
13	3.218	1.502
14	3.184	1.468
15	3.195	1.479
16	3.209	1.493
17	3.186	1.470
18	3.180	1.464
19	3.177	1.461
20	3.134	1.418

Table 2: Group statistics of wear rate in as-cast AA4032 and AA4032 with reinforcement of 10% nano Si_3N_4.

Group statistics		N	Mean	Std. deviation	Std. error mean
Wear rate	As-cast AA4032 (x 10^{-5})	20	3.2426	0.05810	0.01299
	AA4032/nano Si_3N_4 (x 10^{-5})	20	1.5266	0.05810	0.01299



Figure 3: Stir casting process.

Table 4, on the other hand, offers a holistic perspective, encapsulating the descriptive statistics related to the wear rates of both materials. This is especially valuable for researchers and professionals seeking an overarching view of the data, as it compiles the core attributes and metrics of wear rates in a singular table (Figure 4 and figure 5).

Discussion

The study shed light on the remarkable performance of as-cast AA4032 when reinforced with 10% nano Si_3N_4, exhibiting a notably enhanced wear rate compared to the standard as-cast AA4032. Delving into the details presented in the descriptive table, statistics such as the mean, standard deviation, and mean standard error provide a clearer understanding of the results. This granular data interpretation aids in swiftly determining the tensile strengths of the materials under examination.

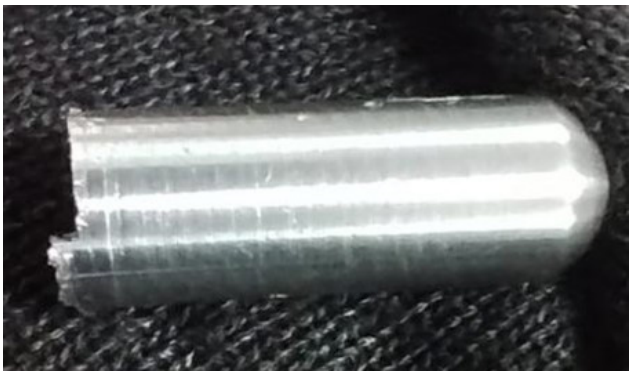


Figure 4: Material for the wear test.

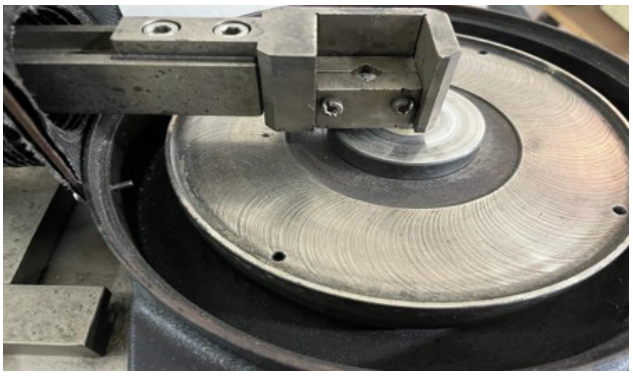


Figure 5: Wear rate test.

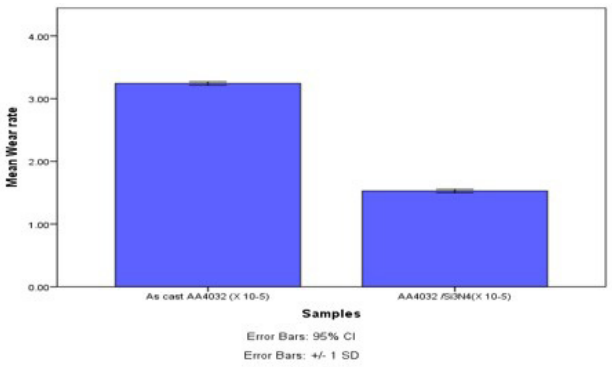


Figure 6: Mean wear rate of comparison with 10% nano Si_3N_4 and without nano Si_3N_4.

Interestingly, past studies on hybrid composites indicated that varying weight percentages of Al_2O_3 consistently resulted in wear rates that were 30% lower than that of the base metal. Furthermore, figure 6 of the present study depicts that the AA4032, when reinforced with 10% nano Si_3N_4, exhibited a wear rate that was 52% less than the as-cast AA4032. This is noteworthy, especially when juxtaposed with another research effort focused on graphite-reinforced composites. In that study, increasing graphite content (with a baseline of 5 wt.%) was instrumental in reducing the wear rate.

A crucial aspect of our study lies in the wear behavior of carbon nanotube-reinforced nanocrystalline AA4032 composites. By leveraging a novel encapsulation technique, we ensured the even dispersion of nano Si_3N_4 reinforcement throughout the aluminum alloy during the stir-casting process. As a result, the composite material we produced, using encapsulation and stir casting techniques, boasted superior wear strength compared to its as-cast counterpart.

Furthermore, the mean data emphasized that the AA5059 reinforced with 10% nano Si_3N_4 outperformed the as-cast metal by 52% in wear resistance. It's also vital to highlight that the pouring and stirrer techniques were pivotal to the study's results. Due to the gravitational pull of the molten metal into the die, our castings largely remained free from common defects like shrinkage cavities, pinholes, and blow holes. However, it's essential to admit that certain casting flaws present limitations in our research. The report's future research ambition is centered on deploying squeeze casting. This method is hoped to circumvent the issue of air bubble formation, thus eradicating the related casting defects.

Conclusion

In the recent study, we closely examined the effects of a new encapsulation method on the wear rate of a composite material made of AA4032 alloy combined with 10% nano Si_3N_4. Our findings reveal a significant enhancement in the wear resistance of this composite. Specifically, the incorporation of 10% nano Si_3N_4 into the AA4032 alloy led to a reduction in wear rate by an impressive 58%, in contrast to the wear rate observed in the untreated AA4032 alloy. The marked improvement can be attributed to the innovative encapsulation process we employed alongside the stir casting technique. Given the inherently low wear rate of AA4032, the addition of Si_3N_4 presents promising applications. For instance, this enhanced composite can be used to craft vehicle armor capable of withstanding substantial wear, potentially caused by factors like corrosion or erosion. Beyond that, the material could be instrumental in designing cryogenic propellant tanks or even certain ship models that necessitate superior wear resistance.

Acknowledgements

None.

Conflict of Interest

None.

References

1. Wogaso D, Hamda M. 2021. Studies on friction behaviour of aluminium AA4032 alloy during forging using ring compression test. *Int J Eng Sci Technol* 13(3): 23-36. https://doi.org/10.4314/ijest.v13i3.3
2. Yang CW, Chang YH, Lui TS, Chen LH. 2012. Effects of friction stir processing and artificial peak aging on erosion resistance of Al-11Si-4Cu-2Ni-0.7 Mg cast alloy. *Mater Des* 40: 163-170. https://doi.org/10.1016/j.matdes.2012.03.018

Table 3: Independent samples test of the wear rate in as-cast AA4032 and AA4032 with reinforcement of 10% nano Si_3N_4.

Wear rate	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	93.400	38	0.000	1.71600	0.01837	1.67881	1.75319
Equal variances not assumed			93.400	38.000	0.000	1.71600	0.01837	1.67881	1.75319

Table 4: Descriptive of the hardness of as-cast AA8176 without reinforcement and AA8176 with reinforcement nano graphene.

Wear rate	N	Mean	Std. deviation	Std. error	95% CI		Minimum	Maximum
					Lower bound	Upper bound		
As-cast AA4032 (x 10^{-5})	20	3.2426	0.05810	0.01299	3.2154	3.2698	3.13	3.34
AA4032/nano Si_3N_4 (x 10^{-5})	20	1.5266	0.05810	0.01299	1.4994	1.5538	1.42	1.63
Total	40	2.3846	0.87082	0.13769	2.1061	2.6631	1.42	3.34

3. Chankitmunkong S, Eskin DG, Limmaneevichitr C, Pandee P. 2023. Synergetic grain refinement and ZrB_2 hardening in *in-situ* ZrB_2/AA4032-type composites by ultrasonic assisted melt treatment. *J Mater Res Technol* 24: 2879-2890. https://doi.org/10.1016/j.jmrt.2023.03.182

4. Natrayan L, Kumar MS, Chaudhari M. 2020. Optimization of Squeeze Casting Process Parameters to Investigate the Mechanical Properties of AA6061/Al_2O_3/SiC Hybrid Metal Matrix Composites by Taguchi and ANOVA Approach. In Rao RV, Taler J (eds) Advanced Engineering Optimization Through Intelligent Techniques. Advances in Intelligent Systems and Computing. Springer, Singapore, pp 393-406.

5. Azizi A, Zangeneh S, Mojtahedi M, Rasaee S. 2023. Hot deformation behavior and microstructure of Ni-Cu rich Al-Si AA4032 alloy. *J Alloys Compd* 940: 168934. https://doi.org/10.1016/j.jallcom.2023.168934

6. Sivasankaran ST, Shanmugakani SK, Subbiah R. 2023. Performance analysis of conventional and DMLS copper electrode during EDM process in AA4032-TiC composite. *3D Print Addit Manuf* 10(3): 569-583. https://doi.org/10.1089/3dp.2021.0030

7. Senthilkumar TS, Muralikannan R, Ramkumar T, Kumar SS. 2021. Studies of kerf width and surface roughness using the response surface methodology in AA4032-TiC composites. *Proc Inst Mech Eng Part E J Process Mech Eng* 235(6): 2240-2253. https://doi.org/10.1177/09544089211041418

8. Kumar MS, Natrayan L, Hemanth RD, Annamalai K, Karthick E. 2018. Experimental investigations on mechanical and microstructural properties of Al_2O_3/SiC reinforced hybrid metal matrix composite. *IOP Conf Ser Mater Sci Eng* 402(1): 012123. https://doi.org/10.1088/1757-899X/402/1/012123

9. Saravanan MSS, Babu SPK. 2015. Synthesis, characterization, and ECAP consolidation of carbon nanotube reinforced AA 4032 nanocrystalline composites produced by high energy ball milling. *J Eng Mater Technol* 137(2): 021004. https://doi.org/10.1115/1.4029196

10. Natrayan L, Singh M, Kumar MS. 2017. An experimental investigation on mechanical behaviour of SiC_p reinforced Al 6061 MMC using squeeze casting process. *Int J Mech Prod Engi Res Dev* 7(6): 663-668.

11. Velavan K, Palanikumar K, Thirumal K, Kannan KR, Kannan M, et al. 2023. Mechanical characterization of aluminium alloy LM25 reinforced with TiC and graphite for structural applications. *Mater Today Proc* 72: 2049-2055. https://doi.org/10.1016/j.matpr.2022.08.105

12. Chawla D, Nayak M, Gupta P. 2023. Fabrication aspect and mechanical properties of aluminium metal matrix composites: a perspective. *AIP Conf Proc* 2800(1): 020266. https://doi.org/10.1063/5.0162962

13. Sathish T, Natrayan L, Christydass SPJ, Sivananthan S, Kamalakannan R, et al. 2022. Experimental investigation on tribological behaviour of AA6066: HSS-Cu hybrid composite in dry sliding condition. *Adv Mater Sci Eng* 2022: 9349847. https://doi.org/10.1155/2022/9349847

14. Padmavathi KR, Ramakrishnan R, Kumar KP. 2015. Aluminium metal matrix composite–an insight into solid state and liquid state processes. *Appl Mech Mater* 766: 234-239. https://doi.org/10.4028/www.scientific.net/AMM.766-767.234

15. Kalita K, Kumar V, Chakraborty S. 2023. A novel MOALO-MODA ensemble approach for multi-objective optimization of machining parameters for metal matrix composites. *Multiscale Multidiscip Model Exp Des* 6(1): 179-197. https://doi.org/10.1007/s41939-022-00138-5

16. Huircapan MP, Franco M, De Rosa H. 2022. Efecto de la microestructura y los tratamientos térmicos sobre aleaciones hipereutécticas de Al-Si Solidificadas Rápidamente. *Matéria* 27: e202149007. https://doi.org/10.1590/1517-7076-RMAT-2021-49007

17. Prasad T, Reddy AC. 2017. Effects of carbon black nanoparticles on wear resistance of AA6063/CB metal matrix composites. *Int J Mater Sci* 12(1): 87-95.

18. Pandiyan GK, Prabaharan T, James DJD, Sivalingam V. 2022. Machinability analysis and optimization of electrical discharge machining in AA6061-T6/15wt.% SiC composite by the multi-criteria decision-making approach. *J Mater Eng Perform* 31(5): 3741-3752. https://doi.org/10.1007/s11665-021-06511-8