Kufa Journal of Engineering
Vol. 17, No. 2, April 2026, P.P. 261-274
Article history: Received 16 May 2025, last revised 1 July 2025,
accepted 12 July 2025

THE INFLUENCE OF ADDING NANO-TUNGSTEN CARBIDE ON THE WEAR RATE AND COEFFICIENT OF FRICTION FOR CHOPPED FIBERS COMPOSITE

Samaher Mohey Fahad[1] and Ali Sadiq Alithari[2]

[1] Mechanical Engineering Department, Faculty of Engineering,University of Kufa, Najaf, 54001, Iraq, Email:samaherm.alhamd@student.uokufa.edu.iq.

[2] Mechanical Engineering Department, Faculty of Engineering, University of Kufa, Najaf, 54001, Iraq, Email:alis.alathari@uokufa.edu.iq.

https://doi.org/10.30572/2018/KJE/170215

ABSTRACT

Although epoxy compounds are often used in engineering and industrial environments, their poor resistance to wear in high-friction environments requires changes to their mechanical and surface properties. To improve wear properties, tungsten carbide nanoparticles WC at concentrations (1%, 1.5%, and 2%) were used to reinforce hybrid epoxy composites with chopped glass fibers (8%) and chopped sisal fibers (4%). A pin-on-disc devise was used to perform the dry wear test according to ASTM G99 guidelines. The best result was obtained with the addition of 1.5% WC compared to pure epoxy, with a 46.4% improvement in wear rate for the glass fiber-reinforced specimen with a friction coefficient of 0.20 and a 33.9% increase for the sisal fiber-reinforced specimen with a friction coefficient of 0.29.

KEYWORDS

Chopped fibers, Nano-tungsten carbide (WC), Epoxy, Wear rate, Coefficient of friction.

1. INTRODUCTION

Wear is a term that refers to the deterioration of solid surfaces, typically involving the gradual loss of material due to relative movement between the surface and the substrate. Corrosion directly affects the lifespan of industrial components (Sharma et al., 2020). To improve properties, hybrid composite materials have received widespread attention because they allow the combination of two or more materials to balance the advantages and disadvantages of each. The hybridization process allows for the creation and acquisition of unique material properties based on the characteristics of its component parts (Seydibeyoğlu et al., 2023). The two main types of fibers are synthetic and natural (Sinha, Narang and Bhattacharya, 2020). Fiber composites come in two types: short fiber (chopped) and continuous fiber (unidirectional or woven). Compared to continuous fiber composites, short fiber composites are less expensive, have better part reproducibility, and can be produced in large numbers (Madhukar, Selvaraj and Rao, 2016). Because natural fibers offer advantages over traditional glass and carbon fibers, among other materials, scientists and researchers have been interested in using them to improve polymer composites for many years (Vangala et al., 2019). For further improvement, nanoparticles, which are materials with one, two, or three external dimensions, ranging from about 1 to 100 nanometers (nanoscale), are used (Sinha, Narang and Bhattacharya, 2020) Due to their high aspect ratio, it has been shown that adding a relatively small weight fraction of nanofillers can significantly improve the mechanical, thermal, electrical, and magnetic properties of nanomaterials (Puttegowda et al., 2018). Polymer composites have been used in engineering applications due to their good mechanical and thermal properties, but their performance in improving these properties was limited. Therefore, many studies have focused on improving the properties by adding natural or synthetic fibers or nano-fillers (Ajibade, Agunsoye and Oke, 2021; Dookhi and Tahir, 2023; Jasim and Abdulsamad, 2025; Çelik and Türkan, 2020; AKGÜL, YALÇIN and ETİCHA, 2023; Betelie et al., 2018; Simamora et al., 2023; Pramanik et al., 2024; Sandeep Yadav and Sanjay Mishra, 2024; Bezy and Fathima, 2015; Alhazmi et al., 2021).

The uniform dispersion of particles and their ability to form protective layers during friction have been shown to significantly increase wear resistance and reduce the coefficient of friction when added to epoxy composites. (Singh et al., 2021) showed that the wear resistance of composites reinforced with silicon and sisal fibers was enhanced by the addition of 2% silica nanoparticles, Based on analysis of variance and experimental design, (Namdev, Telang and Purohit, 2022) discovered that the greatest mechanical and tribological performance was obtained when 0.5% graphene particles were used in carbon fiber hybrid composites. (Vaddar et al., 2023) discovered that by attaining a uniform reinforcement distribution within the matrix, adding carbon nanotubes (MWCNTs) to epoxy composites reinforced with chopped glass fibers enhanced wear resistance. These findings demonstrate that the right filler ratio, manufacturing process, and distribution uniformity all affect composites' best performance. little research has been conducted on the effects of adding tungsten carbide nanoparticles(known for its hardness and high resistance to wear) separately to epoxy composites reinforced with chopped glass fibers or natural sisal fibers, and on comparing the results, particularly with regard to wear resistance and tribological behavior. Therefore, this study compares and examines the wear behavior and coefficient of friction of two epoxy composites with varying percentages of tungsten carbide nanoparticles (1,1.5,2%wt.): one reinforced with 4% chopped sisal fibers and the other with 8%chopped glass fibers. This will help produce high-performance composite materials for a range of industrial uses.

2. MATERIALS AND METHODS

2.1. Epoxy resin

Ren floor HT2000 (2:1) epoxy resin serves as the composite's matrix. Properties of the epoxy used in accordance with the supplier's data sheet.

Table 1. Properties of the epoxy used (Fibers, Alrufaie and Alithari, 2024)

Density (kg/m^3)	Tensile strength (MPa)	Modulus of elasticity (GPa)
1050	27	2.8

2.2. Chopped E-glass fiber (GCF)

The 6 mm long, chopped E-glass fiber (562A) has a silane coating. it is made for injection or compression molding applications and works well with polyester and epoxy resin systems. Superior flow ability, outstanding mechanical qualities, and effective dispersion are some of its attributes.

Table 2. Properties of the CGF used (Seydibeyoğlu et al., 2023)

Density (kg/m3)	Tensile strength (MPa)	Modulus of elasticity (GPa)
2600	3400	77

2.3. Chopped Sisal fiber (CSF)

Is now grown in nations including Mexico, East Africa, Brazil, Haiti, and India and is a member of the Agave Sisalana plant family. are treated with a solution prepared from NaOH and cut into 6 mm lengths. These fibers were obtained from local sources.

Table 3. Properties of the CSF(Okeola, Abuodha and Mwero, 2018)

Density (kg/m^3)	Tensile strength (MPa)	Modulus of elasticity (GPa)
113	371±28	12.43±2.2

2.4. Nano tungsten carbide (WC)

An advanced material composed of tungsten and carbon atoms in specific proportions, possessing exceptional mechanical properties. This material is widely used in applications that require high resistance to friction and pressure, such as industrial tools, parts, and engines. Properties of the WC used show in Table 4

Table 4. Properties of the WC used (Ghani, Alithari and Hasan, 2025)

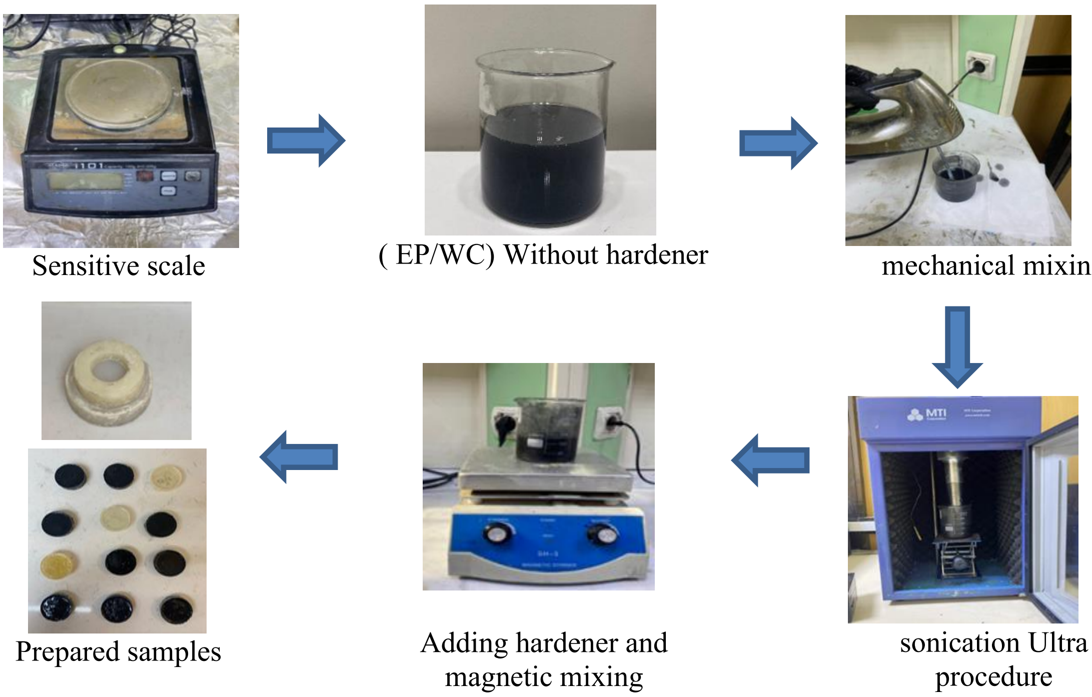
Volume	Purity	Density	Hardens
55	99.9 %	0.01563 kg/cm^3	~ 9 on the mosh scale

3. SISAL FIBERS PROCESSING

To improve the compatibility of the binder with the sisal fibers, the fibers are pretreated with a sodium hydroxide solution. This treatment removes the outer layer of the fiber, which consists of a waxy substance and contaminants, improving its properties. Sodium hydroxide powder, which is readily available and affordable, can improve the fibers' mechanical properties. The ratio of sodium hydroxide was 8% and distilled water to 92%. This ratio is ideal for protecting the fiber structure and preventing damage. Distilled water is mixed with the powder in a bucket. The fibers are then immersed in the solution. To prevent the solution from interacting with air, the container is sealed with a plastic cap and left for approximately three hours. Distilled water is then used to thoroughly rinse the fibers to remove any residual solution and avoid affecting their mechanical properties. To remove any residual moisture and prevent damage, the fibers are exposed to sunlight for three days. Finally, the fibers are cut into 6 mm lengths using scissors. (Gurmu and Lemu, 2023).

4. SAMPLES PREPARATION

In this work, 12 samples were prepared using a 4 cm diameter and 1 cm height Teflon cylindrical mold. The required quantities of nanomaterials (1, 1.5, and 2%) and chopped were prepared using a sensitive scale. The epoxy/fiber samples were prepared by mechanically mixing the epoxy and hardener in a 2:1 ratio for 5-10 minutes**.** The fibers were dispersed into the epoxy using gentle manual mixing. The liquid was carefully poured into the Teflon mold to avoid agglomeration and air bubble formation. The epoxy (without hardener) and nanocomposites were mechanically mixed for approximately 15 minutes to create the epoxy/nanopodies (Moosa, Ramazani A and Nabil Ibrahim, 2016). Ultrasonication was applied for 30 minutes to obtain a suitable dispersion of the nanocomposites (Mohanty and Srivastava, 2015). After ultrasonic treatment, the liquid was stirred using a magnetic stirrer for approximately three minutes to improve the dispersion of the nanocomposites after the addition of the hardener (Karunia, 2016). Then, the mixture was carefully poured into the mold. The same procedure used to create the epoxy/nanoparticle samples was followed to prepare the fiber/nanoparticle samples. Finally, the fibers were placed into the mold after being carefully mixed by hand to avoid agglomeration and poured into the mold. The samples were first cured by leaving them at room temperature (25°C) for approximately 24 hours. Then, the samples were carefully removed from the mold. Post-curing was then performed by placing the samples in an electric oven set at a temperature of 2∓ 60°C for approximately 2 hours (Ghani, Alithari and Hasan, 2025). Fig.1 shows actual images of the sample preparation.



Sensitive scale

(EP/WC) Without hardener

mechanical mixing

sonication Ultra procedure

Adding hardener and magnetic mixing

Prepared samples

Fig. 1. Sample Preparation

5. WEAR TEST

5.1. Wear rate W.R

Twelve cylindrical specimens were manufactured using a Teflon mold and the wear test was performed according to ASTM G99 (International ASTM, 2017)) using a wear tester (pin-on-disc tribometer), consisting of a pin and a rotating disc rotating at a specified speed of 300 rpm, a specified load of 10 N, for 10 minutes, and a rotation radius of 8 mm, as shown in Fig.2.

To calculate the wear rate, the initial weight of the sample was measured before testing, then it was exposed to wear conditions for a specified period of time. The final weight of the sample was then measured, and the difference between the two weights was determined to calculate the amount of material removed. The wear rate was calculated using Eq. 1.

$\mathrm{W.R} = \frac{\Delta w}{s_d}$ (1); $\Delta w = w1 - w2$ (2); $Sd = 2 * \pi * n * r * t$ (3) (Manuscript et al., no date)

Where w1: the initial weight value; w2: the final weight value; s_d: the sliding distance; n: the rotation speed r.p.m; r: the radius of impact in meter; t: the time in second.

Fig.2. Wear test Machen

5.2. Coefficient of friction (C.O.F)

By applying a vertical force, Fn, to the pin, the Pin on Disc device may also be used to compute the coefficient of friction. Weights are used in the device's settings to modify this force. Friction is created between the pin and the disc when the device is turned on and the disc begins to revolve. As the disc rotates, a horizontal force is produced. The horizontal force Ff caused by the friction between the pin and the disk is measured by the apparatus. Eq.3 may be used to get the coefficient of friction from this configuration (Novak and Polcar, 2014)

$$\mathrm{C.O.F} = \frac{\mathrm{Ff}}{\mathrm{Fn}} \tag{4}$$

where Fn is the vertical force applied to the pin, Ff is the horizontal force (the friction force between the pin and disc), and $\mathrm{C.O.F}$ is the coefficient of friction. Data can be extracted from the system directly.

6. RESULT AND DISSECTION

Table 5 shows the wear test results for all tested samples. According to the findings, pure epoxy exhibited a high coefficient of friction of 0.40 and a high wear rate of 1.53×10^{-5} g/m. This is explained by both its high adherence to the contact surface, which increases friction and slide resistance, and its flexible polymeric composition, which renders it incapable of withstanding mechanical stresses. The hardness of the tungsten carbide (WC) particles, which help to improve load distribution on the friction surface and the formation of a protective layer that reduces wear, resulted in a significant decrease in the coefficient of friction to 0.30 and an improvement in wear resistance (1.42×10^{-5} g/m) when 1% of WC was added. Better performance was obtained by increasing the WC ratio to 1.5%, which decreased the coefficient of friction to 0.29 and the wear rate to 0.96×10^{-5} g/m. Better stress tolerance, less deformation, and preservation of the material's homogeneity and durability are all made possible by this ratio, which offers the best particle dispersion inside the matrix without agglomerations (Demir, 2025) observed the same behavior. When 2% WC was added, the wear rate increased to 1.44×10^{-5} g/m, and the coefficient of friction also increased, even though the wear resistance was better than with pure epoxy. This results from the agglomeration of nanoparticles at this ratio, which damages the material's characteristics and reduces the efficiency of reinforcement by causing an uneven distribution within the matrix and stress concentration areas that cause tiny cracks under load.

The findings demonstrated that by uniformly dispersing stress and enhancing the structural composition, 8% chopped glass fibers added to the epoxy increased the wear rate by 15% when compared to pure epoxy and assisted in lowering frictional wear. The coefficient of friction was still somewhat high (0.3), though, suggesting that glass fibers by themselves were insufficient to increase friction resistance Because the friction is on the outer surface while the fiberglass is buried inside the compound. Due to better surface load distribution and the development of a strong transition layer that decreased direct contact, adding 1% tungsten carbide (WC) to the glass fiber-reinforced composite decreased the wear rate by 40.5% and the coefficient of friction to 0.29. The biggest improvements occurred at 1.5% WC, when the coefficient of friction dropped to 0.20 and the wear rate was lowered by 46.4% when compared to pure epoxy. This was explained by the even dispersion of nanoparticles among the fibers, which improved surface hardness and internal bonding. Performance declined at 2% WC, as the wear rate increased to 0.95×10^{-5} g/m and the friction coefficient increased to 0.3. This is explained by poor distribution homogeneity and particle aggregation within the matrix, which resulted in the formation of weak spots, increased wear, and increased slip resistance.

A slight increase in wear resistance was observed in the 4% sisal fiber-reinforced epoxy sample, with the rate decreasing to 1.45×10^{-5} g/m. Additionally, the coefficient of friction decreased from 0.40 (in pure epoxy) to 0.39, indicating a limited effect due to the fiber's high fluidity in moisture and elasticity. The wear rate decreased by 33.9% and the coefficient of friction decreased to 0.29 with the addition of 1.5% tungsten carbide (WC). This was attributed to the extremely hard and well-dispersed nanoparticles, which enhanced the bonding between the fiber and matrix and distributed stresses efficiently. Due to particle aggregation and material heterogeneity, performance declined at 2% tungsten carbide, with the coefficient of friction rising to 0.30 and the wear rate increasing. Due to the compatibility of the stiffness of the glass fibers and nanoparticles, which enhanced the cohesion and resistance to wear and friction, the sample reinforced with 8% and 1.5% glass fibers of WC performed better than sisal.

In addition to the consistent load and speed circumstances, the stability of the transition layer brought about by the nano-distribution of WC on the sample surface is responsible for the restricted range in friction coefficient values, even if they were comparable across the majority of the changed samples. The findings show that wear reduction was the most improved, and the friction coefficient was within the predicted range, indicating stable and mechanically safe performance.

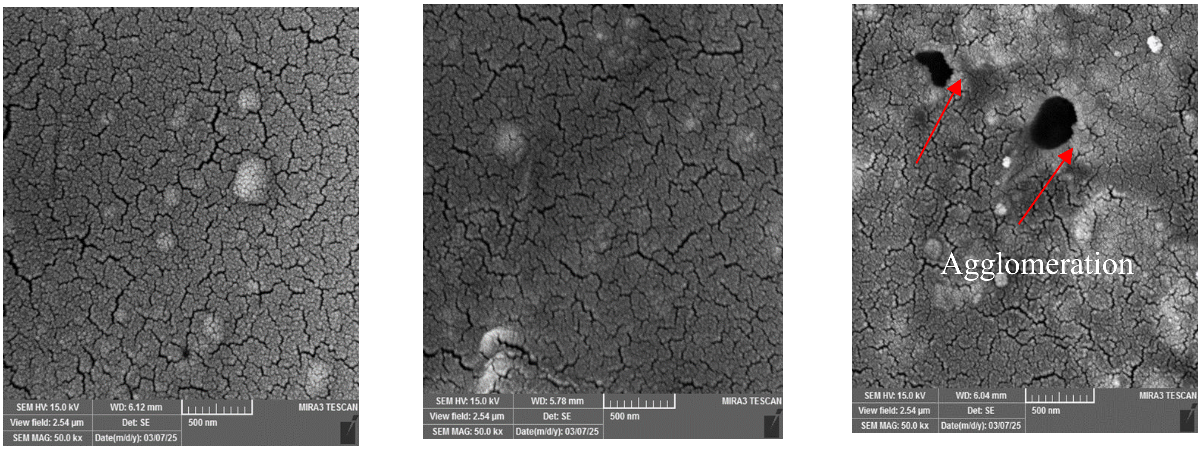
Table 5. Wear test result

Sample	W.R(g/m)	Imp.(%) WR	C.O.F	Imp.(%) C.O.F
A (EP)	$1.53*10^{-5}$	0	0.40	0
B(EP+WC1%wt)	$1.42*10^{-5}$	7.7	0.30	25
C(EP+WC1.5%wt)	$0.96*10^{-5}$	37.2	0.29	27.5
D(EP+WC2%wt)	$1.44*10^{-5}$	5.9	0.39	2.5
E(EP+CGF)	$1.30*10^{-5}$	15	0.3	25
F(EP+CGF+WC1%wt)	$0.91*10^{-5}$	40.5	0.29	27.5
G(EP+CGF+WC1.5%wt)	$0.82*10^{-5}$	46.4	0.20	50
H(EP+CGF+WC2%wt)	$0.95*10^{-5}$	37.9	0.3	25
I(EP+ CSF)	$1.45*10^{-5}$	5.2	0.39	2.5
J(EP+CSF+WC1%wt)	$1.43*10^{-5}$	6.5	0.30	25
K(EP+CSF+WC1.5%wt)	$1.01*10^{-5}$	33.9	0.29	27.5
L(EP+CSF+WC2%wt)	$1.40*10^{-5}$	8.5	0.3	25

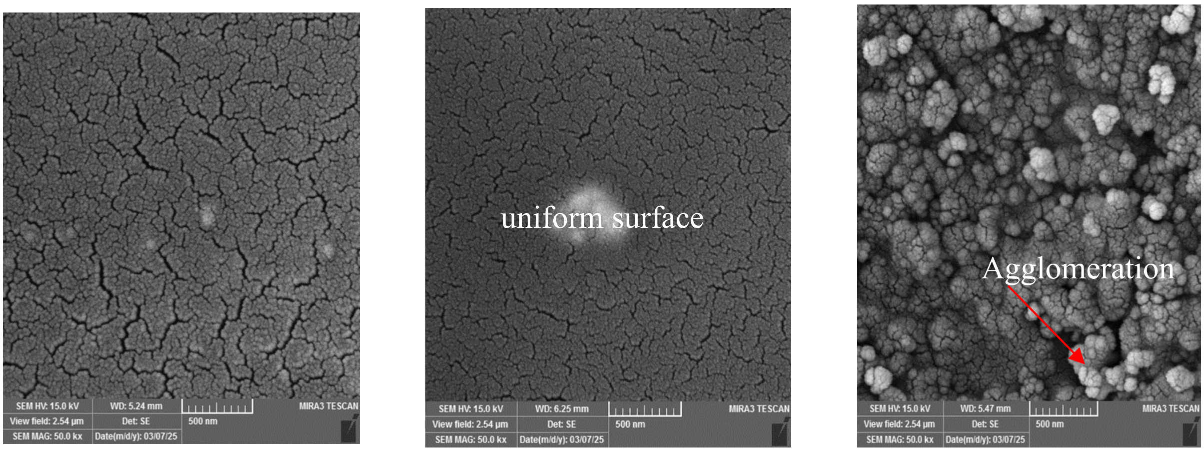
EP: Epoxy resin, WC: Nano tungsten carbide, CGF: Copped E-glass fiber, CSF: Copped Sisal fiber

Fig. 3 shows SEM images of the tested samples. The epoxy sample appears to have a homogeneous surface, but it lacks mechanical reinforcement. The 1.5% epoxy samples have good particle dispersion and good adhesion between the fibers and nanoparticles. This dispersion facilitates smooth stress transmission, which results in the material's increased resistance to corrosion. This sample is more resistant to corrosion due to its lack of gaps and agglomerations, which strengthens the material and reduces weak points, compared to other concentrations. The 2% epoxy samples have clear nanoparticle agglomeration This created weak points within the material, which reduced its wear properties.

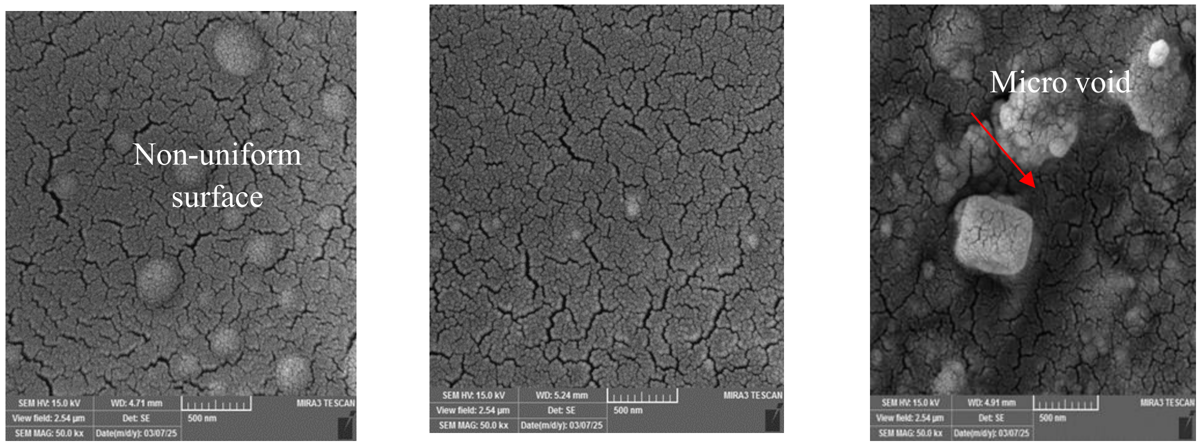
Wear and coefficient of friction values differ because of various control methods. While contact and sliding forces regulate the coefficient of friction, wear is dependent on the amount of material removed from the surface. Fig. 4 show The percentage of improvement in the wear rate and coefficient of friction of the composite materials used in the study.



EP EP+1.5%WC EP+2%WC

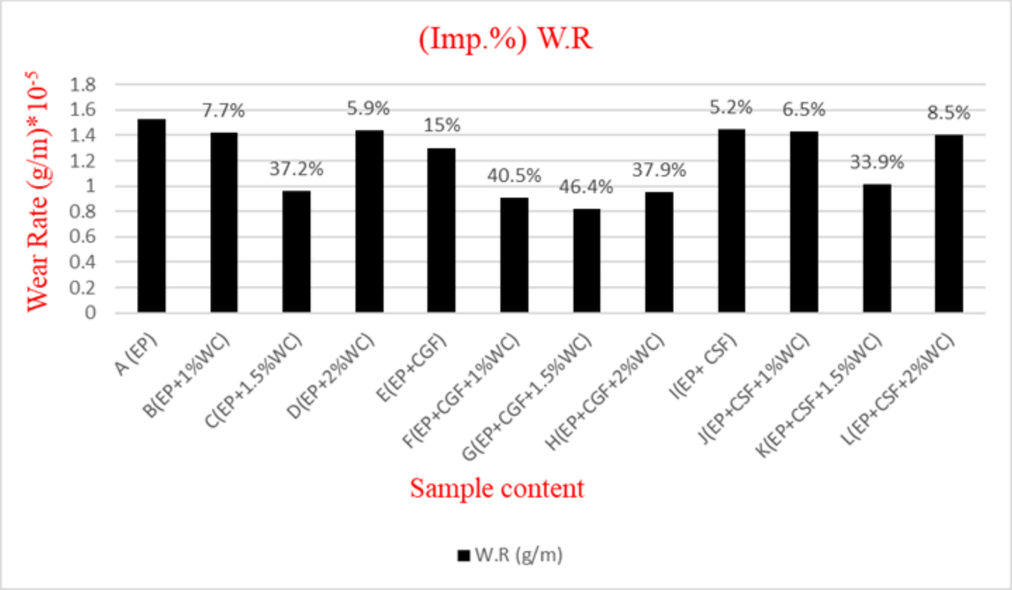


EP+CGF EP+CGF+1.5% EP+CGF+2%W

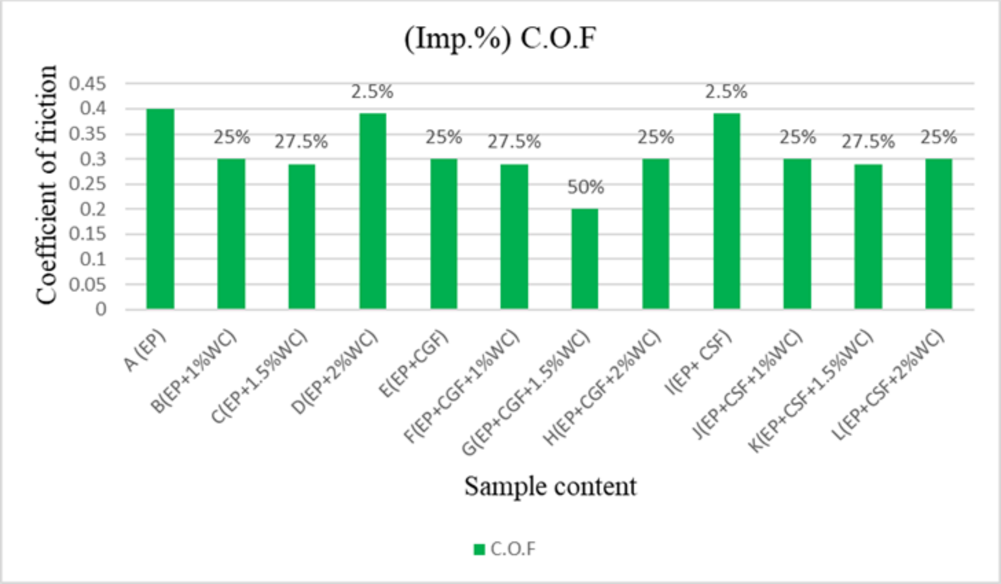


EP+CSF EP+CSF+1.5% EP+CSF+2%WC

Fig. 3. SEM results



(a)



(b)

Fig. 4. (a) Imp. % wear rate result (b) Imp. % Coefficient of friction result

7. CONCLUSION

In this work, epoxy was reinforced with two types of fibers-chopped glass fibers and chopped sisal fibers-and varying weight percentages of nanosized tungsten carbide (WC) at concentrations of 1, 1.5, and 2% wt. to increase wear resistance. Results showed that wear resistance increased significantly with the addition of 1.5% WC, but performance was negatively affected by particle agglomeration when the amount was increased to 2%. The 1.5% WC and 8% CGF blend achieved the best results, achieving an optimal balance between increased hardness and particle dispersion. with a 46.4% improvement in wear rate and a 50 % improvement in the coefficient of friction compared to pure epoxy. The 4% sisal fiber and 1.5%

WC achieved a 33.9% improvement in wear rate and a 27.5% improvement in the coefficient of friction. The good particle distribution and close bonding between the fibers and the matrix at 1.5% WC resulted in reduced friction and increased wear resistance. Particle agglomeration starts to happen at 2%, which causes performance to decline. The kind of fiber is crucial; sisal fibers are more resilient, while glass fiber offers better mechanical support. The manual production process and the absence of an environmental conditions investigation are two of the study's limitations. Future research on hybrid reinforcements that strike a balance between sustainability and efficiency is advised, as is the employment of sophisticated distribution strategies and performance testing in various scenarios

8. REFERENCE

Ajibade, O., Agunsoye, J. and Oke, S. (2021) ‘Parametric Ratio Optimization and Statistical Modelllng of Wear Performance in Dual-Filler Particle Reinforced Epoxy Composites’, Kufa Journal of Engineering, 10(1), pp. 140–159. Available at: https://doi.org/10.30572/2018/kje/100111.

AKGÜL, Y., YALÇIN, M.E. and ETİCHA, A.K. (2023) ‘Effect of Chopped Carbon Fibers Amount on the Mechanical and Tribological Properties of Polyester Matrix Composite’, Düzce Üniversitesi Bilim ve Teknoloji Dergisi, 11(1), pp. 189–198. Available at: https://doi.org/10.29130/dubited.1037140.

Alhazmi, W.H. et al. (2021) ‘Tribological and mechanical properties of epoxy reinforced by hybrid nanoparticles’, Latin American Journal of Solids and Structures, 18(3), pp. 1–14. Available at: https://doi.org/10.1590/1679-78256384.

Betelie, A.A. et al. (2018) ‘Experimental investigation of fracture toughness for treated sisal epoxy composite’, AIMS Materials Science, 5(1), pp. 93–104. Available at: https://doi.org/10.3934/matersci.2018.1.93.

Bezy, N.A. and Fathima, A.L. (2015) ‘Effect of TiO 2 nanoparticles on Mechanical Properties of Epoxy-Resin System’, International Journal of Engineering Research and General Science Volume, 3(5), pp. 143–151.

Çelik, Y.H. and Türkan, C. (2020) ‘Investigation of mechanical characteristics of GFRP composites produced from chopped glass fiber and application of taguchi methods to turning operations’, SN Applied Sciences, 2(5), pp. 1–12. Available at: https://doi.org/10.1007/s42452-020-2684-5.

Demir, M.E. (2025) ‘The effect of filler type (tungsten carbide, zinc oxide) and content on the mechanical and wear behavior of jute/flax reinforced epoxy hybrid composites: Experimental and artificial neural network analysis’, Polymer Composites, (February), pp. 1–20. Available at: https://doi.org/10.1002/pc.29879.

Dookhi, M.A. and Tahir, A.A. (2023) ‘Study the Effect of External Crack on the Mechanical Properties of Composite Materials’, Kufa Journal of Engineering, 14(4), pp. 1–10. Available at: https://doi.org/10.30572/2018/KJE/140401.

Fibers, E.C., Alrufaie, A. and Alithari, A. (2024) ‘The influence of Adding Nanomaterials on Impact Strength of Epoxy The influence of Adding Nanomaterials on Impact Strength of Epoxy Reinforced by E-Glass Chopped Fibers’, (October).

Ghani, S.N., Alithari, A.S. and Hasan, H.S. (2025) ‘Influence of adding tungsten carbide and titanium dioxide nanoparticles on the impact strength of epoxy based composite materials used in marine applications’, Results in Engineering, 25(October 2024), p. 104012. Available at: https://doi.org/10.1016/j.rineng.2025.104012.

Gurmu, D.N. and Lemu, H.G. (2023) ‘Experimental Investigation on Effect of Weight Fraction of Sisal Fiber on Mechanical Properties of Sisal-E-Glass Hybrid Polymer Composites’, Advances in Materials Science and Engineering, 2023. Available at: https://doi.org/10.1155/2023/3948500.

International ASTM (2017) ‘Astm G99’, International ASTM, 05(2016), pp. 5–10. Available at: https://doi.org/10.1520/G0099-17.Copyright.

Jasim, Z.M. and Abdulsamad, H.J. (2025) ‘Investigation of Free Vibration Behavior for Composite Sandwich Beams With a Composite Honeycomb Core’, Kufa Journal of Engineering, 16(1), pp. 177–199. Available at: https://doi.org/10.30572/2018/KJE/160111.

Karunia (2016) ‘A study on mechanical, electrical, and thermal properties of graphene nanoplatelets reinforced epoxy composites.’, 4(June), p. 2016.

Madhukar, P., Selvaraj, N. and Rao, C.S.P. (2016) ‘Manufacturing of aluminium nano hybrid composites: A state of review’, IOP Conference Series: Materials Science and Engineering, 149(1). Available at: https://doi.org/10.1088/1757-899X/149/1/012114.

Manuscript, A. et al. (no date) RSC Advances.

Mohanty, A. and Srivastava, V.K. (2015) ‘Effect of alumina nanoparticles on the enhancement of impact and flexural properties of the short glass/carbon fiber reinforced epoxy based composites', Fibers and Polymers, 16(1), pp. 188–195. Available at: https://doi.org/10.1007/s12221-015-0188-5.

Moosa, A.A., Ramazani A, A.S. and Nabil Ibrahim, M. (2016) 'Mechanical and Electrical Properties of Graphene Nanoplates and Carbon-Nanotubes Hybrid Epoxy Nanocomposites', American Journal of Materials Science, 6(6), pp. 157–165. Available at: https://doi.org/10.5923/j.materials.20160605.02.

Namdev, A., Telang, A. and Purohit, R. (2022) 'Experimental investigation on mechanical and wear properties of GNP/Carbon fiber/epoxy hybrid composites', Materials Research Express, 9(2). Available at: https://doi.org/10.1088/2053-1591/ac4e3f.

Novak, R. and Polcar, T. (2014) 'Tribological analysis of thin films by pin-on-disc: Evaluation of friction and wear measurement uncertainty', Tribology International, 74, pp. 154–163. Available at: https://doi.org/10.1016/j.triboint.2014.02.011.

Okeola, A.A., Abuodha, S.O. and Mwero, J. (2018) 'Experimental investigation of the physical and mechanical properties of sisal fiber-reinforced concrete', Fibers, 6(3). Available at: https://doi.org/10.3390/fib6030053.

Pramanik, T.J. et al. (2024) 'Evaluation of mechanical properties of natural fiber based polymer composite', BenchCouncil Transactions on Benchmarks, Standards and Evaluations, 4(3), p. 100183. Available at: https://doi.org/10.1016/j.tbench.2024.100183.

Puttegowda, M. et al. (2018) Potential of natural/synthetic hybrid composites for aerospace applications, Sustainable Composites for Aerospace Applications. Elsevier Ltd. Available at: https://doi.org/10.1016/B978-0-08-102131-6.00021-9.

Sandeep Yadav and Sanjay Mishra (2024) 'Fabrication and Mechanical Characterization of Natural Fiber-Reinforced Polymer Composites', International Research Journal on Advanced Engineering Hub (IRJAEH), 2(06), pp. 1570–1577. Available at: https://doi.org/10.47392/irjaeh.2024.0215.

Seydibeyoğlu, M.Ö. et al. (2023) 'Review on Hybrid Reinforced Polymer Matrix Composites with Nanocellulose, Nanomaterials, and Other Fibers', Polymers. MDPI. Available at: https://doi.org/10.3390/polym15040984.

Sharma, A. et al. (2020) 'Review on erosion wear characteristic of natural fiber reinforced polymer composite', Materials Today: Proceedings, 44, pp. 4795–4800. Available at: https://doi.org/10.1016/j.matpr.2020.11.395.

Simamora, P. et al. (2023) ‘Mechanical Properties of Polypropylene Composites with Different Reinforced Natural Fibers – A Comparative Study’, Journal of Ecological Engineering, 24(7), pp. 311–317. Available at: https://doi.org/10.12911/22998993/164757.

Singh, T. et al. (2021) ‘Effect of silica nanoparticles on physical, mechanical, and wear properties of natural fiber reinforced polymer composites’, Polymer Composites, 42(5), pp. 2396–2407. Available at: https://doi.org/10.1002/pc.25986.

Sinha, A.K., Narang, H.K. and Bhattacharya, S. (2020) ‘Mechanical properties of hybrid polymer composites: a review’, Journal of the Brazilian Society of Mechanical Sciences and Engineering, 42(8). Available at: https://doi.org/10.1007/s40430-020-02517-w.

Vaddar, L. et al. (2023) ‘Glass Fiber-Epoxy Composites with Carbon Nanotube Fillers for Enhancing Properties in Structure Modeling and Analysis Using Artificial Intelligence Technique’, ACS Omega, 8(26), pp. 23528–23544. Available at: https://doi.org/10.1021/acsomega.3c01067.

Vangala, R. et al. (2019) ‘Comparison of mechanical properties for carbon, E-glass and hybrid (carbon & E-glass) composites’, International Journal of Mechanical Engineering and Technology, 10(2), pp. 407–417.