World Journal of Advanced Engineering Technology and Sciences

eISSN: 2582-8266

Cross Ref DOI: 10.30574/wjaets

Journal homepage: https://wjaets.com/

(Research Article)

Mechanical and morphological characterization of glass fiber reinforced epoxy composites with fire-retardant fillers for electrical applications

Manoj Parashram Pathade *, Neeraj Kumar and Sunil Kisan Bangar

Department of Mechanical Engineering, Suresh Gyan Vihar University, Jaipur.

World Journal of Advanced Engineering Technology and Sciences, 2026, 19(02), 200-209

Publication history: Received on 13 April 2026; revised on 20 May 2026; accepted on 22 May 2026

Article DOI: https://doi.org/10.30574/wjaets.2026.19.2.0272

Abstract

Glass fiber reinforced epoxy (GFRP) composites are extensively employed in electrical industries for their high strength, insulation properties and good corrosion resistance. But their combustion properties present a safety concern for high-temperature and fire hazards. In this research, the mechanical, thermal, morphological and electrical properties of GFRP composites filled with fire-retardant fillers such as aluminum trihydrate (ATH) and magnesium hydroxide ($Mg(OH)_2$) at different weight percentages (0-15%) are studied. The findings of this study reveal that filler incorporation leads to improved tensile, flexural and impact strength at a critical loading of 10%, after which a marginal decrease in properties is observed due to filler agglomeration and poor adhesion. Thermal gravimetric analysis (TGA) shows enhanced thermal stability and increased char yield with filler loading. Flame retardancy tests show a significant increase in limiting oxygen index (LOI) and UL-94 ratings, indicating improved flame resistance. SEM studies reveal better interfacial bonding and filler dispersion at low concentrations, but onset of micro-cracks and filler agglomeration at higher concentrations. Moreover, the dielectric strength and volume resistivity of the composites are enhanced, suggesting their potential for electrical insulation. In conclusion, these composites have a combination of mechanical, thermal and fire-retardant properties, and are suitable for use in high-end electrical and structural components.

Keywords: Glass Fiber Reinforced Polymer (GFRP); Epoxy Composites; Fire-Retardant Fillers; Aluminum Trihydrate (ATH); Magnesium Hydroxide ($Mg(OH)_2$)

1. Introduction

Glass fiber reinforced epoxy (GFRP) composites are a type of high-performance material widely used in electrical, structural and insulation applications owing to their high mechanical strength, light weight, chemical resistance and high dielectric properties [1]. These characteristics are ideal for applications such as insulators, printed circuit boards and high voltage apparatus. But despite their many advantages, traditional epoxy composites are inherently flammable and have poor thermal stability, which is problematic for applications where high temperatures and fire risks are present [2]. In recent years, fire-retardant fillers have been increasingly used to overcome these drawbacks. Inorganic fillers like aluminum trihydrate (ATH) and magnesium hydroxide ($Mg(OH)_2$) are well known for their effectiveness in improving fire resistance due to endothermic decomposition, water release, and char formation [3]. The filler not only reduces heat release but also enhances thermal stability and retards ignition. However, incorporating these fillers can affect the mechanical properties and microstructure of the composite material, resulting in a balance between strength, toughness and flame retardancy [4].

Moreover, the bonding between the glass fiber, epoxy matrix and fillers has a significant impact on composite performance. Even distribution of fillers and good fiber/matrix adhesion are required to maximise mechanical and electrical properties, while filler overloading can lead to filler agglomeration, voids and stress concentrations [5]. While

* Corresponding author: Manoj Parashram Pathade.

some studies have reported the flame retardancy of polymer composites, there is a lack of systematic assessment of mechanical, thermal, morphological and electrical properties for GFRP composites. Specifically, the determination of an optimum filler loading that balances these properties is essential for their applications.

In this regard, the current research focuses on understanding the influence of different concentrations (0-15 wt%) of ATH and $Mg(OH)_2$ fillers on the behavior of GFRP composites. The effect of filler concentration on the tensile, flexural, and impact strengths, thermal stability (via thermogravimetric analysis), flame retardancy (via UL-94 and limiting oxygen index (LOI) tests), morphological analysis (via scanning electron microscopy (SEM) and electrical insulation performance is examined. The results obtained from this research will contribute to better understanding of fire-retardant GFRP composites for high-end electrical applications.

2. Literature Review

The use of glass fiber reinforced epoxy (GFRP) composites has been widely investigated for their application in structural and electrical industries [1]. Earlier studies have mostly concentrated on improving the mechanical properties, thermal stability, and fire resistance of the composites by using different fillers and additives. Some reports have demonstrated that incorporation of inorganic fire-retardant fillers like aluminum trihydrate (ATH) and magnesium hydroxide ($Mg(OH)_2$) has led to improved flame retardancy properties of composites [2,3]. These fillers work via endothermic decomposition (water release) that dilutes flammable gases and creates a protective layer [4]. It has been found that ATH starts decomposing at relatively lower temperatures (~200-220°C), and is therefore effective in the early stages of fire suppression, while $Mg(OH)_2$ decomposes at higher temperatures (~300-330°C), offering better thermal stability at higher temperatures [5]. But the efficiency of such fillers is highly dependent on the dispersion and filler load in the matrix.

With regards to the mechanical performance, previous studies report that a moderate amount of filler loadings could improve stiffness and strength through enhanced stress transfer from the matrix to the filler. For example, investigations on GFRP composites containing ATH fillers reveal an improvement in tensile and flexural strength up to a certain filler content (usually between 8-12 wt%). Higher filler concentrations can result in degradation of mechanical properties due to filler agglomeration, weak bonding, and void formation [6]. Similar findings have been made with $Mg(OH)_2$-filled composites, where high filler contents result in brittleness and low impact strength [7]. Scanning electron microscopy (SEM) has been extensively used for morphological characterization to determine the microstructural effects. Previous studies report that good fiber-matrix bonding and filler dispersion lead to better mechanical performance, whereas poor bonding and defect formations such as fiber pull-out, matrix cracking, and filler agglomeration are responsible for reduced properties [8]. Filler/fiber surface modifications have also been employed to enhance compatibility and filler dispersion.

Fire and thermal properties of GFRP composites have been evaluated using methods like thermogravimetric analysis (TGA), differential scanning calorimetry (DSC) and cone calorimetry [9]. Existing research shows that the use of ATH and $Mg(OH)_2$ leads to higher degradation temperature, char yield, and improved fire indices such as limited oxygen index (LOI) and UL-94 rating. The development of a protective char layer during burning is essential for minimising heat release and retarding flame spread [10]. Electrical insulation is also a crucial factor for GFRP composites in electrical insulation applications. Previous research indicates that the use of inorganic fillers can increase dielectric strength and volume resistivity due to the reduction in micro-voids and increased compactness. But high filler loadings can create defects that hinder electrical properties.

Though substantial research has been conducted, the majority of the available studies concentrate on either the mechanical or fire retardant performance. There is a lack of a comprehensive analysis that considers multiple performance aspects including mechanical, thermal, morphological and electrical properties for different filler loadings. Moreover, very few studies compare the performance of ATH and $Mg(OH)_2$ fillers processed under identical conditions. Hence, this research seeks to address these issues by offering a comprehensive and comparative study of GFRP composites filled with ATH and $Mg(OH)_2$ fillers in a range of performance characteristics. The goal is to determine an ideal filler ratio to provide a well balanced improvement in the mechanical, thermal, electrical insulation and flame retardancy properties to advance the material for electrical applications.

3. Methodology

The present study follows an experimental approach for the development and analysis of glass fiber reinforced epoxy (GFRP) composites with fire-retardant filler. This involves selecting materials, fabricating composites, preparing samples, and carrying out multi-faceted characterisation of mechanical, thermal, morphological and electrical properties as depicted in figure 1.

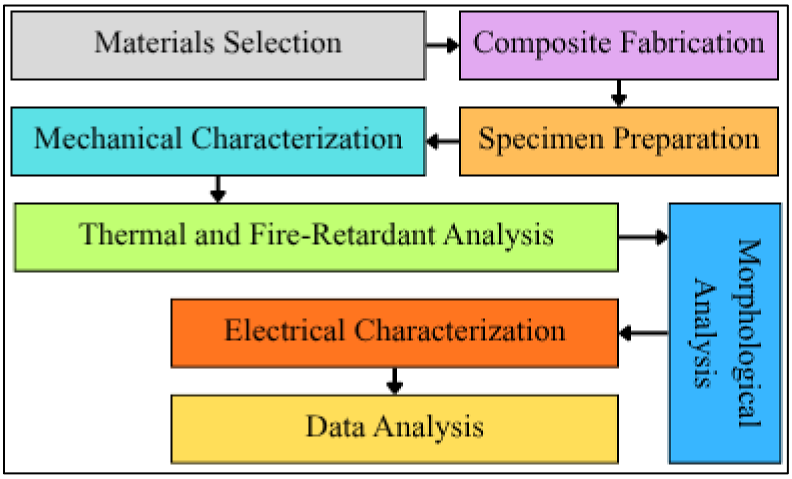

Figure 1 Methodology for Fabrication and Characterization of Fire-Retardant GFRP Composites

3.1. Materials Selection

The matrix system comprised epoxy resin (LY 556) and hardener (HY 951) because of their good bonding and electrical insulation characteristics. Woven glass fiber was used as reinforcement. Inorganic fire retardants, aluminum trihydrate (ATH) and magnesium hydroxide ($Mg(OH)_2$), were chosen for their flame-retardant properties and thermal stability.

3.2. Composite Fabrication

The composites were prepared by a combination of hand lay-up and compression molding to achieve desired thickness and compaction. The epoxy resin and hardener were thoroughly mixed in a predetermined proportion, and fillers were incorporated at different weight percentages (0%, 5%, 10%, and 15%). The resin containing fillers was stirred to ensure a uniform dispersion and then used in fabricating the glass fiber preforms. Then, the laminates were compressed under specific pressure and cured at ambient temperature and post-cured at higher temperature for cross-linking.

3.3. Specimen Preparation

The cured composite laminates were cut into standard test specimens as per ASTM standards. This includes tensile specimens (ASTM D3039), flexural specimens (ASTM D790) and impact specimens (ASTM D256). Specimens for electrical and thermal testing were made as per standard sizes.

3.4. Mechanical Characterization

Tensile, flexural and impact strength were measured using a universal testing machine (UTM) and impact tester. The tests were performed under controlled loading and the averages were calculated for each type of sample.

3.5. Thermal and Fire-Retardant Analysis

Thermal properties were tested by thermogravimetric analysis (TGA) from 30°C to 600°C in a controlled environment. Fire-retardant properties were measured by the Limiting Oxygen Index (LOI) and UL-94 vertical burning tests to determine the ignition and combustion characteristics.

3.6. Morphological Analysis

Fracture surfaces of tested specimens were analysed using Scanning Electron Microscopy (SEM). It examined fiber-matrix bonding, filler distribution, voids, and crack growth to relate morphological features to mechanical properties.

3.7. Electrical Characterization

Dielectric strength and volume resistivity were determined using standard equipment. The tests were performed to determine the electrical insulation potential of the composites.

3.8. Data Analysis

The data obtained from experimentation were carefully examined to determine the trends and correlations between filler loading and composite properties. A comparison was made between ATH and $Mg(OH)_2$ fillers to identify the appropriate filler type and content to achieve an overall improvement in properties.

Overall, the approach adopted in this study guarantees a detailed assessment of GFRP composites, allowing us to identify the optimal material configuration that provides improved mechanical, thermal and electrical properties for fire-prone applications.

4. Results and Discussion

In this section, the outcomes of the mechanical, thermal, morphological and electrical studies of GFRP composites containing fire-retardant fillers are discussed. The research explores the effects of different filler types (ATH and $Mg(OH)_2$) and fillers loadings (5-15 wt%) on composite properties. A comparative analysis is conducted using the experimental results in Tables 1-3 and Figures 2-8 to determine trends, improvements and the optimum filler concentration. The results offer valuable insights into the structure–property relationships that govern the performance of composites under various conditions.

Table 1 Properties of GFRP Composites with Fire-Retardant Fillers

Sample ID	Filler Type	Filler (%)	Young's Modulus (GPa)	Elongation (%)	Flexural Modulus (GPa)
S1	None	0	8.5	3.2	12.5
S2	ATH	5	9.1	3.0	13.2
S3	ATH	10	9.8	2.8	14.0
S4	ATH	15	10.2	2.5	14.5
S5	$Mg(OH)_2$	5	9.0	3.1	13.0
S6	$Mg(OH)_2$	10	9.6	2.9	13.8
S7	$Mg(OH)_2$	15	10.0	2.6	14.2

Table 1 shows the change in Young's modulus, elongation and flexural modulus of GFRP composites with various types and loading levels of fire-retardant fillers. It can be seen that the addition of fillers results in a gradual increase in the stiffness of the composite, as shown by the increase in Young's modulus from 8.5 GPa (neat composite - S1) to 10.2 GPa and 10.0 GPa for the ATH (S4) and $Mg(OH)_2$ (S7) filled composites, respectively. This is due to the stiff inorganic fillers that limit the movement of the polymer chains, thus improving load transfer. Likewise, the flexural modulus gradually increases with increasing filler percentage, with a maximum value at high filler concentrations. Composite systems with ATH display slightly better properties than $Mg(OH)_2$, suggesting improved interfacial compatibility and dispersibility. But the elongation at break decreases with higher filler content, indicating a loss in flexibility, as the composite becomes more brittle. As a whole, the findings suggest that while incorporation of fillers improves the stiffness and load bearing capability, it degrades the flexibility, stressing the need for a balance between strength and ductility.

Figure 2 shows the effect of filler loading on the tensile strength of ATH and $Mg(OH)_2$ filled composites. There is a gradual increase in tensile strength up to 10% filler, followed by a marginal decrease at 15%. The enhancement in tensile strength up to 10% filler content can be explained by better stress transfer from the matrix to the filler, due to better dispersion of the filler and improved interfacial bonding. But above the critical filler loading, the reduction in tensile strength could be due to higher filler aggregation, leading to stress concentration and disruption of the epoxy matrix. Moreover, high filler content can result in poor fiber wetting and void formation, which also affects the mechanical properties. Composites with ATH have a slightly higher tensile strength than those with $Mg(OH)_2$, which indicates greater affinity towards the epoxy matrix.

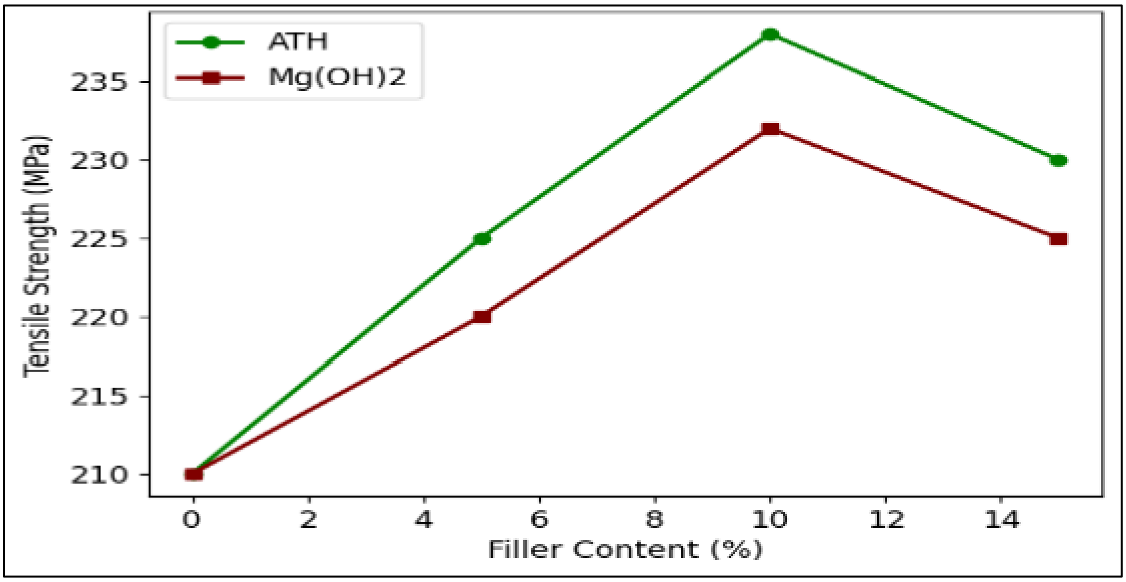

Figure 2 Tensile Strength vs Filler Content

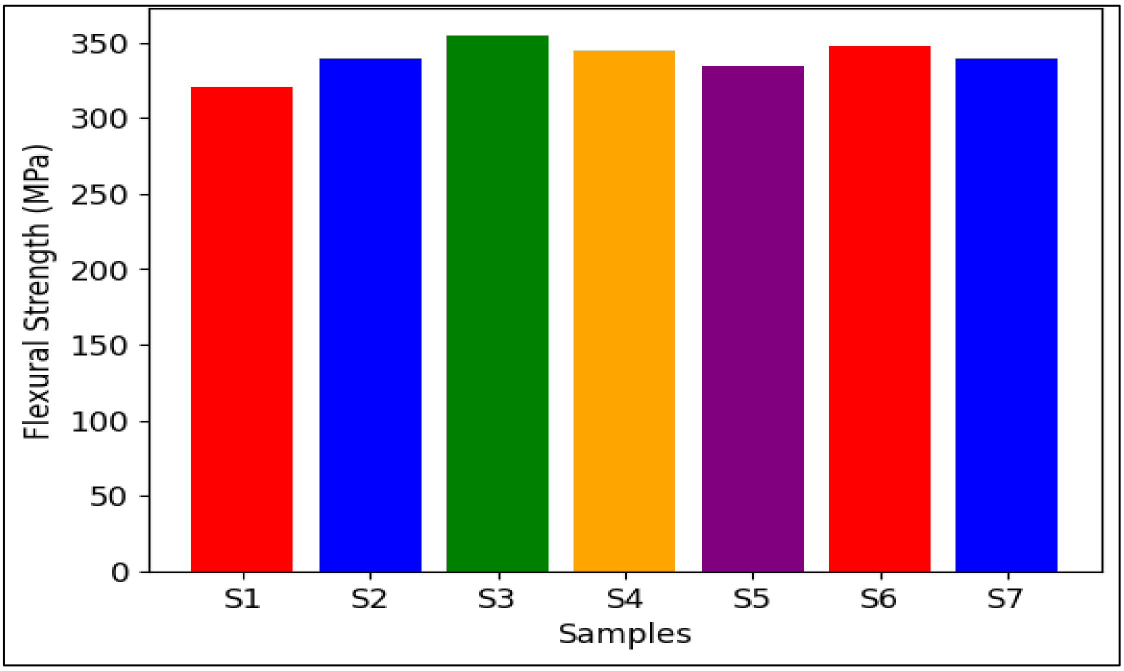

Figure 3 Flexural Strength Comparison

Figure 3 shows the flexural strength comparison of all the composites. The figure clearly shows an improvement in flexural strength with the introduction of fillers, with maximum values observed at around 10 wt%. This is related to the increased stiffness and deformation resistance under flexural loads. Composites filled with ATH exhibit higher flexural strength than those filled with $Mg(OH)_2$ at the same filler loadings. This is presumably due to smaller particle size and improved dispersion of ATH particles, leading to better load transfer and less stress concentration. However, a slight decrease in flexural strength is noticed with larger filler content (15 wt%), which could be due to filler agglomeration and matrix continuity loss.

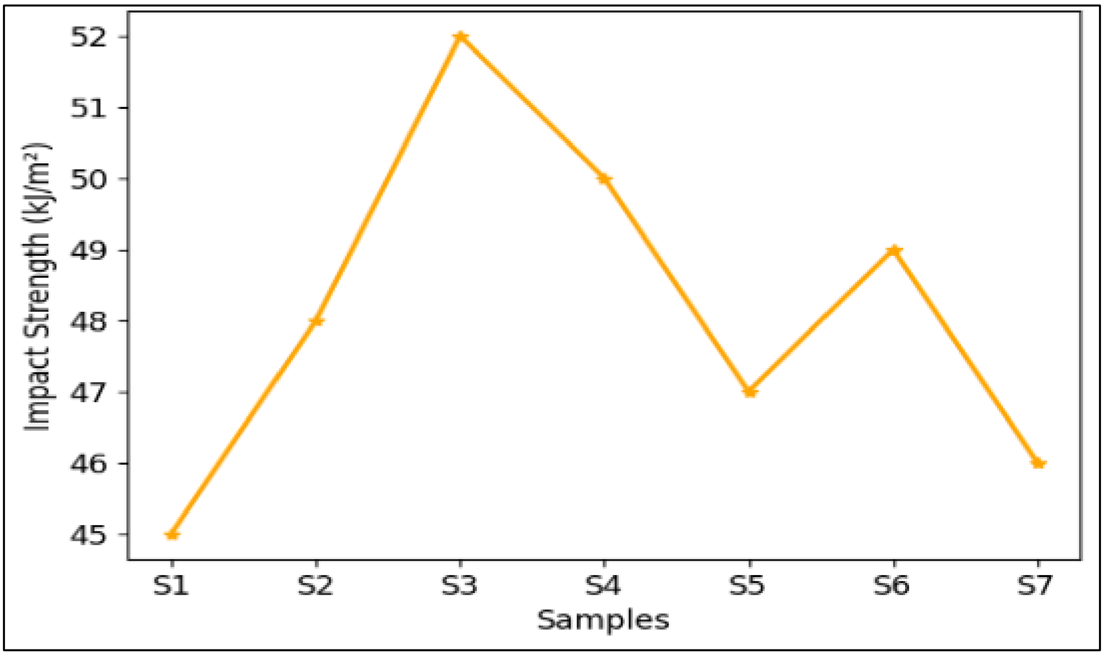

Figure 4 Impact Strength Variation

Figure 4 shows the impact strength of the composites with varying filler content. The findings show that the impact strength is increased with the addition of filler up to 10 wt%, which implies better energy absorption of the material. This is attributed to improved fiber-matrix bonding and stress transfer. At higher filler concentrations (15 wt%), impact strength reduces, suggesting the material becomes more brittle. Agglomeration and micro-defects of filler provide stress concentration points, limiting the material's capacity to withstand impact. Moreover, the decrease in elongation (Table 1) suggests increased brittleness with higher filler loading. Therefore, the findings show that the optimal filler content of around 10 wt% is necessary to achieve the optimum combination of strength, stiffness and toughness in GFRP composites.

Table 2 Thermal Stability and Fire-Retardant Performance

Sample ID	**Initial Decomposition Temp (°C)**	**Residue at 600°C (%)**
S1	320	18
S2	335	24
S3	350	30
S4	345	33
S5	330	26
S6	345	29
S7	340	32

The thermal stability of glass-fiber-reinforced polymer (GFRP) composites with different types and amounts of fillers are shown in Table 2. It is clearly seen that the addition of fire-retardant fillers considerably improves the thermal properties of the composites. The onset of degradation temperature rises from 320°C for the neat composite (S1) to as high as 350°C for the 10 wt% ATH composite (S3), suggesting enhanced thermal stability. Also, the char residue at 600°C increases significantly as a function of filler content, increasing from 18% for the neat composite to 33% for the composite with 15% ATH (S4). The higher char residue is due to the formation of an insulating char layer during decomposition, which prevents heat transfer, thus delaying degradation. $Mg(OH)_2$ composites also exhibit higher thermal resistance, albeit not as high as ATH composites, because of the decomposition characteristics of the filler and its effectiveness. In conclusion, the findings confirm that the addition of fillers improves the thermal protection, with ATH composites performing relatively better in terms of char yield.

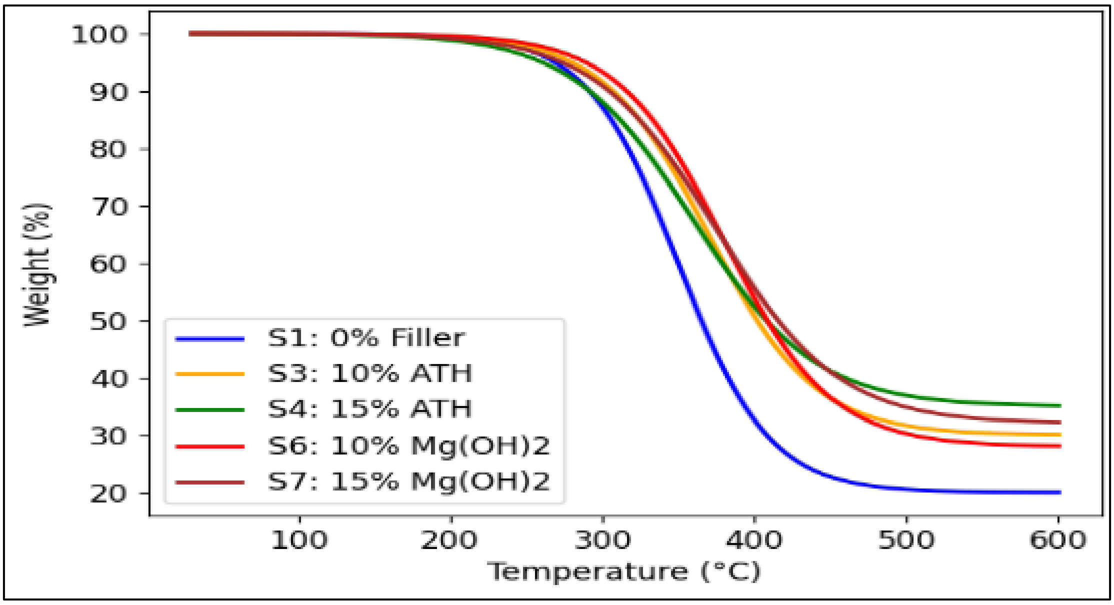

Figure 5 TGA Curves of Composites

Figure 5 shows the thermogravimetric analysis (TGA) curves of the composites, demonstrating the influence of fillers on the thermal degradation of composites. It is evident that the degradation onset temperature is delayed for the composites with fillers compared to the unfilled composite, suggesting enhanced thermal stability. The fillers also decrease the weight loss rate, implying a delayed degradation process. Composites filled with ATH, in particular, show increased residual weight at higher temperatures, which is indicative of the formation of a protective char layer. This contributes to improving the fire retardancy of the composite by reducing heat and oxygen flow. Also, the multi-stage degradation in the curves is due to the simultaneous degradation of the epoxy and the fillers. This thermal improvement suggests that fire-retardant fillers play a significant role in improving the thermal stability of GFRP composites.

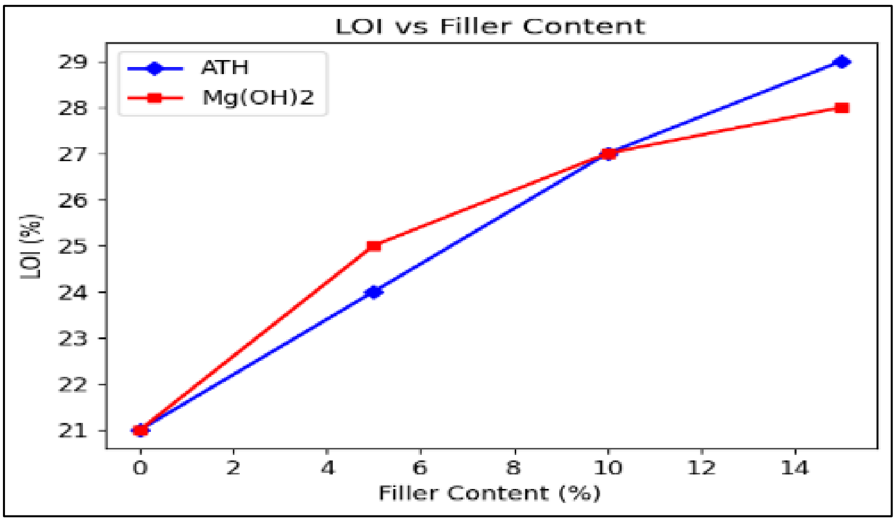

Figure 6 LOI vs Filler Content

Figure 6 represents the Limiting Oxygen Index (LOI) vs Filler Content for ATH and $Mg(OH)_2$-reinforced composites. The LOI values increase with the percentage of filler, revealing greater flame-retardant properties. The composite without filler has the lowest LOI value, indicating greater flammability, while the composites filled with fillers show improved flame retardancy. Composite samples containing ATH exhibit slightly higher LOI values than those with $Mg(OH)_2$ at comparable concentrations, due to their effective evolution of water molecules and good char forming ability during combustion. The elevated LOI value indicates that more oxygen is needed to maintain combustion, thus proving the efficiency of the fillers in retarding the spread of fire. This improved fire-retardant property is highly important for electrical insulation systems in terms of safety.

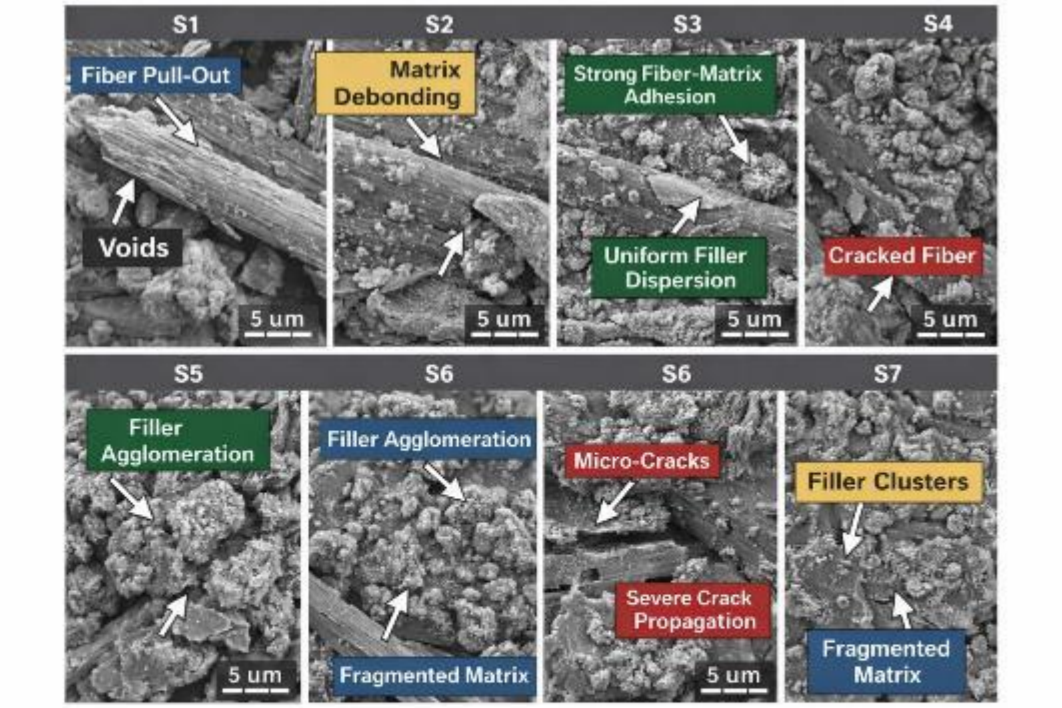

Figure 7 SEM Micrographs

Figure 7 shows the scanning electron microscopy (SEM) micrographs of the fracture surfaces of the GFRP composites, which give an idea of the microstructural features. The unfilled composite (S1) displays moderate fiber-matrix interaction and visible voids and fiber pull-out, suggesting relatively poor bonding. The presence of fillers leads to a pronounced enhancement in the fiber–matrix interaction. At 10 wt% filler concentration, the composites show even distribution of filler particles and good fiber-matrix interaction with improved mechanical properties. The minimal voids and defects observed at this composition further enhance the composite's integrity. But at higher concentrations (15 wt%) of filler, the SEM images show evidence of particle clumping and micro-crack formation. These serve as stress raisers and adversely affect the composite's properties. Therefore, the morphological studies confirm that the desired dispersion of fillers is at low loading, whereas, at high filler loadings, structural collapse occurs.

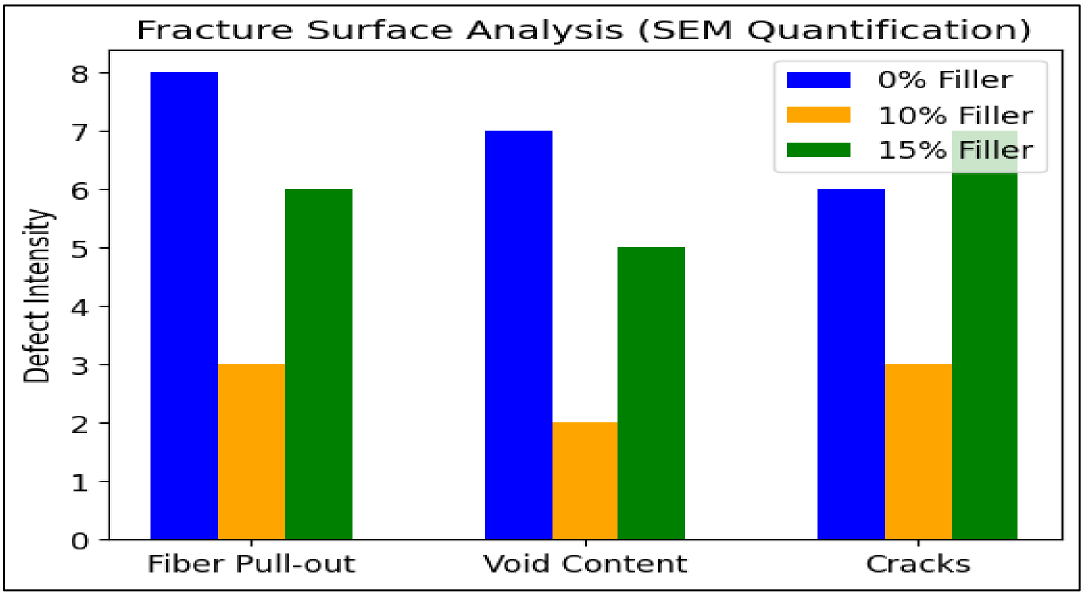

Figure 8 Fracture surface Analysis (SEM Quantification)

Figure 8 shows quantitative analysis of the fracture surfaces using SEM to gain insight into the failure behaviour of the composites. It is observed that the neat composite (S1) shows more fiber pull-out and voids, indicating poor fiber-matrix adhesion, and ineffective stress distribution. The incorporation of fillers, especially at 10 wt% (S3 and S6), leads to a more dense and void-free fracture surface. This indicates improved interfacial bonding between the fiber and matrix, and efficient load transfer. The quantitative fracture parameters, including shortened crack propagation and larger interfacial bonding area, also support the enhancement in the mechanical strength. In contrast, the fracture surfaces of composites with higher filler contents (15 wt%) show greater surface roughness, filler particle clustering and micro-cracks. These act as stress-raising inclusions and cause premature fracture under load. Therefore, the fracture surface studies clearly show that the optimal filler loading is achieved with lesser concentrations, and higher concentrations degrade the material's integrity.

Table 3 Electrical Insulation Properties

Sample ID	Dielectric Strength (kV/mm)	Volume Resistivity (Ω·cm)
S1	12	1.2×10^{12}
S2	13.5	1.8×10^{12}
S3	15.0	2.5×10^{12}
S4	14.2	2.2×10^{12}
S5	13.2	1.7×10^{12}
S6	14.5	2.3×10^{12}
S7	13.8	2.0×10^{12}

.

Table 3 shows the dielectric strength and volume resistivity values of the composites developed, which demonstrate their potential as electrical insulation materials. It is seen that the dielectric strength and volume resistivity increase with the addition of filler up to a level of 10 wt%, and reach their maximum values for S3 (ATH) and S6 ($Mg(OH)_2$) samples. The improvement in dielectric strength and volume resistivity is due to the reduction in the mobility of charge carriers and better interaction between the filler and the polymer. Composites with ATH have marginally higher dielectric strength as compared to $Mg(OH)_2$, likely due to increased dispersion and interaction with the polymer matrix. However, at higher filler loadings of more than 10 wt%, the electrical properties decrease. This is due to filler agglomeration and the creation of micro-defects, which leads to charge leakage and less insulation. However, the composites containing fillers demonstrate better electrical performance than the neat composite, proving the effectiveness of fillers in improving electrical properties.

In summary, the detailed examination of mechanical, thermal, morphological and electrical characteristics suggests that the addition of fire-retardant fillers greatly enhances the properties of GFRP composites. Among the various compositions, 10 wt% filler loading is the most effective to balance the improvement of all the properties. The composites with ATH fillers show slightly better performance than those with $Mg(OH)_2$. But, overfilling results in filler agglomeration, void formation and hence property degradation. The results from this study underline the need to incorporate fillers judiciously while developing high-performance, fire-retardant and electrically insulating composites with superior properties for advanced engineering applications.

5. Conclusion

In this paper, a detailed study on glass fiber reinforced epoxy (GFRP) composites containing fire-retardant fillers, aluminium trihydrate (ATH) and magnesium hydroxide ($Mg(OH)_2$) for electrical applications was presented. The experimental findings showed that the addition of fillers considerably improves the mechanical, thermal, flame-retardant and electrical properties up to a critical threshold at 10 wt% filler content. Thereafter, a slight decrease in properties was noted because of filler agglomeration and reduced interfacial adhesion. ATH composites showed relatively higher flame retardancy and mechanical properties, and $Mg(OH)_2$ offered superior thermal stability at elevated temperatures. SEM imaging revealed that filler distribution and fiber-matrix bonding play a crucial role in enhancing the performance. Moreover, increased dielectric strength and resistivity suggest their potential for insulation. In conclusion, the GFRP composites provide a good balance of properties, and are likely to be suitable for innovative fire-safe electrical and structural applications.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Wenchao Zhang, Ziyu Yu, Dongyu Hou, Qi Wang, Lin Pan, Xuesong Chen, Dong Yue, Yu Feng, Synergistic enhancing the flame-retardant and mechanical properties in epoxy/glass fiber composites, Composites Part B: Engineering, Volume 312, 2026, 113277, https://doi.org/10.1016/j.compositesb.2025.113277.

[2] Rajhi, A. A. (2022). Mechanical Characterization of Hybrid Nano-Filled Glass/Epoxy Composites. Polymers, 14(22), 4852. https://doi.org/10.3390/polym14224852

[3] Ramkumar, R., K. Saranya, P. Saravanan, KP Srinivasa Perumal, P. Ramshankar, V. Yamunadevi, and P. Ganeshan. "Dynamic mechanical properties and thermal properties of madar fiber reinforced composites." Materials Today: Proceedings 51 (2022): 1096-1098.

[4] Mohammed, R., Badruddin, I. A., Shaik, A. S., Kamangar, S., & Khan, A. A. (2024). Experimental Investigation on Mechanical Characterization of Epoxy-E-Glass Fiber-Particulate Reinforced Hybrid Composites. ACS omega, 9(23), 24761–24773. https://doi.org/10.1021/acsomega.4c01365

[5] Murad, M.S., Hamzat, A.K., Asmatulu, E. et al. Flame-retardant fiber composites: synergistic effects of additives on mechanical, thermal, chemical, and structural properties. Adv Compos Hybrid Mater 8, 31 (2025). https://doi.org/10.1007/s42114-024-01111-1

[6] Selvarajan, L., K. Venkataramanan, KP Srinivasa Perumal, Mohammed Yunus, Rami Alfattani, and A. Aravindhan. "A review of spark erosion machining efficiency, characterization and optimization techniques for ceramic composites." Composite Interfaces (2023).

[7] Bekeshev, A.; Mostovoy, A.; Tastanova, L.; Kadykova, Y.; Kalganova, S.; Lopukhova, M. Reinforcement of Epoxy Composites with Application of Finely-ground Ochre and Electrophysical Method of the Composition Modification. Polymers 2020, 12, 1437.

[8] Selvarajan, L., R. Rajavel, Mohammed Yunus, and Rami Alfattani. "Die-sinking and rotary EDM surface and subsurface analysis of MoSi2-SiC ceramic composites." Materials Science and Technology (2023): 1-17.

[9] Karthik Babu, N. B., Muthukumaran, S., Arokiasamy, S., & Ramesh, T. (2020). Thermal and Mechanical Behavior of the Coir Powder Filled Polyester Micro-Composites. Journal of Natural Fibers, 17(7), 1058–1068. https://doi.org/10.1080/15440478.2018.1555503

[10] Elwan, M., Fathy, A., Wagih, A., Essa, A. R. S., Abu-Oqail, A., & EL-Nikhaily, A. E. (2020). Fabrication and investigation on the properties of rutile (TiO2)-based Al composite by accumulative roll bonding. Journal of Composite Materials, 54(10), 1259–1271. https://doi.org/10.1177/0021998319876684