Journal of Mines, Metals and Fuels, *73(11): 3455-3467; 2025. DOI: 10.18311/jmmf/2025/50278*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.co.in/index.php/jmmf*

Thermo-Mechanical Properties of Synthetic Fibres Filled with Ceramic Filler Reinforced Epoxy Hybrid Composites

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Abstract

This study evaluates the thermo-mechanical features of hybrid epoxy composites reinforced with carbon, E-glass, and S-glass fibres, incorporating 10 wt % alumina (Al_2O_3) filler. Laminates were fabricated via hand lay-up using 45 wt % fibre and 45 µm alumina particles. EDAX and SEM confirmed high-purity alumina with sub-angular morphology. Thermo-mechanical properties were studied using DSC, TGA, and DMA techniques. DSC showed S-Ec/Al_2O_3 $_{10}$ had the highest peak temperature (396.68 °C), indicating strong thermal transition stability. C-Ec/Al_2O_3 $_{10}$ showed the highest heat absorption (46.97 J/g), indicating greater enthalpic response. TGA revealed all composites decomposed near 880 °C, with C-Ec/Al_2O_3 $_{10}$ retaining the most residual mass (47.06 %). S-Ec/Al_2O_3 $_{10}$ had the lowest residual mass (21.16 %), indicating rapid post-transition breakdown. DMA results showed C-Ec/Al_2O_3 10 had the highest storage (12941.70 MPa) and loss modulus (2199.94 MPa). It also had the highest damping factor (Tan δ = 0.575), indicating superior mechanical damping. E-Ec/$Al_2O_3$$_{10}$ recorded the highest thermal onset (152.42 °C), showing strong thermal stiffness retention. C-Ec is ideal for high-strength damping use, E-Ec for thermal endurance, and S-Ec for moderate load applications.

Major Findings: *C-Ec/$Al_2O_3$$_{10}$ showed the highest heat absorption, residual mass, and mechanical properties, indicating superior thermal resistance and stiffness. S-Ec/Al_2O_3 $_{10}$ had the highest DSC peak but degraded fastest, while E-Ec/Al_2O_3 $_{10}$ had the highest onset temperature; fillers were pure and well-bonded.*

Keywords: *Epoxy, Fibres, Fillers, Hybrid, Thermo-Mechanical*

1.0 Introduction

Fibre-reinforced composites offer good mechanical properties, making them critical in high-performance structural applications. Their design versatility and reluctance to fatigue and corrosion significantly enhance the reliability and longevity of components across aerospace, automotive, and civil engineering sectors[1]. Fibre-reinforced polymer composites exhibit enhanced load-bearing capacity and dimensional stability due to effective stress transfer between matrix and fibre phases. Their tunable interfacial characteristics and multifunctionality position them as pivotal materials for next-generation lightweight and durable engineering applications[2]. The morphological control of FRP's composites is crucial for optimizing interfacial adhesion

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and mechanical ability. The alignment and dispersion of fibres within the polymer matrix are vital for structural integrity, impact resistance, and functional reliability[3]. Thermally conductive fibres-reinforced polymer composites enable efficient heat dissipation, crucial for thermal management in electronic and high-power applications. The integration of thermally conductive fillers and fibre networks enhances anisotropic thermal conductivity while maintaining structural integrity and electrical insulation[4]. FRP composites exhibit superior mechanical and thermal characteristics due to synergistic reinforcement-matrix interactions. Their advanced thermal stability and mechanical tunability make them ideal candidates for demanding structural applications in aerospace, automotive, and thermal barrier systems[5]. Epoxy resins in fibres-reinforced composites provide exceptional matrix-fibres bonding, contributing to enhanced load transfer and mechanical integrity. Their inherent thermal stability, low shrinkage, and chemical resistance make are meant for high-performance polymer matrix composites in structural applications[6]. Thermal analysis of FRP composites is critical for understanding phase transitions, thermal degradation, and stability under service conditions. Accurate thermal characterization ensures optimal composite design, enabling prediction of performance and reliability in thermally demanding environments[7]. Fibre-reinforced polymer matrix composites offer exceptional strength-to-weight ratios and multifunctionality, essential for advanced structural applications. Their customizable architecture enables integration of structural and functional properties[8]. Incorporating alumina fillers into fibre composites significantly enhances thermal conductivity, dielectric strength, and wear resistance without compromising structural integrity. Alumina's high thermal stability and hardness make it an ideal functional filler for improving composite performance in high-temperature and electrically insulating applications[9]. The synergistic integration of fibres and fillers in hybrid composites optimizes mechanical reinforcement while significantly enhancing thermal stability and conductivity. The tailored combination of these constituents enables the design of advanced polymer composites with superior multifunctional performance for demanding thermal and structural applications[10].

The literature review on fibres, fillers, and thermal aspects of hybrid composites is crucial for understanding the current state of material performance, processing techniques, and characterization methods. It provides a comprehensive foundation to identify knowledge gaps, optimize composite formulations, and tailor properties for specific thermal and mechanical requirements, ultimately guiding the development of advanced hybrid systems with enhanced multifunctionality and reliability.

Suchitra et al. work reveals notable effects on fracture toughness. Fillers alter thermal conductivity and expansion coefficients, influencing crack propagation and fracture resistance. Optimal filler content and dispersion significantly impact fracture toughness, crucial for material performance under thermal stress[11].

Noel et al. test results reveal distinct thermal transitions and degradation behaviour within the material. Quantitative analysis underscores the influence of composite composition on thermal stability. The findings provide crucial insights for optimizing manufacturing processes and enhancing material performance[12].

Bücheler *et al.* applied thermogravimetric analysis to accurately measure the carbon fibre content in fibre-reinforced plastics. Their method offers a reliable, non-destructive way to quantify fibre weight percentage—critical for quality control in composite manufacturing[13].

Giżyński *et al.* explored the thermal degradation patterns of carbon fibre-reinforced thermoplastic polymers using thermogravimetric analysis, offering a deeper understanding of their stability under heat. Their work contributes significantly to composite material science by mapping decomposition stages and residue behavior[14].

Ambigai *et al.* thermal analysis reveals a collaborative effect among glass /carbon fibres, enhancing thermal stability. Differential Scanning Calorimetry (DSC) indicates improved heat resistance due to hybridization. Thermogravimetric Analysis (TGA) shows increased decomposition temperatures with hybridization, indicating enhanced thermal performance[15].

Drzeżdżon *et al.* explored how differential scanning calorimetry (DSC) can effectively characterize the thermal properties of polymers, such as melting behavior and glass transition[16].

Chinnasamy *et al.* investigated the thermal behavior of hybrid composites made from glass fibre, Kevlar fibre, and modified epoxy resin. Their study used thermal analysis to reveal how these materials respond to heat, highlighting improvements in stability and performance[17].

Grund *et al.* focused on accurately determining the fibre volume fraction in carbon fibre-reinforced polymers using thermogravimetric methods. Their approach offers a precise, efficient alternative to traditional techniques, vital for assessing composite quality[18].

Moon *et al.* showed that TGA effectively quantifies mass loss attributed to fibre combustion, allowing accurate estimation of fibre content. Results demonstrate a direct relationship between mass loss and fibre content percentage. The technique offers a reliable and efficient method for assessing FRP composition. Implementing TGA can enhance quality control and ensure the desired fibre content in FRP materials[19].

Yatim *et al.* explore how carbon fibre reinforced polymers break down under heat, using TGA and DSC to reveal important thermal behaviors. Their findings shed light on how these materials respond in high-temperature conditions. This research helps guide the development of safer, more resilient materials for real-world use[20].

Vu *et al.* examined how adding coal fly ash along with nano- and micro-glass fibres enhances the mechanical strength and mode I interlaminar fracture toughness of carbon fibre-filled vinyl ester composites. Their work shows a synergistic effect of fillers in improving durability and structural performance[21].

Gori *et al.* investigated the thermal and dynamic mechanical behavior of polyester-based hybrid composites reinforced with glass and basalt fibres. Their study highlights improved thermal stability and mechanical performance due to the hybrid fibre synergy[22].

Blaznov *et al.* conducted a thermomechanical characterization of basalt fibre-reinforced (BFRP) and glass fibre-reinforced polymers (GFRP) at varying degrees of resin conversion. Their study reveals how the degree of cure impacts mechanical strength and thermal stability in these composites[23].

Karvanis *et al.* take a closer look at how different fibres—glass and carbon—change the way polymer composites behave under stress. By using dynamic mechanical analysis, they reveal how these materials respond in real-world conditions.[24].

Karvanis *et al.* explore how adding basalt fibres to epoxy can make the material stronger and more stable when exposed to heat. Their findings show real potential for using these composites in tough, high-stress environments[25].

Salasinska *et al.* made a comparative analysis of the thermal behaviour of epoxy-based composites reinforced with different materials. Results indicated variations in thermal conductivity and heat resistance based on the type of reinforcement used. TGA revealed differences in thermal degradation profiles, influencing the burning characteristics of the composites. DSC highlighted variations in glass transition temperatures, impacting the thermo-mechanical performance[26].

Samoilenko *et al.* worked on thermo-mechanical characterization of GFRP and BFRP. DSC revealed distinct glass transition temperatures, influencing thermal behaviour. TGA indicated improved thermal stability in BFRP compared to GFRP. DMA showed variations in storage and loss moduli, reflecting differences in thermal response[27].

Yong *et al.* investigated the impact of heating rates on measuring the glass transition temperature (Tg) in composite materials. Results demonstrated that higher heating rates led to elevated Tg values due to kinetic effects. Differential Scanning Calorimetry (DSC) analysis revealed variations in Tg with changing heating rates, affecting thermal characterization. To elucidate the kinetics governing Tg measurements in composite materials across varying heating rates[28].

Hahne *et al.* provides a thorough introduction to differential scanning calorimetry (DSC), tailored for practitioners in material science and chemistry. It also helps in providing the foundation for understanding how DSC reveals material transitions and stability[29].

Montoro *et al.* research findings on DMA (dimethylacetamide) from the article reveal its significant role as a solvent in pharmaceutical applications due to its high solvency power and low toxicity profile. the study highlights DMA'S effectiveness in dissolving various Active Pharmaceutical Ingredients (APIS) and its potential for enhancing drug delivery systems. moreover, the research underscores DMA'S stability and compatibility with different formulation components, making it a promising candidate for pharmaceutical formulations requiring a safe and efficient solvent[30].

Joseph *et al.* have investigated the CFRF mixed with rubber granules using Dynamic Mechanical Analysis (DMA). DMA findings reveal improved mechanical properties with rubber granule addition, including enhanced stiffness and damping characteristics[31].

Bommegowda *et al.* studied how combining micro- and nanofillers influences the dynamic mechanical properties of glass fibre-reinforced epoxy composites. Their findings

reveal that hybrid fillers enhance stiffness and damping, improving overall composite performance[32].

Abu *et al*. research examines hybrid fibre composites reinforced with GNPs and Al_2O_3 using Dynamic-Mechanical-Thermal Analysis (DMA). DMA results highlight enhanced mechanical properties, such as increased stiffness and improved thermal stability, crucial for marine applications. The study underscores the effectiveness of GNPs and Al_2O_3 in reinforcing the composites, offering insights into their dynamic performance under varying environmental conditions. Overall, DMA findings support the potential of these hybrid materials for advanced marine structural applications, emphasizing their durability and performance benefits[33].

Despite extensive studies on the thermal-mechanical properties of filler-fibres hybrid composites, there remains a lack of comprehensive understanding of the synergistic effects of combined synthetic fibres with alumina fillers on both thermal stability and dynamic mechanical performance. Most research focuses on individual fibre types or filler additions, with limited exploration of optimized hybrid formulations under varying processing conditions. Furthermore, the influence of filler morphology and dispersion on interfacial bonding and long-term thermal degradation requires deeper investigation.

There is also a need for standardized methodologies to accurately correlate thermal analysis results with real-world service performance. Addressing these gaps will advance the design of multifunctional composites tailored for high-temperature-based structural uses.

2.1 Experimental and Methods

2.1.1 Materials

Plain weave woven E-glass fabric (300 gsm), s-glass fibres (195 gsm), carbon fibres (200 gsm) have been employed. The epoxy resin (Lapox L-12) was mixed with the hardener. The filler alumina was used in the present work at different weight percentages with a filler size of 45 microns.

Vendor Details of Materials Procured

i. E-glass Fibres – Suntech Composites, Bangalore, Karnataka, India.
ii. Carbon Fibres -Composites Tomorrow, Vadodara, Gujarat, India.
iii. S-glass Fibres – Marktech Composites, Bangalore, Karnataka, India.
iv. Alumina Filler – Nano Research Elements, Kurukshetra, Haryana, India.
v. Polymer Matrix Materials – Yuji Enterprises, Bangalore, Karnataka, India.

2.1.2 Fabrication

Synthetic fibres compatible with epoxy resin were used as reinforcement. The epoxy resin and hardener were mixed in a 100:10 weight ratio. Using the hand lay-up method (Figure 1), the lamina was prepared, then compressed and



Figure 1. Hand layup technique.



Figure 2. AJM and samples cut.

cured at room temperature under 0.5 MPa pressure. All composites contained 55 wt % reinforcement. To achieve a 3 mm thick laminate, the necessary number of fabric layers or filler content was used. The final laminates, each measuring 300 mm × 300 mm × 3 mm, were prepared for thermo-mechanical property testing. For hybrid composites, specific fillers (with or without) were blended into the epoxy resin as per design. The composite types are summarized in Table 1. Samples were cut using abrasive water jet machining and oven-dried according to ASTM standards (Figure 2).

Table 1. Properties of alumina filler

Sl. No	Properties	Units
1	Density	3.97 g/cm^3
2	Boling Point	2,977 °C
3	Melting Point	2,072 °C
4	Molecular Weight	101.96 g/mol

2.1.3 Energy Dispersive X-Ray Analysis of Fillers

Energy-Dispersive X-Ray Analysis (EDAX), performed using a Scanning Electron Microscope (SEM), helps identify and measure elements in a sample. It works by generating X-rays from the specimen when it's hit by an electron beam. These X-rays are unique to each element, allowing both identification and concentration analysis. In this study, EDAX was used to examine alumina filler. The test confirmed a high presence of pure alumina along with traces of oxygen, as shown in Figure 4. The sample was placed on a non-interfering substrate to ensure accurate results. Table 1 shows the properties of alumina filler used for the study.

Scanning Electron Microscopy (SEM) is widely used to study surface features at various magnifications. SEM

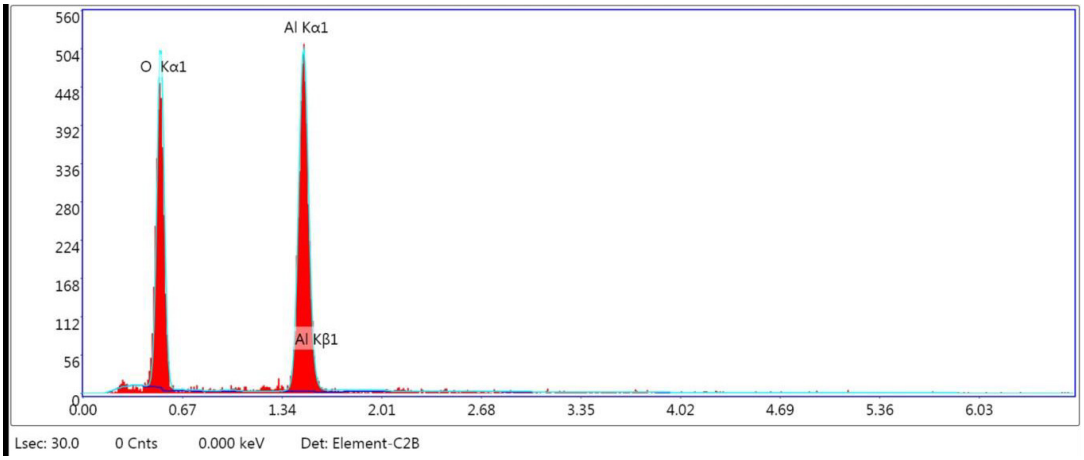


Figure 3. EDAX – alumina filler.

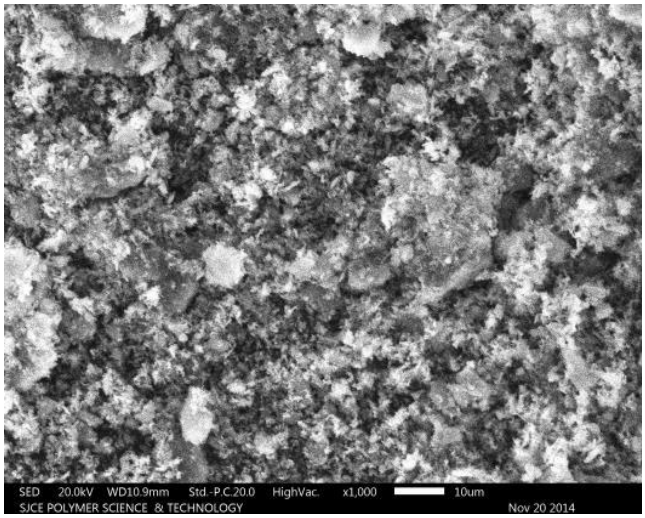


Figure 4. SEM analysis alumina particles.

Table 2. Composition of hybrid composites

Sl. No	Reinforcement (Synthetic Fibres)	Matrix (Epoxy Resin)	Filler (Alumina)	Material Code
1	Carbon Fibres - 45 %	45 %	10 %	C-E_c/ Al_2O_3 10
2	E-glass Fibres 45 %	45 %	10 %	E-E_c/ Al_2O_3 10
3	S-glass Fibres 45 %	45 %	10 %	S-E_c/ Al_2O_3 10

images of the alumina filler (Figure 4) reveal a sub-angular particle shape and provide insight into its size and morphology.

A series of composite laminates were fabricated using the aforementioned processing method, with constant Al_2O_3 filler loadings incorporated into various fibres reinforced epoxy polymer matrix systems to form hybrid composites. The specific compositions of the prepared laminates are detailed in Table 2.

3.0 Thermo-Mechanical Testing

3.1 Differential Scanning Calorimetry (DSC)

Figure 5 shows the Differential Scanning Calorimetry (DSC) setup, operated per ASTM D 3148[34]. DSC test was conducted at Poornayu Research Laboratory, Bengaluru. This measures the heat flow needed to raise the temperature of a sample compared to a

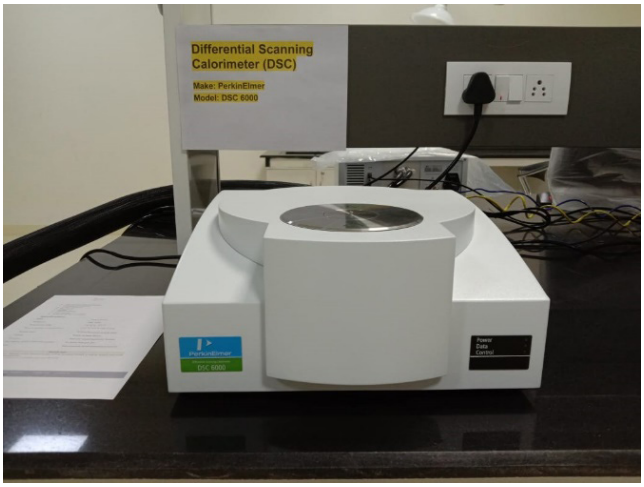


Figure 5. DSC instrument.

reference. Both are kept at similar temperatures, with the sample's temperature increasing linearly over time. The output is a heat flux vs. temperature curve, from which enthalpy changes (ΔH) are calculated using $\Delta H = K \times A$, where K is the instrument constant and A is the peak area.

3.2 Thermogravimetric Analysis (TGA)

Figure 6 shows the Thermogravimetric Analysis (TGA) instrument, operated according to ASTM E 1131[35]. The test was carried out in Poornayu Research Lab, Bangalore. In TGA, a sample is continuously weighed while heated under an inert gas atmosphere. Gaseous byproducts evolve and are removed, and mass changes are recorded. Three common TGA modes are:

- Dynamic TGA: Temperature increases continuously while mass is recorded, identifying decomposition temperatures and mass loss.
- Static TGA: Temperature is held constant to study decomposition or material stability at a fixed temperature.
- Quasistatic TGA: Heating occurs in steps with holds until mass stabilizes, ideal for materials decomposing in stages.

TGA is essential for designing high-temperature materials by detecting decomposition and measuring reaction kinetics. When combined with Differential Scanning Calorimetry (DSC), phase changes and heat capacity variations can be monitored alongside mass

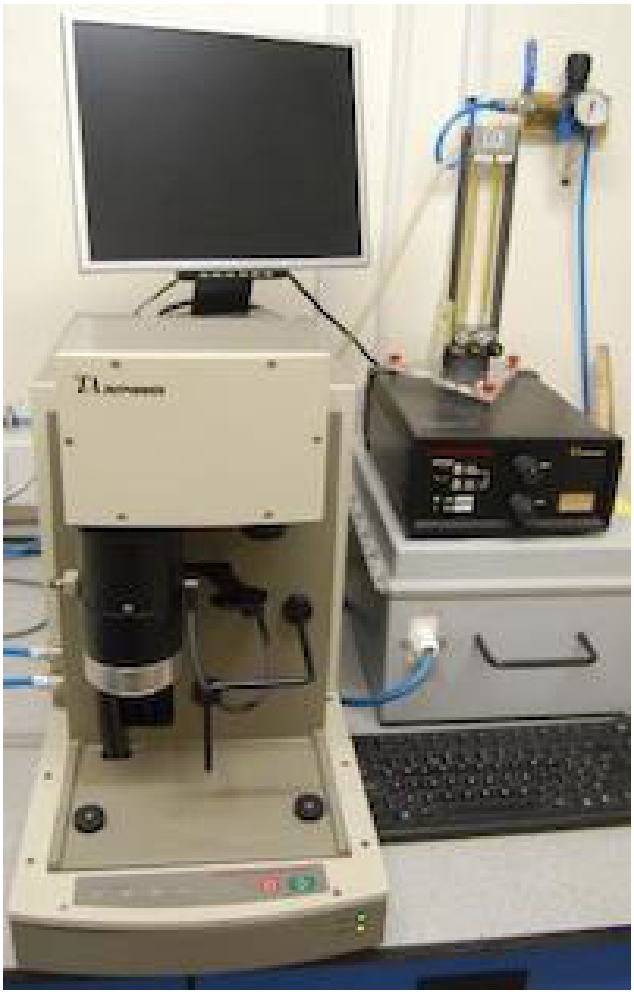


Figure 6. Thermogravimetric analysis apparatus.

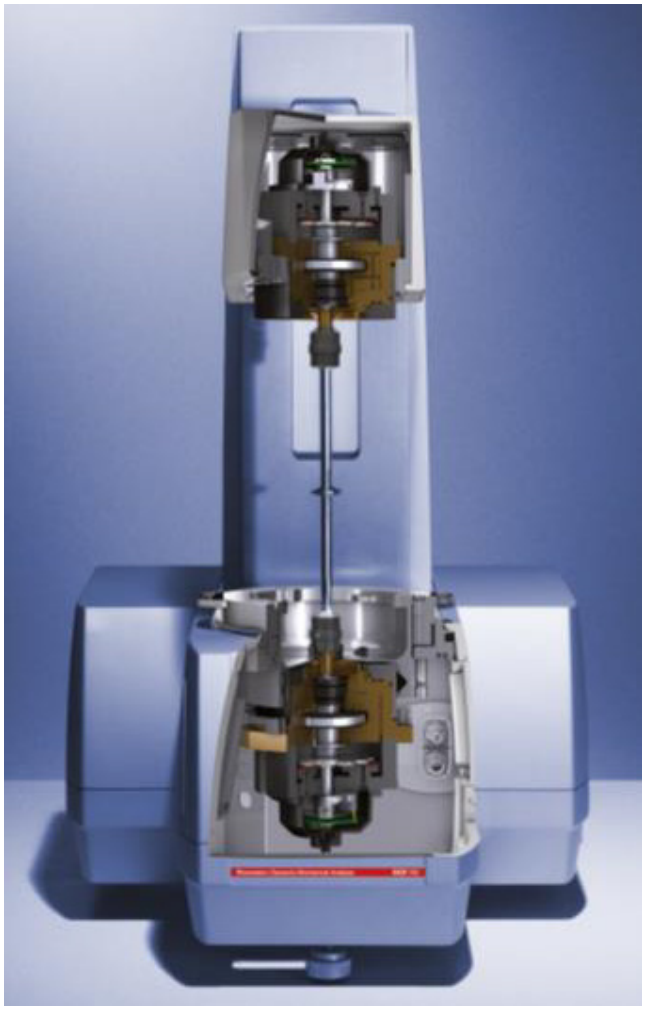


Figure 7. DMA instrument.

changes, allowing simultaneous analysis of thermal decomposition and phase transitions.

3.3 Dynamic Mechanical Analysis (DMA)

To study DMA property, the test center - Advanced Polymer Design and Development Research Laboratory (APDDRL), part of the CIPET Bangalore Aerospace division facility, was provided, where the samples were tested. Figure 7 shows the Dynamic Mechanical Analysis (DMA) instrument, operated according to ASTM D 4065[36]. DMA evaluates the mechanical properties of polymers under varying temperature, frequency, and strain. It measures viscoelastic parameters such as storage modulus (E'), loss modulus (E"), and damping factor (tan δ), revealing important information about material behaviour, including glass transition temperature (Tg) and relaxation processes. This technique is essential for understanding polymer structure-property relationships and optimising material performance in various applications. The sample dimension adopted for the DMA test was - 63.5 mm x 12.7 mm, with a thickness of 3 mm and Table 3 indicates the test conditions incorporated for DMA test on the prepared specimens.

Table 3. DMA test conditions

`Sl. No	Test Conditions	Units/ Range
1	Load	10N
2	Frequency	1Hz
3	Amplitude	1 mm
4	Rate of heating	2 ^{o}C/min
5	Temperature range	25 ^{o}C to 150 ^{o}C.

5.0 Results and Discussion

5.1 DSC Analysis of Hybrid Composites

The Differential Scanning Calorimetry (DSC) test results are provided in Table 4 and Figure 8. DSC Curves of Hybrid Composites (a to c) give insight into the thermal transitions and heat absorption of the three hybrid composite materials. DSC measures how much heat is required to raise the temperature of a sample, which is crucial in understanding the thermal stability and curing behaviour of polymer composites.

5.1.1 Onset Temperature (Start of Thermal Degradation / Transition)

- S-Ec/Al_2O_3 $_{10}$ has the highest onset temperature (393.54°C), indicating the best thermal stability among the three.
- C-Ec/Al_2O_3 $_{10}$ starts transitioning at a much lower temperature (304.26°C), suggesting it's less thermally stable.

5.1.2 Peak Temperature (Maximum Reaction Rate)

- This is the point at which the reaction (e.g., curing or decomposition) occurs most rapidly.
- S-Ec/Al_2O_3 $_{10}$ again shows the highest peak temperature (396.68°C), confirming its superior heat resistance.
- C-Ec/Al_2O_3 $_{10}$ shows the lowest (278.23°C), meaning it reacts (or degrades) faster and earlier when heated.

5.1.3 End Set Temperature

- The temperature at which the thermal event is completed.
- Follows the same trend: S-glass > E-glass > Carbon fibres, confirming overall thermal resilience of S-glass-based composite.

5.1.4 Heat of Reaction (Enthalpy Change)

- C-Ec/Al_2O_3 $_{10}$ absorbs the most heat (46.97 J/g), indicating a more intense thermal transition—possibly due to higher energy absorption during curing or breakdown.
- S-Ec/Al_2O_3 $_{10}$ shows the lowest (29.08 J/g), possibly due to a more gradual or stable thermal transition.

5.1.5 Analysis

- S-Ec/Al_2O_3 $_{10}$ (S-glass fibres composite) demonstrates the best thermal stability.
- C-Ec/Al_2O_3 $_{10}$ (Carbon fibre composite) shows lower thermal stability but higher heat absorption.
- E-Ec/Al_2O_3 $_{10}$ (E-glass fibres composite) sits between the two in both thermal stability and heat absorption.

5.2 TGA Analysis of Hybrid Composites

Thermogravimetric Analysis (TGA) test results for the hybrid composites in Table 5 and 6 with Figure 9. TGA Curves of Hybrid Composites (a to c), we will examine the residual mass (%) and temperature, which reflect the thermal stability and decay characteristics of each composite.

5.2.1 Understanding TGA

- Residual mass (%) indicates how much solid material remains after decomposition—often linked to the filler content (e.g., alumina) and the thermal stability of the reinforcement/matrix.
- Decomposition temperature (here, all around 876–880°C) marks the point at which significant mass loss has ended.

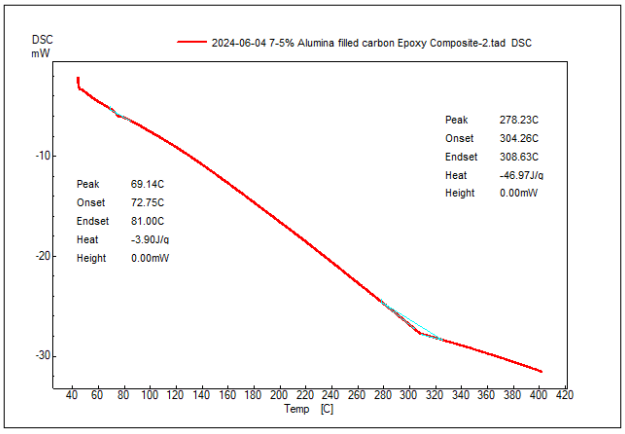
From Table 5, all composites degrade at similar high temperatures, but C-Ec retains more mass, aligning with TGA outcomes. S-Ec peaks highest (415.7°C) in DTA but has the lowest residual mass, indicating fast or complete thermal breakdown post-transition.

5.3 Dynamic Mechanical Analysis of Hybrid Composites

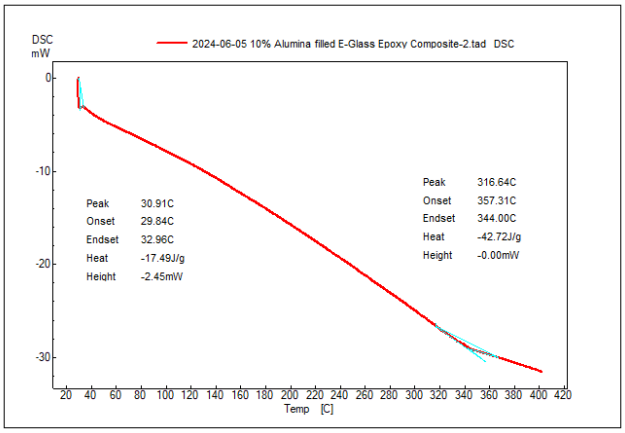
The Dynamic Mechanical Analysis (DMA) results are in Table 7 and Figure 10. DMA Curves of Hybrid

Table 4. Differential scanning calorimetry of hybrid composites

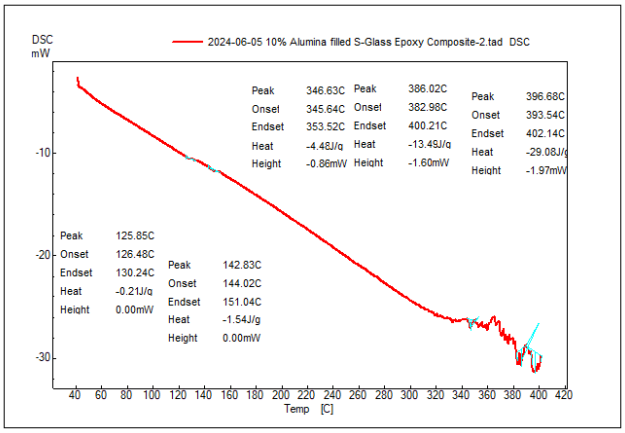
Sl. No.	Material Code	Peak Temperature(°C)	Onset Temperature (°C)	End Set Temperature(°C)	Heat J/g
1	C-E_c/ Al_2O_3 $_{10}$	278.23	304.26	308.63	46.97
2	E-E_c/ Al_2O_3 $_{10}$	316.64	357.31	344.00	42.72
3	S-E_c/ Al_2O_3 $_{10}$	396.68	393.54	402.14	29.08



(a). DSC graph of 10 % Al_2O_3 + C-E-C.



(b). DSC graph of 10 % Al_2O_3 + E-G-E-C.



(c). DSC graph of 10 % Al_2O_3 + S-E-C.

Figure 8. DSC Curves of Hybrid Composites (a to c).

Table 5. DTA results of the onset and peak temperature of composites

Sl. No.	Material Code	Onset Temperature (°C)	Peak Temperature (°C)
1	C-E_c/ $Al_2O_{3\ 10}$	383.7	413.5
2	E-E_c/ $Al_2O_{3\ 10}$	391.8	413.8
3	S-E_c/ $Al_2O_{3\ 10}$	379.5	415.7

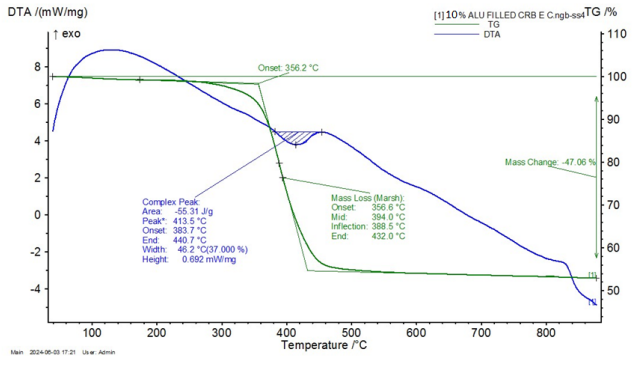
Table 6. TG results of residual mass and temperature of Composites

Sl. No.	Material Code	Residual mass (%)	Temperature (°C)
1	C-E_c/ $Al_2O_{3\ 10}$	47.06	880
2	E-E_c/ $Al_2O_{3\ 10}$	42.03	880
3	S-E_c/ $Al_2O_{3\ 10}$	21.16	876

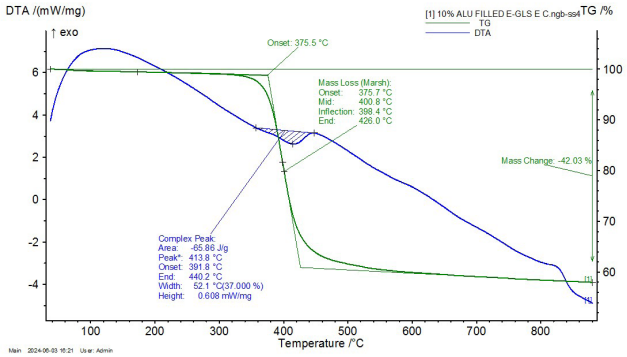
Composites (a to c) provide critical insights into the thermo-mechanical behaviour of the hybrid composites by evaluating how they respond to stress, temperature, and frequency. Here's a detailed interpretation based on the DMA properties measured:

5.4 DMA Parameters Explained

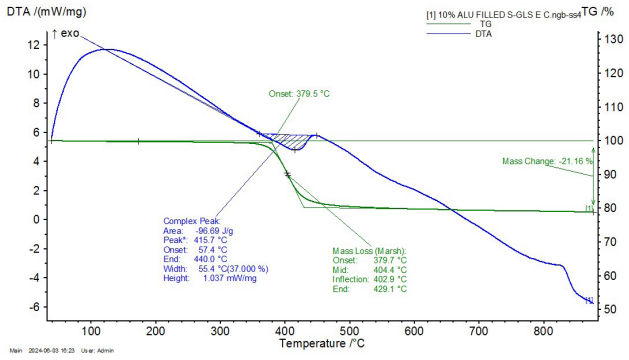
1. Onset Temperature (°C)
   - o Indicates temperature of transition from glassy to rubbery state.
   - o Higher values imply better thermal resistance in terms of stiffness retention.
2. Storage Modulus (MPa)
   - o Reflects the elastic or "stored" energy—i.e., stiffness.
   - o Higher modulus = better ability to store mechanical energy, thus higher stiffness.
3. Loss Modulus (MPa)
   - o Measures the viscous or "lost" energy—how much energy is dissipated as heat.
   - o Higher values suggest better energy-damping capacity.
4. Tan δ (Damping Factor = Loss Modulus / Storage Modulus)
   - o Indicates the material's damping behaviour: ability to absorb and dissipate energy.
   - o High Tan δ → Good damping (but possibly lower stiffness).
   - o Low Tan δ → Low damping, stiffer material.



(a) TGA graph of 10 % Al_2O_3 + C-E-C.



(b) TGA graph of 10 % Al_2O_3 + G-E-C.



(c) TGA graph of 10 % Al_2O_3 + S-E-C.

Figure 9. TGA Curves of Hybrid Composites (a) to (c).

Table 7. Dynamic mechanical analysis - properties of hybrid composites

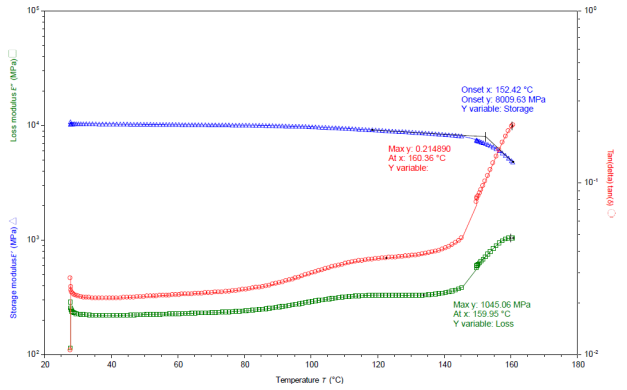
Sl. No.	Material Code	Onset Temperature(°C)	Storage Modulus (MPa)	Loss Modulus (MPa)	Tanδ
1	C-E_c/ $Al_2O_{3\ 10}$	74.17	12941.70	2199.94	0.575
2	E-E_c/ $Al_2O_{3\ 10}$	152.42	8009.63	1045.06	0.214
3	S-E_c/ $Al_2O_{3\ 10}$	76.44	6211.72	1122.07	0.557

5.4.1 C-Ec/$Al_2O_{3\ 10}$ (Carbon Fibres Composite)

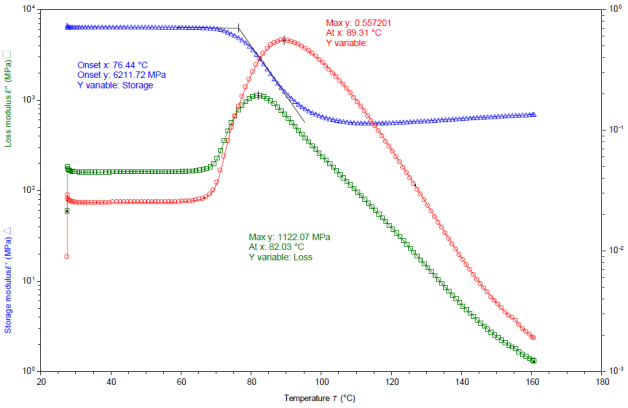
- Highest Storage Modulus (12941.70 MPa): → Most rigid and stiff, excellent mechanical strength.
- Highest Loss Modulus (2199.94 MPa): → Excellent at absorbing energy under dynamic loads.
- Highest Tan δ (0.575): → Strong damping capability; balances stiffness with energy dissipation.
- Lowest Onset Temp (74.17°C): → Loses stiffness earlier with heat; not ideal in high-temp applications.

5.4.2 E-Ec/$Al_2O_{3\ 10}$ (E-glass Fibres Composite)

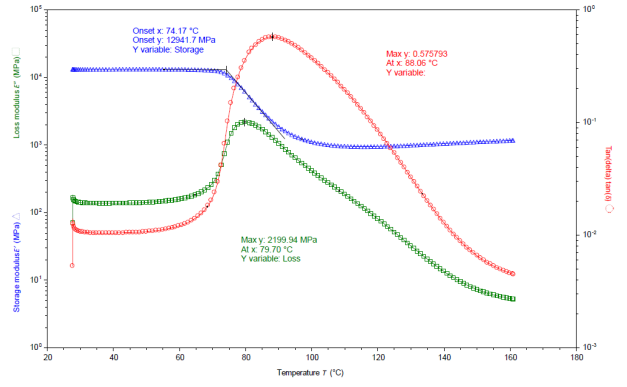
- Moderate Storage Modulus (8009.63 MPa): → Decent stiffness.
- Lowest Loss Modulus (1045.06 MPa): → Less energy dissipation; more elastic.
- Lowest Tan δ (0.214): → Least damping; responds elastically with minimal energy loss.
- Highest Onset Temp (152.42°C): → Excellent thermal stiffness retention; most thermally stable.



(a) DMA graph of 10 % Al_2O_3 + E-G-E-C.



(b) DMA graph of 10 % Al_2O_3 + S-E-C.



(c) DMA graph of 10 % Al_2O_3 + C-E-C.

Figure 10 . DMA Curves of Hybrid Composites (a) to (c)

5.4.3 S-Ec/Al_2O_3 $_{10}$ (S-glass Fibres Composite)

- Lowest Storage Modulus (6211.72 MPa): → Least stiff material.
- Moderate Loss Modulus (1122.07 MPa): → Reasonable energy dissipation.
- High Tan δ (0.557): → Good damping performance.
- Moderate Onset Temp (76.44°C): → Similar to Carbon composite; limited thermal stiffness.

6.0 Conclusion

The thermo-mechanical characterization of the hybrid —C-Ec/Al_2O_3 $_{10}$, E-Ec/Al_2O_3 $_{10}$, and S-Ec/$Al_2O_3$$_{10}$, through DSC, TGA/DTA, and DMA analyses, reveals key differences in performance, influenced by the type of synthetic fibre reinforcement.

- DSC Analysis shows that S-Ec/Al_2O_3 $_{10}$ exhibits the highest peak temperature (396.68 °C), indicating superior thermal transition stability, whereas C-Ec/Al_2O_3 $_{10}$ shows the highest heat absorption (46.97 J/g), suggesting a more intense thermal event or energy storage capability.
- TGA and DTA Results confirm that all composites degrade at similarly high temperatures (≈876–880 °C). However, C-Ec/Al_2O_3 $_{10}$ retains the highest residual mass (47.06%), highlighting its better thermal decomposition resistance—likely due to the carbon fibres and alumina filler synergy. In contrast, S-Ec/Al_2O_3 $_{10}$, despite showing the highest DTA peak temperature (415.7 °C), has the lowest residual mass (21.16%), indicating rapid breakdown post-thermal transition.
- DMA Results reveal that C-Ec/Al_2O_3 $_{10}$ possesses the highest storage modulus (12941.70 MPa) and loss modulus (2199.94 MPa), indicating excellent stiffness and energy dissipation. It also exhibits the highest Tan δ (0.575), suggesting superior damping behavior. However, its lower onset temperature (74.17 °C) reflects reduced thermal stiffness. In contrast, E-Ec/Al_2O_3 10 shows the highest onset temperature (152.42 °C), indicating the best thermal stiffness retention, but has lower damping capacity (Tan δ = 0.214).

7.0 References

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