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Influence of Carbon Nano Tube and Coconut Shell Ash in Aluminium Metal Matrix Composites

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Abstract

In this investigation, Aluminum 1050 (Al), Carbon Nanotubes (CNTs), and Coconut Shell Ash (CSA) composite was fabricated using a double stage stir casting technique. During fabrication, molten aluminium is initially combined with 0.2wt% of CNT, additionally, varied amounts of CSA in 1%, 2%, 3%, 4%, 5%, 6%, 7%, and 8% are added to the CNT-Al matrix to evaluate the material's density, micro hardness, and tensile, compressive strength and wear properties. The analysis encompassed an examination of the composites' structure, the distribution of reinforcing materials, and the basic composition. The microstructure of the composite versions were then assessed and compared to Al-0.2%CNT. The density of the Al-0.2% CNT-8% CSA composite is 2.46%, which is slightly lower than that of the Al-0.2%CNT composite. In phrases of hardness, tensile and compressive strength of Al-0.2% CNT-6% CSA composite verified an incredible increase by 53.2%, 45.42% and 38.58% respectively. However, the addition of 8% CSA decreases the hardness by 6.27% tensile strength by 6.79%, compressive strength by 14.12% when compared to hybrid composite containing 6%CSA. The wear loss of hybrid composites is lower due to the cushioning effect of CSA particles.

1. Introduction

Composites are substances that result from the mixture of two or more extraordinary substances on a macroscopic scale, and they generally exhibit a discernible boundary or interface among these parts. These composite materials play an essential role in the manufacturing of diverse automotive components, which includes panels and chassis, as well as aerospace packages, which include the development of wings and fuselages [1–4].

Notably, nowadays, metal matrices have turn out to be a vital thing inside the introduction of metal matrix composites (MMCs). The studies and improvement of MMCs have a visible significant surge in activity in latest years due to their capacity to offer similar energy and offer resistance to wear, corrosion, and fatigue, making them quite suitable for more than a few applications [5-10].

The production of aluminum metal matrix composites employs various methods, including powder metallurgy; spray coating, electroplating, and the stir casting process [11-18]. Among these, the stir casting method is favored for its economic efficiency and suitability for large-scale production. This technique is primarily employed for manufacturing metal matrix composites that utilize whiskers and particulate reinforcement [6].

In this work, the author’s have created a composite material known as Al-CNT-CSA using a double stir casting technique. This involved blending multi-walled carbon nanotubes (MWCNTs) with pure aluminum and coconut shell ash (CSA) powders. The study aimed to examine the combined mechanical characteristics, such as strength and hardness, when varying amounts of CSA were introduced into the composite.

2. Materials and methods

Pure aluminum served as the foundational material for crafting hybrid composites in this study. Multi-walled carbon nanotubes (MWCNT) with a purity exceeding 99% and Coconut Shell Ash (CSA) particles sized between 40 and 80 micrometers were employed as reinforcement materials. Ingots of pure aluminium procured from PMC Corporation, Bengaluru was used as a matrix material for the composites, CSA procured from Kasturi Coconut Processings, Karnataka and CNT procured from Ad nano Technologies were used as reínforcement.

Al	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Zr
Bal.	0.087	0.111	0.004	<0.005	0.011	<0.005	<0.004	0.017	---

Table 1: Chemical Composition of Aluminium 1050

Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	Na_2O	SiO_2	MnO	ZnO
15.6	0.57	12.4	0.52	16.2	0.45	45.05	0.22	0.3

Table 2: Chemical Composition CSA

Sl No.	**MWCNT standards**	**Description**	**Characterization Method**
1	Production Method	Chemical Vapour Deposition	Propritary method
2	Available Form	Black Powder	Visual
3	Diameter	Outer Diameter: 10-30mm	TEM, SEM
4	Length	10 Micron	TEM, SEM
5	Nanotubes Purity	98+% & above pure carbon	TGA, XRD
6	Metal Particles	<4%	TGA
7	Amorphous Carbon	<1%	TGA, XRD
8	Specific Surface Area	330 m2/g	BET

Table 2: CNT Description

The stir casting furnace used for fabrication of composite is Cerathermo, which has the furnace capacity of 5 kg. Aluminum rods with a predetermined weight were placed within a graphite crucible and exposed to gradual heating in a electric furnace, reaching a temperature of 750°C at a controlled increment of 5°C per minute. To maintain the temperature during the casting process, a PID controller was employed. To enhance the melt's fluidity, 1% magnesium powder was introduced. Stirring was carried out using a stainless steel stirrer quipped with four blades. The reinforcement particles 0. 2% CNT was added and stirred for 3 minutes. This process yielded the Al-0.2% CNT composite melt. Subsequently, eight hybrid composite were generated by adding CSA in varying amounts, ranging from 1% to 8%, into the Al-0.2% CNT composite melt. A double-stage stirring method was employed to ensure the even distribution of the low-density CSA particles within the Al-0.2% CNT melt. In this double-stage stir casting process, the Al matrix was initially heated to 750°C and transformed into a semi-solid state, followed by continuous stirring for 3 minutes. Subsequently, the partially solidified matrix material underwent reheating to 750°C to revert it to a molten state. During this process, CNT and CSA particles were introduced and continuously stirred for approximately 3-4 minutes. Ultimately, the resulting mixture was poured into a preheated mould, resulting in the fabrication of composite billets.

2.1 Characterization study

Microstructures were observed in different magnification ranges using JSM-IT300 Scanning Electron Microscope. Samples were prepared using standard metallographic procedure for microstructure observation.

2.2 Density

The experimental density of the casting was established by employing Archimedes' principle, with water serving as the submersion medium. Meanwhile, the theoretical density of the casting was calculated in accordance with the rule of mixtures [19].

The percentage of porosity within the composite was approximated by comparing the theoretical and experimental densities using the following method.

$$\% \text{ porosity} = \frac{Theoretical\ density - Experimental\ density}{Theoretical\ density} \text{x } 100\ \%$$

2.3 Hardness

Hardness assessments were carried out using a Vickers hardness tester V1202, Buehler in accordance with the ASTM E-384 standard procedure. In this test, a 1 kg load was applied to the material for duration of 10 seconds. The hardness tests were conducted at five distinct positions on the test material, and the resulting values were averaged.

2.4 Tensile and compression strength

The FIE UTN40 model universal testing machine was employed to perform both tensile and compression tests, with a crosshead movement speed set at 3 mm/min. The tensile test adhered to the ASTM E-8 standard, with specific parameters: a gauge length of 24mm, a diameter of 6mm, a fillet radius of 4mm, and a reduced section length of 20mm, all maintained within a tolerance of 0. 1mm. Meanwhile, the compression test followed the ASTM E-9 standard and utilized samples with dimensions of 20mm in diameter and 20mm in height.

2.5 Wear test

The wear loss and coefficient of friction for the hybrid composite were evaluated using a pin-on-disc wear tester, specifically the DUCOM model. The testing procedures adhered to the ASTM G99-04 standard and were conducted under dry sliding conditions at room temperature. These wear tests were carried out under two different loads, namely 10N and 20N, while maintaining a constant speed of 2.62 m/s and covering a distance of 100mm. The test specimens had dimensions of 10mm in diameter and 30mm in length. To quantify the wear, the weight of the specimens was measured before and after the tests using a digital weighing machine with a resolution of ±0. 001g. Using the difference in mass (Δm), the volumetric wear loss (V), coefficient of friction (μ), and specific wear rate were calculated.

3. Result and discussion

3.1 Morphology of Al-0.2% CNT and its composites

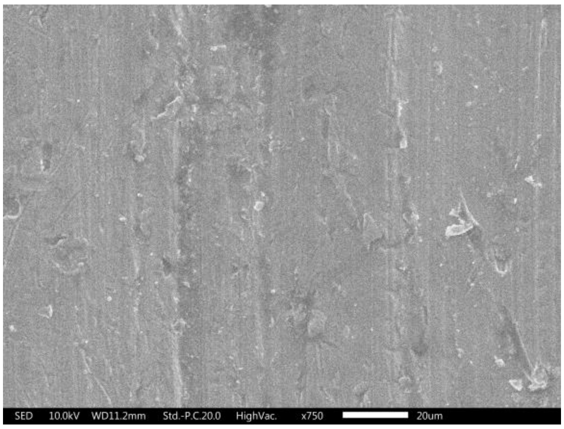

Fig 2 (a) Al-0.2%CNT-0%CSA

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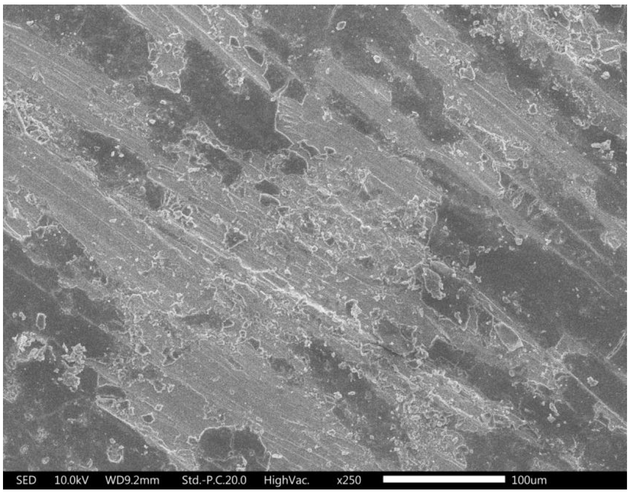

Fig 2 (b) Al-0.2%CNT-1%CSA

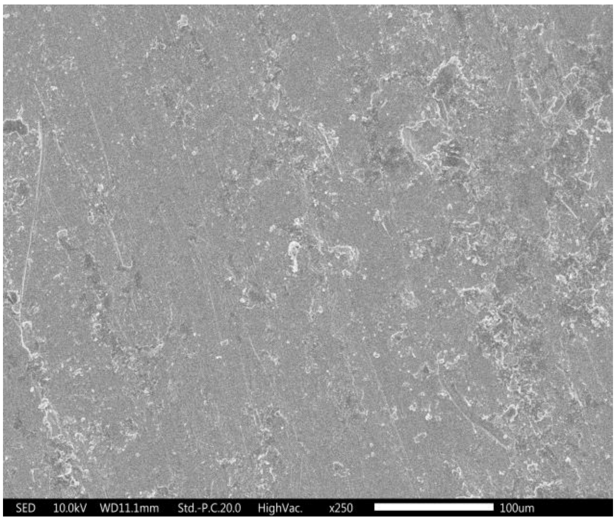

Fig 2 (c) Al-0.2%CNT-2%CSA

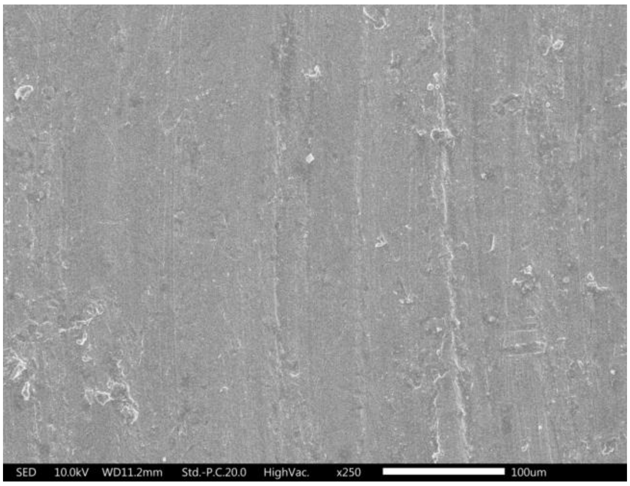

Fig 2 (d) Al-0.2%CNT-3%CSA

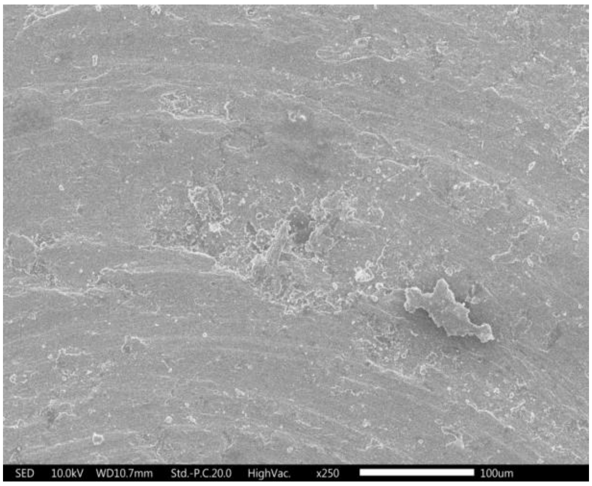

Fig 2 (e) Al-0.2%CNT-4%CSA

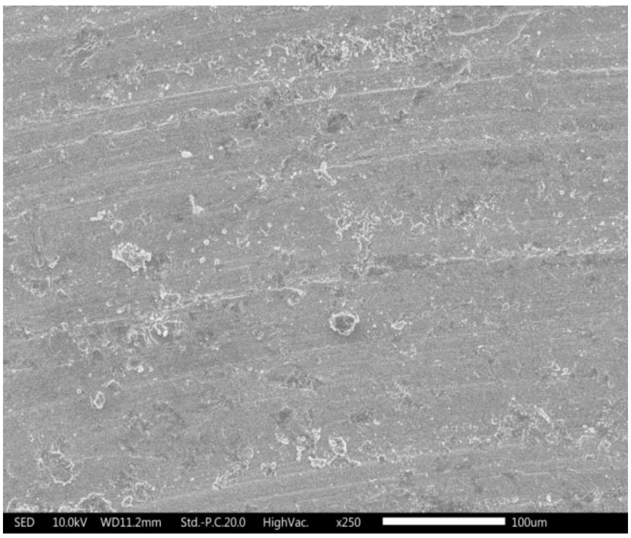

Fig 2 (f) Al-0.2%CNT-5%CSA

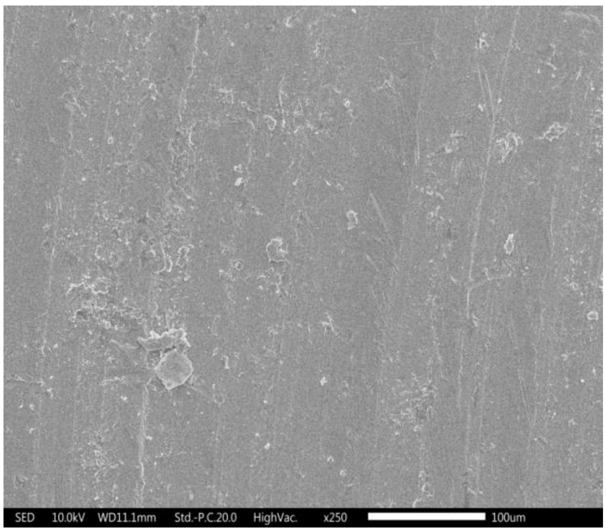

Fig 2 (g) Al-0.2%CNT-6%CSA

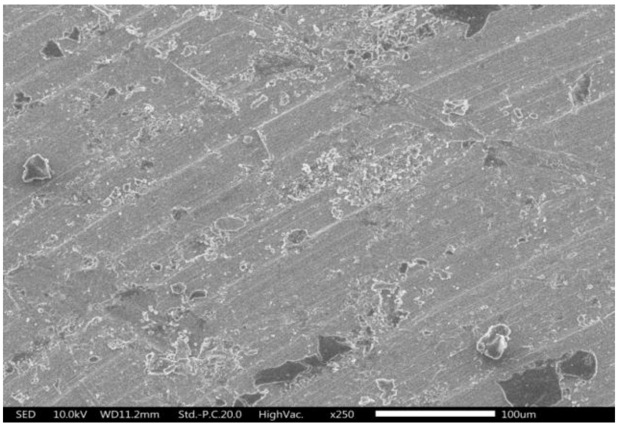

Fig 2 (h) Al-0.2%CNT-7%CSA

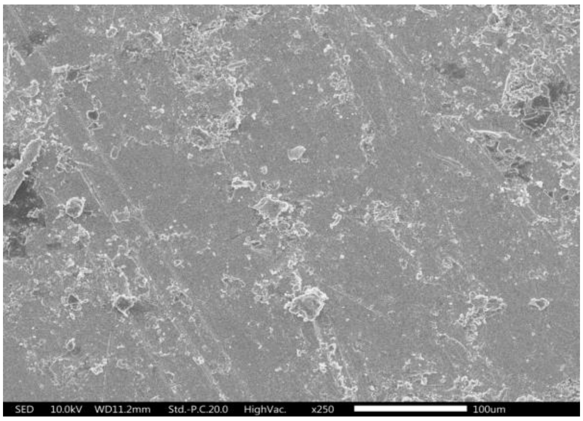

Fig 2 (i) Al-0.2%CNT-8%CSA

Fig.2(a)-(i): SEM micrographs of Al-0.2%CNT-CSA

Fig. 2(a)-(i) shows the SEM images of the cast Al - 0.2% CNT composite. It can be observed from Figures 2b to 2f that there is a consistent and even dispersion of the reinforcement particles and there is no evidence of particle clustering or agglomeration. However, the SEM micrograph of Al-0.2% CNT-7% CSA (Fig. 2 g), Al-0.2% CNT-8% CSA (Fig. 2 h) showed agglomerations of reinforcement and voids. The observation suggests that adding Coconut Shell Ash (CSA) up to 6 wt% into the matrix leads to effective dispersion of the reinforcement materials.

3.2 Density of Al-0.2% CNT and its composites

Table 1 presents a comparative analysis between theoretical and experimental outcomes regarding density. It is evident that in both scenarios, the density of the sample reduces as the amount of reinforcing particles increases. The findings indicate that both the theoretical and experimental densities are below the density of aluminum, which is 2.71 g/cm³.. The level of porosity in the composites was determined to be quite low, falling within the range of 2 to 3.5%, as illustrated in Table 1. As indicated in the table, it is noticeable that the theoretical density of the composite decreased with an increase in the amount of reinforcement. This is due to the low density of the CSA. A general trend could not be observed in case of experimental density due to the presence of different percentages of porosity.The data depicted in the table reveals that experimental density values are lower than theoretical ones due to the presence of pores or irregularities stemming from the casting process.

Table 1: Theoretical and experimental density and % porosity of Al-0.2% CNT composites

Sl. No	Composition	Theoretical Density (g/cm^3)	Experimental Density(g/cm^3)	% Porosity
1	Al +0.2% CNT	2.678	2.624	2.02
2	Al +0.2% CNT + 1% CSA	2.671	2.597	2.77
3	Al +0.2% CNT + 2% CSA	2.658	2.572	3.24
4	Al +0.2% CNT + 3% CSA	2.66	2.58	3.01
5	Al +0.2% CNT + 4% CSA	2.658	2.591	2.52
6	Al +0.2% CNT + 5% CSA	2.642	2.583	2.23
7	Al +0.2% CNT + 6% CSA	2.633	2.576	2.16
8	Al +0.2% CNT + 7% CSA	2.624	2.559	2.48
9	Al +0.2% CNT + 8% CSA	2.612	2.546	2.53

3.3 Hardness of Al-0.2% CNT and its composites

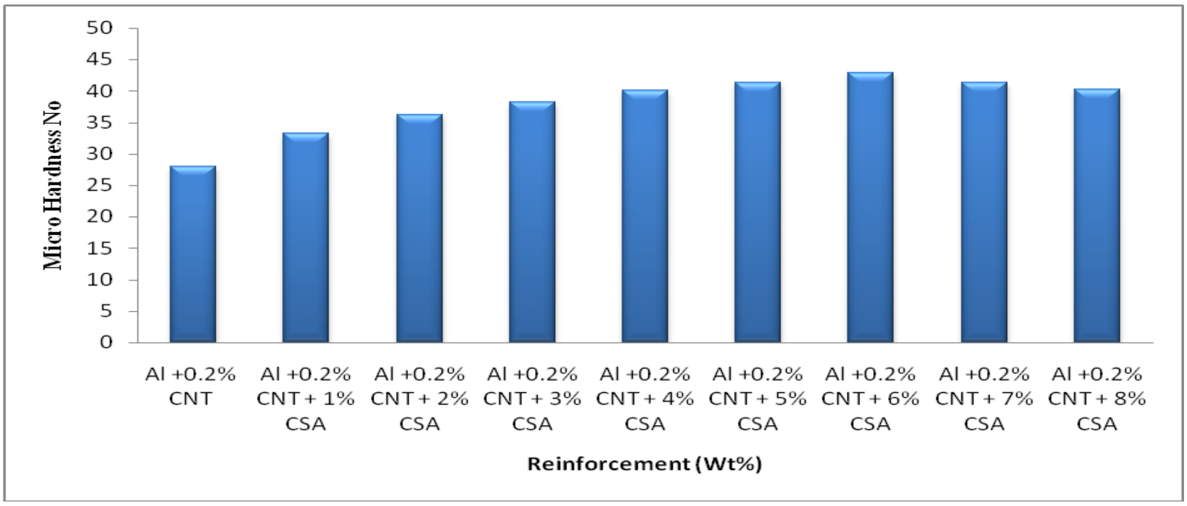

Fig 3: Micro - Hardness of Al-0.2% CNT and its composites

Fig. 3 show the micro - hardness of Al-0.2% CNT and its composites. It's worth observing that the hardness of the hybrid composites rises as the weight percentage (wt %) of CSA particles in the matrix increases. The micro-hardness of Al 0. 2% CNT is 28HV. Incorporating 8% CSA results in a significant hardness increase of 53. 2%. Further, the introduction of CSA into the Al-0.2%CNT matrix leads to incremental improvements in micro-hardness, specifically by approximately 18.17%, 29. 2%, 36. 43%, 43. 2%, 47. 85% and 53.2% respectively, as the CSA content increases from 1 to 6 wt% in 1 wt% increments. Thus the CSA particles help to improve the hardness of the hybrid composites. However, when 7% and 8% CSA is added, there is a reduction in hardness by approximately 3.73% and 6.27%, respectively. It can be observed that the hardness of the Al-0. 2% CNT - 8% CSA composite is lower when compared to the Al-0.2% CNT - 6% CSA hybrid composite. This disparity in hardness could be attributed to the potential formation of reinforcement particle agglomerations during the casting process.

3.4 Tensile strength of Al-0.2% CNT and its composites

Fig. 4 shows the tensile strength of Al and its composites. It can be noted that by increasing wt% of CSA particles in the matrix, the tensile strength of the hybrid composites increases. The tensile strength increases by 7.56% for Al-0.2%CNT-1%CSA composite compared to that of Al-0.2%CNT casted material. Further, it increases by 12.08%, 17.29%, 26.58%, and 34. 12% and 45. 42% respectively for addition in 2%, 3%, 4%, 5% and 6% CSA compared to that of Al-0.2% CNT composite. This may be due to uniform dispersion of CSA particles in the matrix and better interfacial bonding between reinforcement particles and the matrix phase. On further increasing the CSA content to 7% and 8% the tensile strength decreases by 3.75% and 6.79 % compared with that of Al-0.2%CNT-6%CSA. The reason for this reduction in tensile strength may be attributed to the formation of agglomeration and voids.

The elongation values of cast composites, which have been reinforced with varying weight percentages of reinforcement, are depicted in Fig 5. It is evident from the graph that as the content of CSA increases the elongation of the composites decreases. In comparison to the composite Al+0.2%CNT, the most significant reduction in elongation is observed in the hybrid composite Al-0.2%CNT-8%CSA, with a substantial decrease of 37.42%. The extent of elongation also serves as an indicator of ductility. The graph also illustrates that the ductility of composite materials is lower when compared to the composite Al-0.2%CNT, primarily due to the presence of rigid ceramic particles in CSA.

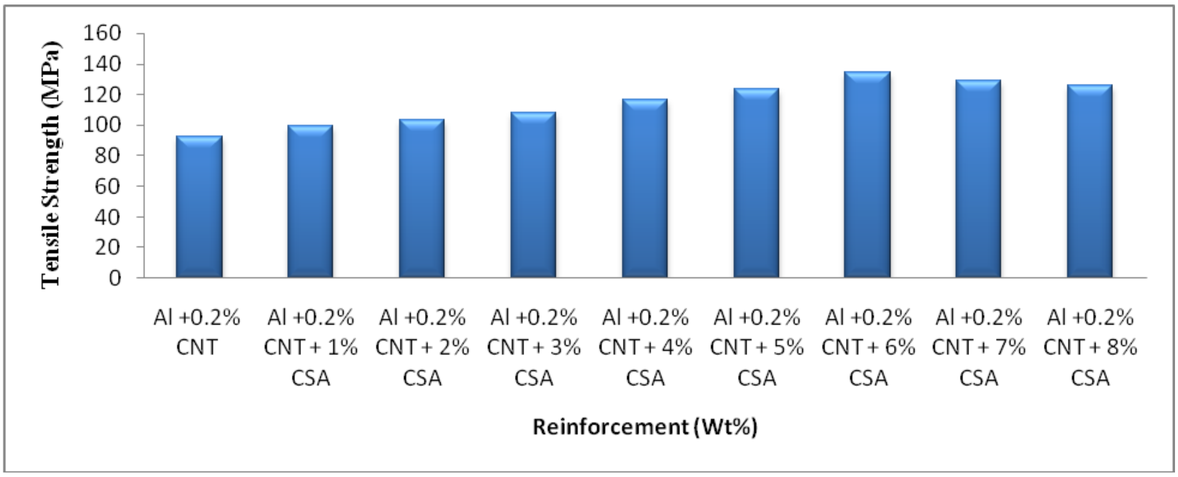

Fig 4: Tensile Strength of Al-0.2% CNT and its composites

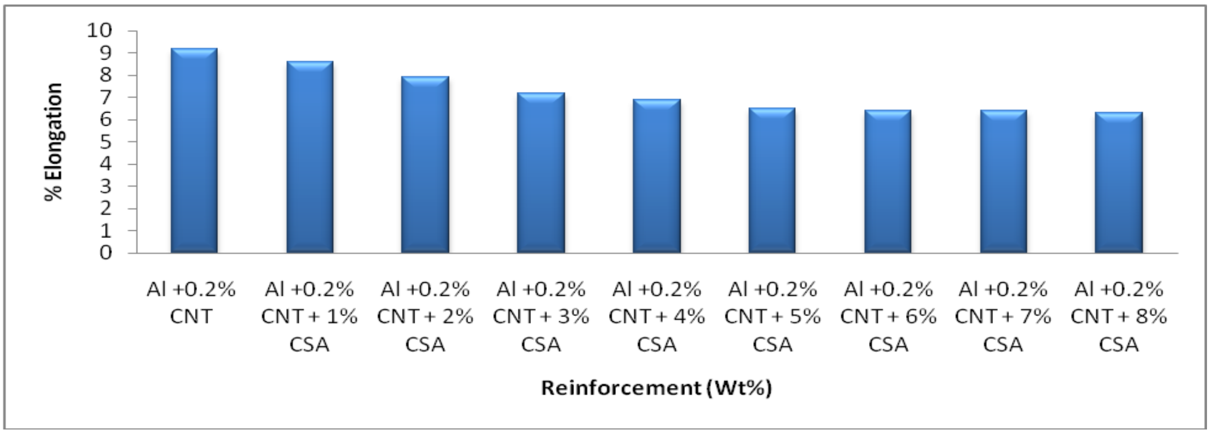

Fig 5: Percentage elongation of Al-0.2% CNT and its composites

3.5 Compressive strength of Al-0.2% CNT and its composites

Fig 6 illustrates the compressive strength characteristics of Al-0.2%CNT and its associated composites. The Al-0.2%CNT-1%CNT composite showcases a compressive strength higher than the original alloy, Al-0.2%CNT, by a margin of 3.79%. Further, it increases by 7.64%, 12.33%, 20.11%, and 26. 43% and 38.58% respectively for addition in 2%, 3%, 4%, 5% and 6% CSA compared to that of Al-0.2% CNT composite. On further increasing the CSA content to 7% and 8% the tensile strength decreases by 9.7% and 14.12 % compared with that of Al-0. 2%CNT-6%CSA.

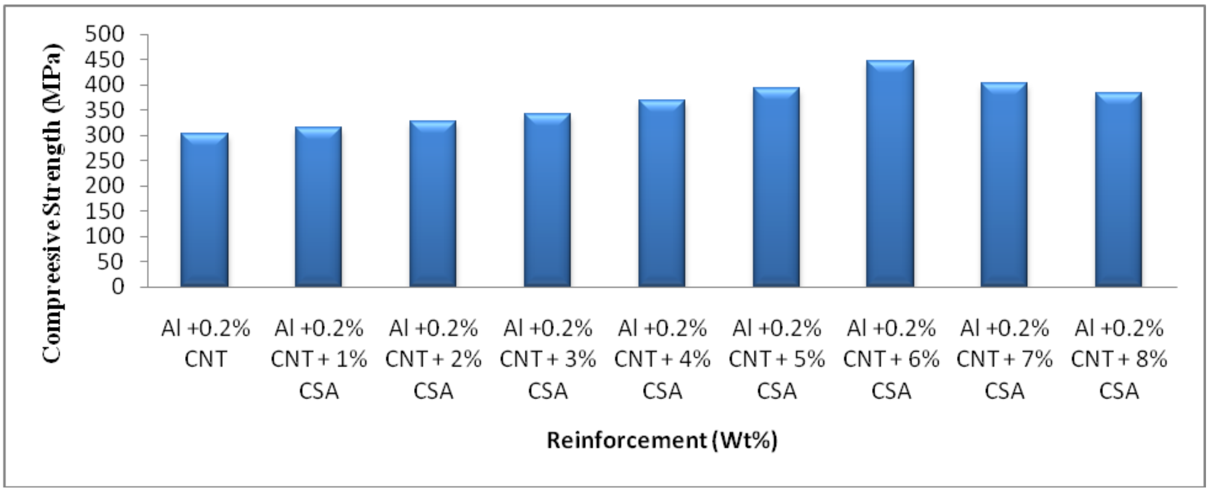

Fig 6: Compressive strength of Al-0.2% CNT and its composites

3.6. Wear behavior

3.6.1. Wear losses, co-efficient of friction and specific wear rate of Al-0.2%CNT and its composites

Fig 7 illustrates how wear loss changes in response to varying loads of 10 N and 20 N. It indicates that as the weight percentage (wt %) of CSA in the hybrid composites increases, wear loss decreases. The CNT particles distributed within the composite matrix contribute to improved composite hardness. On the other hand, the gentle CSA particles intervene between mating surfaces, leading to decreased wear loss by reducing friction. However, as the applied load increases, wear loss increases due to heightened friction between the pin surface and the disc.

Fig 8 illustrates how the coefficient of friction changes in Al-0.2%CNT and its composites. It's evident that with a rise in the weight percentage (wt %) of CSA reinforcement, the coefficient of friction decreases. This reduction is consistent regardless of the load since the disc's sliding speed remains constant. However, when the applied load grows, the coefficient of friction increases. This is because there’s greater contact between the pin and the disc in such cases.

Fig 9 depicts the relationship between the specific wear rate and the weight percentage (wt. %) of CSA content at various applied loads. It's evident that when the wt% of CSA reinforcement increases, the specific wear rate diminishes. This is attributed to the phenomenon of work hardening that both the base alloy and the composites undergo during the wear test. Notably, there’s a slight decrease in the specific wear rate at a 20 N load compared to a 10 N load. Furthermore, for composites containing 7 and 8 wt% CSA content, the specific wear rate remains relatively consistent across different loads (10 N and 20 N).

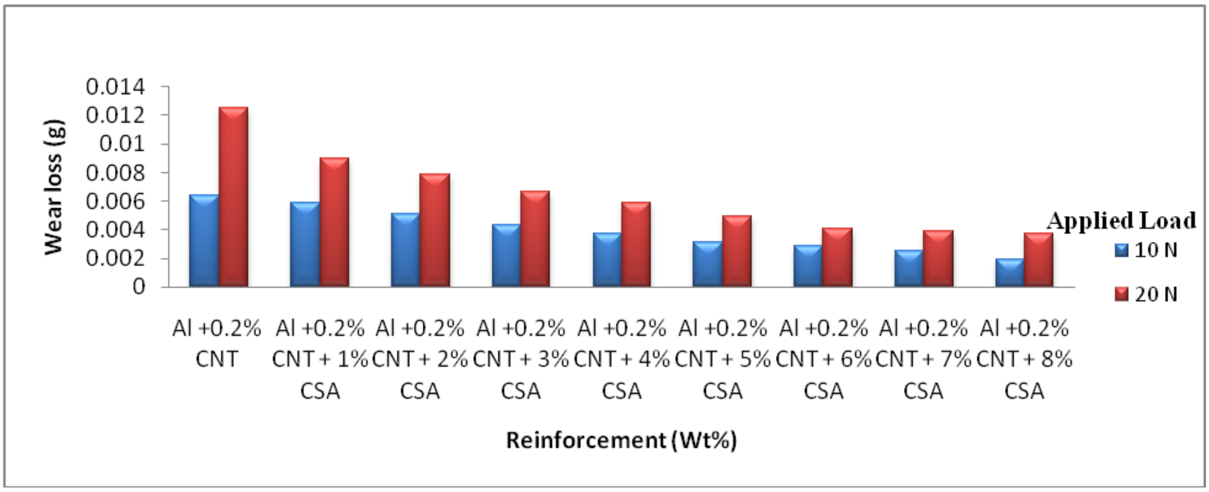

Fig 7: Wear loss of Al-0.2% CNT and its composites

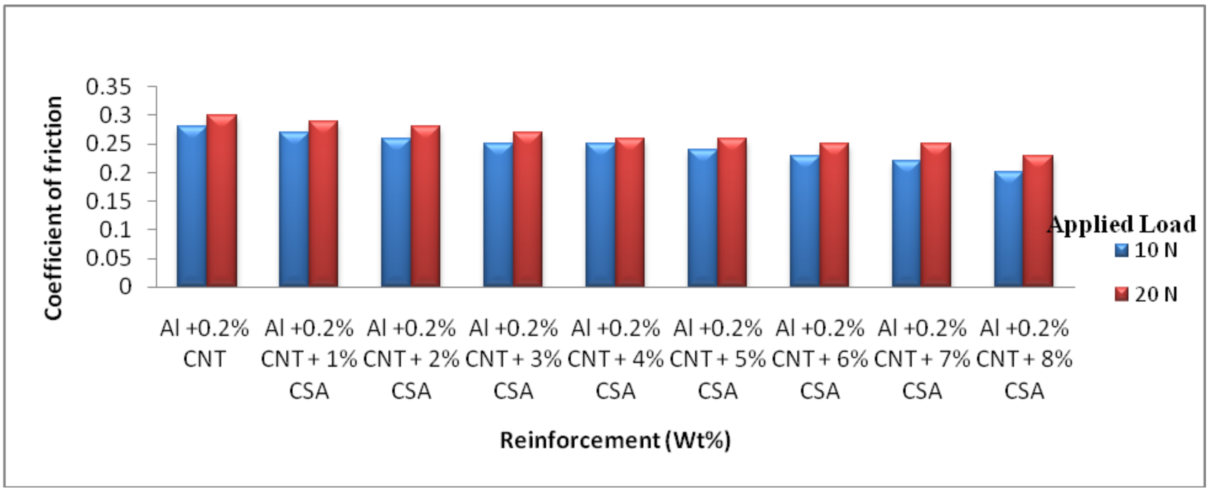

Fig 8: Coefficient of friction of Al-0.2% CNT and its composites

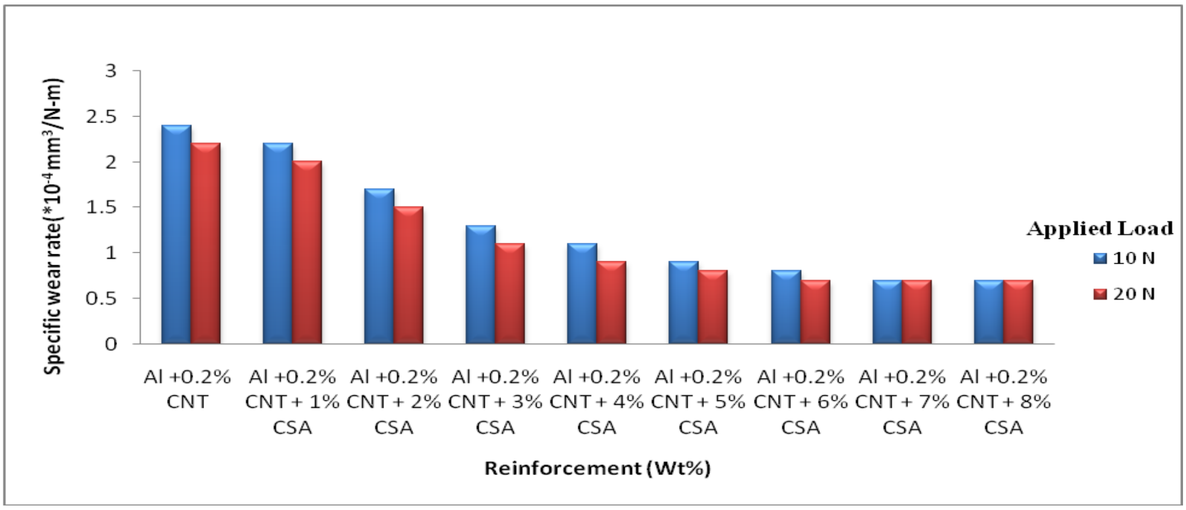

Fig 9: Specific wear rate of Al-0.2% CNT and its composites

4. Conclusion

A double stage stir casting process was utilized to manufacture Al-CNT-CSA hybrid composites. This involved altering the CSA proportions in increments of 1%, ranging from 1% to 8%. It was observed that the density of the Al-0. 2%CNT-8%CSA composite is 2. 46% lower than that of the Al-0.2%CNT composite. The morphological examination revealed a consistent and even dispersion of reinforcement particles within the hybrid composites. The micro-hardness, tensile and compressive strength tests revealed that the micro-hardness of hybrid composites improves by 53.2%, tensile strength by 45.42%, Compressive strength by 38.58% by adding CSA particles upto 6%. The study on wear behavior indicates that incorporating CSA particles into the Al-0.2%CNT composite enhances its resistance to wear. Further, as the load on the hybrid composites grows, the amount of wear loss also rises in tandem with an increase in the coefficient of friction.

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