Applied Sciences, Computing and Energy, 2025, 3(2), 204-211

Effect of Filler Loading on Tribology of Epoxy/Nanoclay Nanocomposites

Bisike Chidiebere Egere, Ibeneme Uche, Ejiogu Ibe Kevin, Philip Abubakar, Catherine Kigbo Oseshi, Sunday Adaogoshi Eya, Yusuf Omeiza Lawal

Received: 28 July 2025/Accepted: 28 August 2025/Published: 05 September 2025

***Abstract**: In this research, the effect of nanoclay concentration on the tribology of epoxy/nanoclay composites was carried out and précis thus. 0(control), 1, 2, 3, 4, 5, 6, 7, 8 9 and 10 wt percent of nanoclay particulates were used to fabricate nanoclay/epoxy composites using hand layout method. The wear properties of the composites were characterized using abrasion wear resistance testing machine manufactured by Taber Industries. ASTM D 958 was employed to study the tribology while scanning electron microscopy (SEM) was used to study the distributions of nanoclay inside the composites. It was found that nanoclay/epoxy composites have an improvement on the wear resistant property of the composite when compared to control sample A. The results from the tribology of epoxy composites studied proved that composites E with nanoclay to epoxy composition of 4:96 wt % to be the overall best wear resistant materials with wear value of 2.94 % and improvement of 80 % recorded when compared to the control sample A with wear value of 20 %. SEM images show that the more the addition of nanoclay into the epoxy matrix, the better the wear resistant values of the composites until saturation point, which was found to be 4:96 wt % nanoclay to epoxy content. After the saturation, the wear resistant value begins to diminish due to poor interfacing between the matrix and the reinforcements (nanoclay). It concluded that the nanoclay particles in minute quantities are good reinforcement for epoxy materials.*

***Keywords**: Nanocomposite, Composite, Epoxy, Nanoclay, Tribology and SEM*

Bisike Chidiebere Egere
Department of Chemical Engineering, Nasarawa State University, Keffi, Nigeria
Email: egerebisike@nsuk.edu.ng
Orcid id:https://orcid.org/0000-0001-5573-3867

Ibeneme Uche
Department of Polymer Technology, Nigerian Institute of Leather and Science Technology, Zaria, Nigeria
Email: ucheibeneme2016@gmail.com
Orcid id: https://orcid.org/0000-0001-6274-7685

Ejiogu Ibe Kevin
Directorate of Research and Development, Nigerian Institute of Leather and Science Technology, Zaria, Nigeria
Email: ibek6018@gmail.com

Philip Abubakar
Department of Civil Engineering, Nasarawa State University, Keffi, Nigeria
Email: abubakarphilip@nsuk.edu.ng

Catherine Kigbo Oseshi
Department of Chemical Engineering, Nasarawa State University, Keffi, Nigeria
Email: oseshicatherine@gmail.com

Sunday Adaogoshi Eya
Department of Civil Engineering, Nasarawa State University, Keffi, Nigeria
Email: eyasunday@nsuk.edu.ng

Yusuf Omeiza Lawal
Department of Polymer and Textile Engineering, Ahmadu Bello University, Zaria, Nigeria
Email: lawbil2002@gmail.com

1.0 Introduction

Wear is one of the most common failure mechanisms in engineering components, leading to loss of material and degradation of mechanical performance under service conditions. Abrasive wear, in particular, is caused by the gradual removal or deformation of a solid material at the surface when in contact with another harder surface, resulting in significant material loss and reduced durability (Chan *et al*., 2021). The study of wear and related processes is encompassed within the field of tribology, which examines friction, wear, and lubrication to improve the performance of engineering materials (Senthil Kumar *et al*., 2022). Polymer composites, due to their lightweight, processability, and tunable properties, have gained widespread application in tribological systems; however, their inherent low wear resistance remains a limitation (Shelly *et al*., 2024).

To address these limitations, polymer nanocomposites have been extensively explored. The incorporation of nanofillers such as carbon nanotubes, silica, graphene, and nanoclays has been shown to enhance wear resistance, mechanical strength, and thermal stability of polymer composites (Chan *et al*., 2021; Senthil Kumar *et al*., 2022). Among these fillers, nanoclay is particularly attractive due to its high aspect ratio, cost-effectiveness, and ability to form strong interfacial interactions with polymer matrices. Recent studies have demonstrated the potential of nanoclay in epoxy-based composites. For instance, Gbadeyan *et al*. (2023) reported that nanoclay loading significantly improved the wear resistance and water absorption properties of banana fiber–reinforced epoxy composites, with 3 wt% nanoclay providing an 80% increase in abrasion resistance. Similarly, Kumar *et al*. (2025) showed that the addition of ceramic nanoclays to epoxy-based glass fiber-reinforced polymer (GFRP) composites enhanced wear resistance by restricting abrasive particle penetration and improving interfacial bonding.

Despite these advances, challenges remain. The hydrophilic nature of pristine clay often hinders uniform dispersion in the epoxy matrix, leading to agglomeration and poor interfacial bonding (Shelly *et al*., 2024). Consequently, the performance of epoxy/nanoclay nanocomposites is highly dependent on filler content, dispersion quality, and matrix–filler interactions. Previous reviews (Chan *et al*., 2021; Senthil Kumar *et al*., 2022) highlight that while improvements in tribological properties have been reported, inconsistencies exist in determining the optimal nanoclay loading and the saturation point beyond which properties deteriorate. Moreover, most prior research has focused on hybrid systems with natural fibers or ceramic clays, while limited attention has been given to systematically studying epoxy/nanoclay composites across a broader range of filler loadings.

This study seeks to address these gaps by investigating the effect of nanoclay filler loading on the tribological behavior of epoxy nanocomposites across a wide concentration range (0–10 wt%). The aim is to determine the optimal nanoclay content for maximum wear resistance and to understand how filler concentration influences the microstructural features and matrix–filler interactions. The significance of this research lies in its potential to provide insights into tailoring nanoclay/epoxy composites for high-performance tribological applications. Optimized epoxy/nanoclay systems can serve as cost-effective, lightweight, and wear-resistant materials for industries such as aerospace, automotive, and coatings, where durability under frictional conditions is critical (Shelly *et al*., 2024; Kumar *et al*., 2025). By establishing the filler loading thresholds that maximize wear resistance without compromising interfacial bonding, this study contributes to advancing the design and application of polymer nanocomposites in engineering systems.

2.0 Materials and Method

2.1 Materials

The test specimens used for the tribological experiments in this research were fabricated from carefully selected materials and chemicals. Montmorillonite nanoclay (particle size ≥20 nm, modulus 10–400 GPa, density 1.72 g/cm³, product code 682608-500G) served as the primary nanofiller. E-glass fiber in fabric form with a specification of 300 GSM and a specific gravity of 2.6 g/cm³ was incorporated as reinforcement. The polymer matrix was prepared using Araldite LY 506 epoxy resin with a specific gravity ranging from 1.15 to 1.20 g/cm³, while Aradur HY 951 epoxy hardener with a specific gravity of 0.97–0.99 g/cm³ was employed as the curing agent. A polyvinyl alcohol (PVA) mould release agent was also used. All materials and chemicals were sourced from Zayo-Sigma, Germany.

The experimental work was carried out using various instruments and equipment. A Wear/Abrasion Tester (Model 11884, capacity 230-1-50) was used to evaluate the tribological properties of the composites. Open glass moulds were utilized for specimen casting, while a diamond cutter facilitated precise cutting of the samples. Mixing of resin, hardener, and nanoclay was performed with a motorized stirrer operating at a speed of up to 1000 revolutions per minute (rev/min).

2.2 Methods

The two different groups of composites glassfibre/epoxy composites and nanoclay/epoxy nanocomposites were prepared using the following method:

2.2.1 Mould Design and Fabrication Method

The moulds used for fabricating all the composites were prepared from silicate glass and have the same dimensions of 200 x 200 x 3 mm dimension. They were all fabricated in the locally.

2.2.2 Composites Formulation and Fabrication Method

As show in Table 2 nanoclay/epoxy composites of 99, 98, 97, 96, 95, 94, 93, 92 and 91 wt % epoxy with 1, 2, 3, 4, 5, 6, 7, 8, and 9 wt % nanoclay respectively were prepared by casting method, the ratios were mixed using high-speed motorised stirrer. Mould release agent PVA was applied on moulds in order to have smooth removal of moulded composites after curing by hand layup method. The moulds were left undisturbed for 24 hours and the samples were removed and cut into rectangular shapes with diamond cutter.

Table 2: The Compositions of Epoxy/nanoclay Composites Formulated

S/N	Composite Name	Composite Code	Epoxy (wt %)	Nanoclay (wt %)
1	EP100NC0	A	100	0
2	EP99NC01	B	99	1
3	EP98NC02	C	98	2
4	EP97NC03	D	97	3
5	EP96NC04	E	96	4
6	EP95NC05	F	95	5
7	EP94NC06	G	94	6
8	EP93NC07	H	93	7
9	EP92NC08	I	92	8
10	EP91NC09	J	91	9

2.2.3 Tribology Testing Method

The scratch wear resistance test were carried out on all the composites samples using abrasion wear resistance testing machine with serial number 01554, supply number 230-01-50, manufactured by Taber Industries, ASTM D 958 was employed. The test specimens were prepared in rectangle of 50 x 10 x 3 mm similar to flexural properties test specimen.

3.0 Results and Discussion

2.1 Wear Property Analysis of the Composites

Comparative analysis was conducted to investigate the effects of filler loading on the abrasion wear properties of epoxy/nanoclay composites. The results, as presented in Fig. 1, show that the percentage wear of the composites varied from 20% to 2.94%. The highest wear value of 20% was obtained for the control sample (100 wt% epoxy), whereas the lowest wear value of 2.94% was recorded for composite E, which contained 96 wt% epoxy and 4 wt% nanoclay.

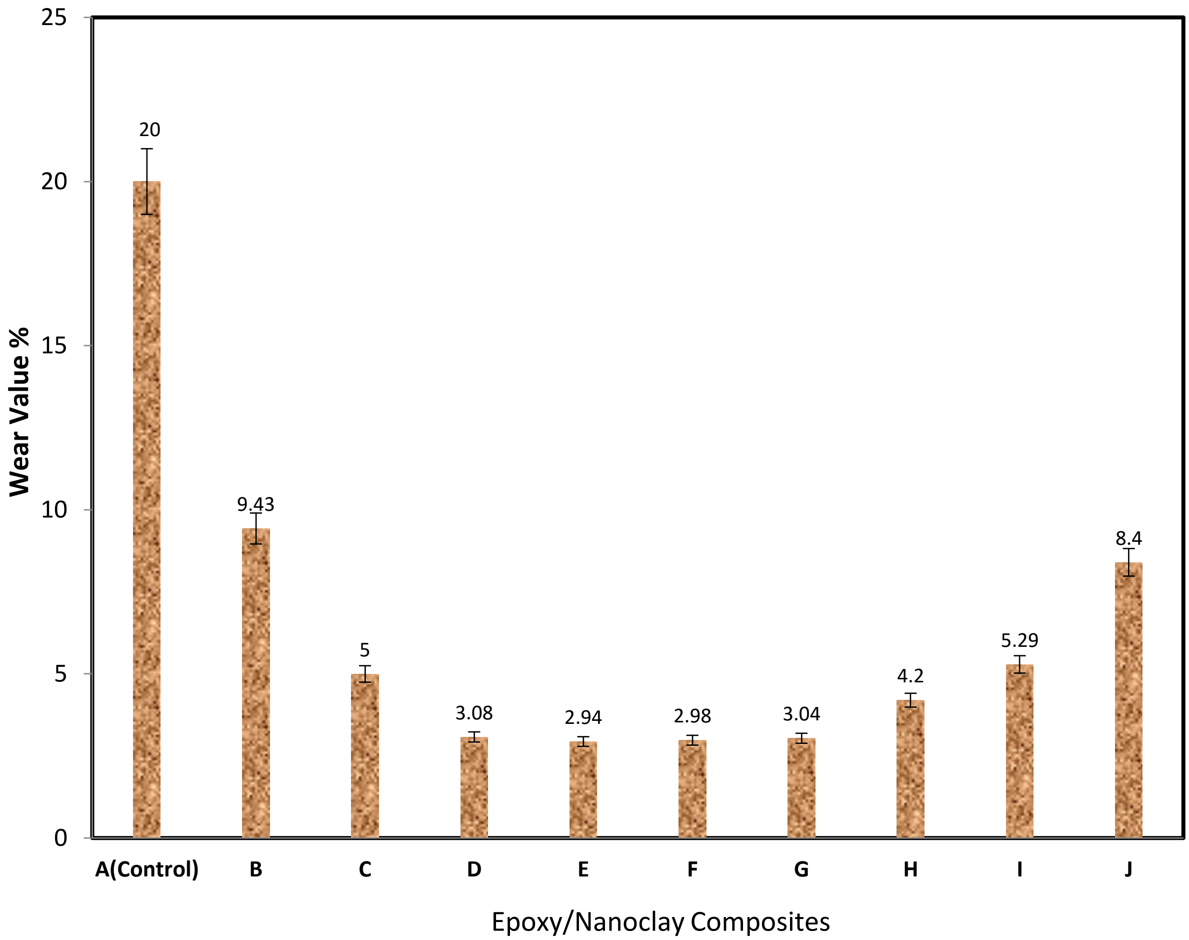

Fig. 1: Wear Behaviour of the Epoxy/Nanoclay Composites Fabricated

The gradual reduction in wear percentage from the control sample to composite E can be attributed to the reinforcing ability of the nanoclay fillers, which enhanced the wear resistance of the epoxy matrix by promoting strong interfacial interaction between the nanoparticles and the polymer chains (Patnaik *et al*., 2020; Zhu *et al*., 2014). The improvement in wear resistance was also due to the inherent capacity of nanoparticles to occupy intermolecular spaces and surface voids within the epoxy matrix, thereby reducing weak points that contribute to material loss during abrasion (Njuguna & Alcock, 2018; Njuguna *et al*., 2019; Parida *et al*., 2013).

However, when the nanoclay content exceeded 4 wt% (composites F–J), a decline in wear resistance was observed. This reduction in performance is linked to poor particle–matrix interfacial bonding and the tendency of nanoparticles to agglomerate at higher concentrations, which introduces stress concentration zones and weakens the overall composite (Sahay *et al*., 2024; Venkateswarulu, 2018). Prior studies have similarly reported that nanoclay provides optimal reinforcement when used in small proportions (typically 3–5 wt%), as this concentration range enhances surface hardness and wear resistance without significantly affecting matrix homogeneity (Raja & Manisekar, 2023; Wang *et al*., 2019).

In summary, the control sample without nanoclay exhibited the weakest wear resistance, while the epoxy/nanoclay composite with 4 wt% nanoclay demonstrated the best tribological performance. The improvement in wear resistance up to this optimum filler loading can be attributed to uniform filler dispersion and efficient load transfer, whereas higher filler contents led to diminishing returns due to poor distribution and reduced interfacial compatibility (Shubham & Tiwari, 2023; Shiamaa & Mustafa, 2015).

3.2 Morphological Analysis of the Composites

To better understand the tribological performance, morphological analysis of the control sample and the best-performing composite (E) was carried out using SEM imaging.

The SEM image of the control sample (100 wt% epoxy) shown in Fig. 1 revealed the absence of nanoclay reinforcement, with randomly distributed voids and surface fractures caused by shrinkage and entrapped air bubbles during the curing process. The exothermic reaction of epoxy and hardener introduced air voids, and despite careful degassing, traces of these voids remained visible as defects in the cured matrix (Man-Wai *et al*., 2016; Kusmono *et al*., 2013). These structural imperfections reduce the surface integrity of the material, making it more susceptible to wear. Cracks and uneven reductions in surface area further contributed to premature failure during abrasion testing (Mehdikhani *et al*., 2018; Singla & Chawla, 2020).

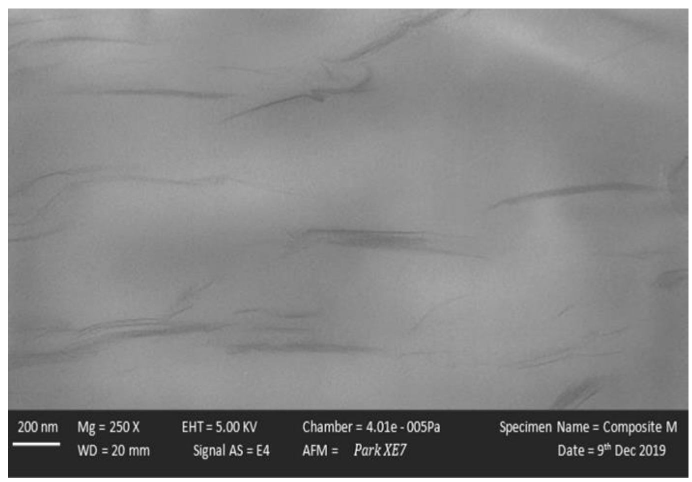

Fig 2:SEM Image of Control Sample A (100 wt % epoxy)

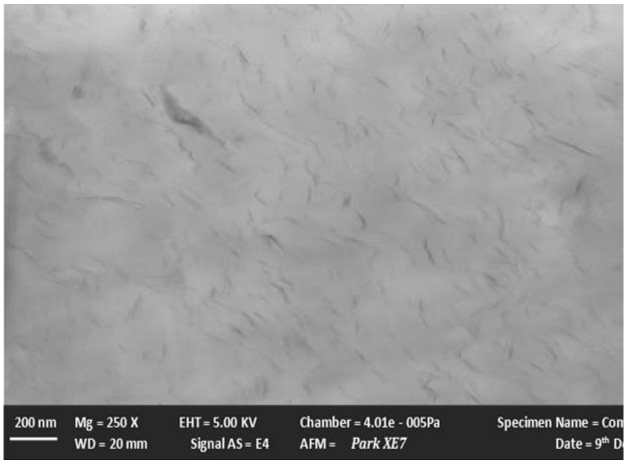

Fig. 3: SEM Image of Epoxy/nanoclay Composite E (4 wt % epoxy & 96 wt % nanoclay)

In contrast, the SEM image of composite E (96 wt% epoxy and 4 wt% nanoclay) shown in n Fig. 3 displayed a homogeneous microstructure with evenly distributed nanoclay particles. The nanoparticles filled the voids and cracks typically found in the epoxy matrix, improving surface compactness and overall toughness. This strong matrix–filler interaction was instrumental in reducing material loss during abrasion and producing a tougher, more wear-resistant material (Marquis *et al*., 2021; Yang *et al*., 2016; Kamel, 2017). The morphology confirmed that nanoclay reinforcement at an optimal concentration enhances structural integrity and contributes significantly to improved tribological performance.

Overall, both the wear property analysis and the morphological study demonstrated that nanoclay is an effective reinforcement material for epoxy composites, particularly when used in moderate quantities. These findings are consistent with previous research on polymer nanocomposites, which highlights the role of nanofillers in improving wear resistance, hardness, and long-term durability (Njuguna *et al*., 2019; Zheng-Dong *et al*., 2019).

4.0 Conclusion

The findings of the study revealed that the incorporation of montmorillonite nanoclay and E-glass fibre into the epoxy resin matrix significantly enhanced the wear resistance and overall tribological performance of the fabricated composites. The use of the motorized stirrer ensured uniform dispersion of the nanoclay within the polymer matrix, which contributed to improved load-bearing capacity and reduced material loss during abrasion testing. The experimental results also showed that the synergistic effect of the nanoclay and fibre reinforcement provided better structural integrity and durability compared to the unmodified epoxy resin. From these observations, it can be concluded that nanoclay and glass fibre reinforced epoxy composites demonstrate strong potential for applications requiring superior wear resistance and mechanical stability. The performance of the developed materials indicates that they can be considered as promising alternatives for use in structural, automotive, and industrial applications where tribological properties are critical.

It is recommended that further studies should investigate the effect of varying nanoclay loading percentages and fibre orientations to optimize the composite properties. Long-term durability testing under diverse environmental conditions such as temperature fluctuations and chemical exposures should also be carried out to establish broader application suitability. Additionally, scaling up the fabrication process could provide insights into the commercial viability of these nanocomposites for industrial use.

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Declaration

Competing Interest:

The authors declared no conflict of interest in this research work

Authors' Contribution:

Uche Ibeneme, Bisike Chidiebere Egere, Ejiogu Ibe Kevin contributed to the proof reading and writing of the research work. Amoke Austin, Catherine Kigbo Oseshi, Philip Abubakar, Yusuf Lawal Omeiza and Sunday Adagoshi took part in the characterization of the work and collection of the raw materials that were used for the research studies. All the authors contributed to the sponsoring of the research work.