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Investigating the influence of local mineral fillers on the properties of epoxy-based composite materials

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Abstract: This study presents the development of an epoxy-based composite material reinforced with locally sourced mineral fillers for application in railway fastening system insulators. The composite formulation combines ED-20 epoxy resin as the polymer matrix, methyl-5-norbornene-2,3-dicarboxylic anhydride as a curing agent, acrylic resin as a flexibilizing modifier, and mineral fillers including basalt dust, ceramic brick waste, kaolin, and quartz sand. The filler content and particle size distribution were optimized to achieve uniform dispersion, high mechanical strength, enhanced dielectric performance, and superior vibration damping. Experimental characterization demonstrated that the composite exhibits compressive strength of 95–110 MPa, flexural strength of 38–44 MPa, and an elastic modulus of 2.7–3.1 GPa, with low wear (0.03–0.05 g/cm²) and stable performance over a wide temperature range (−40 to +120°C). Dielectric testing showed volume resistivity of 10^{12}–10^{13} Ω·cm and dielectric strength of 18–22 kV/mm, with minimal water absorption (0.6–0.9%). Vibration damping measurements indicate a coefficient of 0.53, significantly higher than conventional polyamide insulators. The study confirms that the heterogeneous mineral-filled epoxy structure enhances load distribution, interfacial adhesion, and energy dissipation. The use of industrial mineral waste contributes to cost reduction and environmental sustainability. The developed composite demonstrates a balanced combination of mechanical, electrical, and damping properties, making it a promising material for durable, safe, and reliable railway fastening system insulators.

Keywords: epoxy composite, railway fastening system, insulator, mineral fillers, basalt dust, dielectric materials

1. Introduction

Railway fastening systems are crucial components that ensure track stability, reliability, and safety. One of their primary elements is the insulating component located between the rail and fastening clips. Insulators serve multiple functions: electrical insulation, reduction of vibration and noise, and prevention of lateral displacement of rails.

Traditional insulators are often made of polyamide or glass-fiber reinforced polymers. Despite acceptable performance, these materials have limitations including high production cost and moderate durability under cyclic dynamic loads [1-2]. Recently, polymer composites reinforced with mineral fillers have gained attention due to enhanced mechanical, thermal, and dielectric properties [3-5].

The use of locally available industrial mineral waste—such as basalt dust, ceramic brick residues, and kaolin—not only improves structural performance but also reduces environmental impact and production costs [6]. This study aims to develop a composite material based on epoxy resin and local mineral fillers, optimized for application as railway fastening system insulators [7].

2. Research methodology

2.1 Materials

The composite material was developed using a carefully selected combination of polymer matrix, curing agent, flexibilizing modifier, and locally sourced mineral fillers to achieve optimal mechanical, dielectric, and vibration damping properties for railway fastening system insulators.

ED-20 epoxy resin served as the polymer matrix, providing a chemically resistant, dimensionally stable framework with high adhesion to mineral fillers. Its epoxy equivalent (185–192 g/eq) ensures effective crosslinking during curing.

Methyl-5-norbornene-2,3-dicarboxylic anhydride was employed as a curing agent to achieve high crosslink density, enhancing mechanical strength, thermal stability, and chemical resistance of the composite .

Acrylic resin functioned as a flexibilizing modifier, improving toughness and impact resistance, reducing brittleness under cyclic dynamic loads.

Local mineral fillers were incorporated to reinforce and stabilize the polymer matrix:

Basalt production dust – an industrial by-product providing reinforcement and wear resistance.

Ceramic brick waste – finely ground brick fragments increasing rigidity and hardness.

Kaolin – a clay mineral improving interfacial adhesion and dispersion stability.

Quartz sand – added as mechanical reinforcement to enhance stiffness.

All mineral fillers were pre-dried at 110–120°C for 2–3 hours to eliminate moisture. The combination of polymer

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matrix and fillers was designed to provide a durable, cost-effective, and environmentally sustainable material [8].

2.2 Composite Preparation

The preparation of the epoxy-based composite material involved a multi-stage process to ensure uniform dispersion of mineral fillers, complete polymerization of the epoxy matrix, and optimal mechanical and dielectric performance. All mineral fillers—basalt dust, ceramic brick waste, kaolin, and quartz sand—were first dried at 110–120°C for 2–3 hours to remove moisture and then mechanically activated and sieved to ensure uniform particle size distribution [9].

ED-20 epoxy resin and acrylic resin were mixed at 60–70°C to form a homogeneous base mixture with reduced viscosity, facilitating the incorporation of fillers. The curing agent, methyl-5-norbornene-2,3-dicarboxylic anhydride, was gradually added under continuous stirring to initiate polymerization and ensure uniform hardener distribution.

Pre-treated mineral fillers were then gradually incorporated into the resin mixture with careful control of addition rate to prevent agglomeration. Kaolin acted as a dispersion stabilizer, enhancing interfacial adhesion between the polymer matrix and fillers. The resulting mixture was thoroughly homogenized to eliminate air bubbles and ensure even distribution of all components.

The composite was poured into molds and compacted under a pressure of 8–12 MPa to remove voids and achieve high density. Thermal curing was performed at 120–140°C for 2–3 hours to complete crosslinking of the epoxy network, providing high mechanical strength, thermal stability, and excellent electrical insulation. Finally, the samples were cooled gradually to room temperature and conditioned under controlled humidity to stabilize their properties before testing.

3. Results and discussion

3.1 Composition of the Developed Composite

The developed epoxy-based composite material was designed to combine the advantageous properties of a polymer matrix with the reinforcing and stabilizing effects of locally available mineral fillers. The formulation balances mechanical strength, dielectric performance, and vibration damping, which are critical for railway fastening system insulators.

The polymer matrix provides the structural framework and determines the chemical, thermal, and mechanical behavior of the composite. A curing agent and a flexibilizing modifier are incorporated to control crosslinking density, impact resistance, and toughness. These components work synergistically to produce a stable, durable, and resilient material capable of withstanding the cyclic and dynamic loads present in railway applications.

Mineral fillers were carefully selected to reinforce and stabilize the polymer network. Basalt dust and ceramic waste contribute to compressive and flexural strength, wear resistance, and rigidity, while kaolin improves dispersion and adhesion within the matrix. Quartz sand provides additional mechanical reinforcement and dimensional stability. The particle sizes and proportions of fillers were optimized to achieve a uniform distribution, minimizing defects and ensuring consistent performance.

Table 1

Composition of the developed epoxy composite material (wt. parts)

Component	Function	Content (wt. parts)
ED-20 epoxy resin	Polymer matrix	100
Methyl-5-norbornene-2,3-dicarboxylic anhydride	Curing agent	7
Acrylic resin	Flexibilizer	6
Basalt production dust	Reinforcing filler	12
Ceramic brick waste	Mineral filler	15
Kaolin	Dispersion stabilizer	8
Quartz sand	Mechanical reinforcement	6

The composite composition was optimized to combine the toughness and chemical stability of the polymer network with the reinforcing effect of mineral fillers. This combination ensures enhanced compressive and flexural strength, wear resistance, dielectric performance, and vibration damping, while also utilizing locally sourced industrial waste materials for cost-effectiveness and environmental sustainability.

3.2 Mechanical Properties

The mechanical performance of the developed epoxy-based composite was evaluated to ensure its suitability for railway fastening system insulators, which are subjected to cyclic dynamic loads, compressive stresses, and potential impact during operation. The material demonstrated a balanced combination of strength, stiffness, and durability required for structural components in railway applications.

Experimental tests showed that the composite exhibits high compressive strength, ranging from 95 to 110 MPa, indicating its ability to withstand heavy static and dynamic loads without permanent deformation. Flexural strength measurements ranged from 38 to 44 MPa, reflecting sufficient resistance to bending stresses typically encountered in fastening system components [10,11].

The elastic modulus of the material (2.7–3.1 GPa) demonstrates that the composite maintains adequate stiffness, ensuring dimensional stability under operational stresses. Wear resistance, evaluated under controlled abrasive conditions, was found to be between 0.03 and 0.05 g/cm², confirming the composite's suitability for long-term service with minimal surface degradation.

The combination of polymer matrix and mineral fillers results in a heterogeneous microstructure that distributes stresses effectively and prevents crack propagation. This structural arrangement enhances both load-bearing capacity and resilience to repeated mechanical stresses, which is critical for the safety and reliability of railway infrastructure.

Table 2

Mechanical properties of the developed composite

Property	Unit	Value
Density	g/cm³	1.75
Compressive strength	MPa	95–110
Flexural strength	MPa	38–44
Elastic modulus	GPa	2.7–3.1
Wear resistance	g/cm²	0.03–0.05

Operating temperature	°C	−40 to +120

The reinforced polymer network and well-dispersed mineral fillers provide the composite with high mechanical stability, resistance to deformation under load, and enhanced wear characteristics. These properties ensure reliable performance under both static and dynamic conditions in railway fastening systems, while maintaining structural integrity over a wide temperature range.

3.3 Dielectric Properties

Electrical insulation is a critical requirement for railway fastening system insulators, as these components must prevent unintended current flow and interference with railway signaling circuits. The dielectric properties of the developed composite were evaluated through volume resistivity, dielectric strength, water absorption, and insulation class measurements.

The composite demonstrated excellent electrical insulation performance, with volume resistivity values ranging from 10^{12} to 10^{13} Ω·cm and dielectric strength between 18 and 22 kV/mm. Water absorption was measured at 0.6–0.9%, indicating minimal moisture uptake that could otherwise compromise insulation. The material was classified as a high-grade electrical insulator [12,13].

The uniform dispersion of mineral fillers within the epoxy matrix contributes to the stability of dielectric properties by reducing localized stress points and preventing conductive pathways. Additionally, the combination of epoxy matrix with inorganic fillers improves thermal and chemical resistance, maintaining insulation performance under varying environmental conditions.

Table 3

Electrical insulation properties

Property	Unit	Value
Volume resistivity	Ω·cm	10^{12}–10^{13}
Dielectric strength	kV/mm	18–22
Water absorption	%	0.6–0.9
Electrical insulation class	–	High

The incorporation of basalt dust, ceramic waste, kaolin, and quartz sand into the epoxy matrix enhances the dielectric performance by creating a structurally stable and non-conductive composite. The low water absorption and high resistivity ensure reliable insulation under both dry and humid environmental conditions. These properties make the composite suitable for railway applications where electrical isolation is essential for safety and system reliability.

3.4 Effect of Mineral Fillers on Compressive Strength

The influence of mineral filler content on the compressive strength of the epoxy-based composite was systematically investigated to determine the optimal composition for railway fastening system insulators. Different proportions of mineral fillers (basalt dust, ceramic waste, and kaolin) were incorporated into the polymer matrix, and the resulting composites were tested under standardized compressive loading conditions.

Experimental results indicate that compressive strength increases with filler content up to an optimal level of 30 wt%. At this concentration, the composite reached a maximum compressive strength of 102 MPa. Further increases in filler content beyond 30 wt% resulted in a slight reduction in compressive strength, likely due to particle agglomeration and incomplete stress transfer between the polymer matrix and fillers.

The improved compressive performance at optimal filler loading is attributed to the effective reinforcement provided by mineral particles and the enhanced interfacial adhesion between the matrix and fillers. The combination of different fillers creates a heterogeneous microstructure that distributes mechanical stresses more uniformly, reduces microcracking, and enhances the load-bearing capacity of the composite.

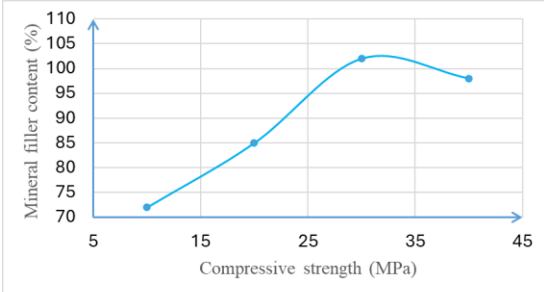

Fig. 1. Effect of mineral fillers on compressive strength

The study confirms that an optimal filler concentration exists, where the mechanical reinforcement and stress distribution are maximized. Exceeding this optimal level can cause particle agglomeration and reduce the efficiency of load transfer, slightly decreasing compressive strength. This analysis provides a scientific basis for selecting the filler content to achieve the best balance between mechanical performance and processability in railway insulator applications.

3.5 Vibration Damping Performance

Vibration damping is a critical property for railway fastening system insulators, as it reduces dynamic stress on rails and sleepers, minimizes noise, and prolongs the service life of railway tracks. The damping behavior of the developed epoxy-based composite was evaluated and compared with conventional polyamide insulators and rubber pads.

The experimental results demonstrated that the composite exhibits superior vibration attenuation, with a damping coefficient of 0.53, which is 30–40% higher than that of polyamide insulators (0.32) and rubber pads (0.41). The enhanced vibration damping is attributed to the heterogeneous microstructure of the composite, where the rigid polymer matrix is reinforced with mineral fillers of varying particle sizes. This structure effectively dissipates vibrational energy and prevents stress concentration within the material.

The incorporation of kaolin and ceramic fillers contributes to interfacial friction at the polymer–filler boundaries, further enhancing energy dissipation. Additionally, the composite maintains its damping performance over a wide temperature range (−40 to +120°C), ensuring reliable operation under varying environmental conditions.

Table 4

Vibration damping coefficient of different materials

Material	Damping coefficient
Polyamide insulator	0.32
Rubber pad	0.41
Developed composite	0.53

The mineral-filled epoxy matrix creates a multi-phase structure that combines stiffness with energy dissipation capacity, resulting in improved vibration damping. This property is essential for railway insulators, as it reduces dynamic stresses, mitigates noise, and enhances the durability of the fastening system under continuous train loads. The results provide a scientific basis for the composite's superior performance compared with conventional insulating materials.

4. Conclusion

A novel epoxy-based composite material reinforced with local mineral fillers has been successfully developed for railway fastening system insulators. The combination of ED-20 epoxy resin, a curing agent, acrylic resin, and fillers such as basalt dust, ceramic waste, kaolin, and quartz sand provides a synergistic enhancement of mechanical, dielectric, and vibration damping properties. The optimized filler content ensures uniform dispersion, high compressive strength (up to 102 MPa), adequate flexural strength, and improved wear resistance. Dielectric properties are excellent, with volume resistivity up to 10^{13} Ω·cm and low water absorption, ensuring reliable electrical insulation. Vibration damping performance is significantly enhanced due to the heterogeneous microstructure and interfacial interactions between polymer and mineral phases. Furthermore, the incorporation of industrial mineral waste reduces production cost and supports environmental sustainability. Overall, the developed composite represents a cost-effective, durable, and technically advanced material suitable for high-performance railway insulators, providing a promising alternative to conventional polymer-based solutions.

References

[1] Al-Bayati, S. I. A., & Aydoğmuş, E. (2026). Sustainable Epoxy Composites Filled with Natural Mineral Rocks: Comparative Evaluation of Mechanical, Thermal, and Dielectric Performance. Polymers, 18(5), 571.

[2] Fajdek-Bieda, A., & Wróblewska, A. (2024). The use of natural minerals as reinforcements in mineral-reinforced polymers: a review of current developments and prospects. Polymers, 16(17), 2505.

[3] Matykiewicz, D., Barczewski, M., & Michałowski, S. (2019). Basalt powder as an eco-friendly filler for epoxy composites: Thermal and thermo-mechanical properties assessment. Composites Part B: Engineering, 164, 272-279.

[4] Haider, I., Gul, I. H., Faraz, M. I., Aziz, S., Jaffery, S. H. I., Khan, M. A., & Jung, D. W. (2023). Investigation of dielectric, mechanical, and thermal properties of epoxy composites embedded with quartz fibers. Polymers, 15(20), 4133.

[5] Kim, Y. N., Jeong, H., Yoon, S., Choi, Y. S., Shim, J. H., Zha, J. W., ... & Jung, Y. C. (2025). Eco-friendly hybrid composite fillers for high-performance epoxy insulators: Advancing thermal and electrical durability. ACS Applied Engineering Materials, 3(4), 938-946.

[6] Prasetyo, M. T., Sulistyo, S., Nugroho, S., Syakur, A., & Mohamed, A. I. (2025). Fabrication and Testing of Epoxy Resin-Based Composites for Electrical Insulation Material Applications. Journal of Advanced Research in Applied Mechanics, 135(1), 71-82.

[7] Yan, B., Zhang, Z., Li, Y., Cui, H., Zhang, C., & He, J. (2023). Research and application progress of resin-based composite materials in the electrical insulation field. Materials, 16(19), 6394.

[8] Pelin, C. E., & Pelin, G. (2024). Mechanical properties of basalt fiber/epoxy resin composites. Incas Bull, 16, 99-111.

[9] Pukánszky, B. (2016). Mineral filled polymers.

[10] Haider, I., Gul, I. H., Faraz, M. I., Aziz, S., Jaffery, S. H. I., Khan, M. A., & Jung, D. W. (2023). Investigation of dielectric, mechanical, and thermal properties of epoxy composites embedded with quartz fibers. Polymers, 15(20), 4133.

[11] Xue, C., Qin, Y., Fu, H., & Fan, J. (2022). Thermal stability, mechanical properties and ceramization mechanism of epoxy resin/kaolin/quartz fiber ceramifiable composites. Polymers, 14(16), 3372.

[12] Ziyamukhamedova, U., Torskaya, E., Nafasov, J., Turgunaliyev, E., & Jalolova, Z. (2025). Studying the Tribological Properties of Polymer Composite Materials FIlled with Production Waste. Material and Mechanical Engineering Technology, (4), 104-109.

[13] Ziyamukhamedova, U., Bakirov, L., Donaev, S., Miradullaeva, G., & Turgunaliev, E. (2023). Study of structure formation processes in matrices of mixed components with reinforcing natural fillers. In E3S Web of Conferences (Vol. 401, p. 05074). EDP Sciences.

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