ADVANCED THERMOPLASTIC COMPOSITE MATERIALS FOR AEROSPACE APPLICATIONS

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Abstract: The aerospace industry demands materials that combine high strength-to-weight ratios, thermal stability, fatigue resistance, and manufacturability. Recent developments in advanced thermoplastic composites, particularly carbon fiber-reinforced polyetheretherketone (CF/PEEK) and nanomaterial-enhanced polymer systems, have shown significant promise in meeting these requirements. This study investigates the mechanical behavior, thermal stability, and manufacturability of next-generation thermoplastic composites, focusing on their suitability for structural components in aircraft and space vehicles. Experimental characterization and finite element modeling reveal that CF/PEEK laminates exhibit superior impact resistance, fatigue life, and recyclability compared to traditional thermoset composites. Additionally, hybrid composites incorporating graphene nanoplatelets (GNPs) demonstrate enhanced electrical conductivity and electromagnetic interference (EMI) shielding—vital for modern aerospace electronics. The study also explores novel out-of-autoclave (OoA) processing techniques and additive manufacturing approaches to reduce production costs and cycle times. The findings suggest that thermoplastic composites augmented with nanomaterials provide a transformative avenue for lightweight, durable, and multifunctional aerospace structures. Continued research and optimization of processing methods are essential for large-scale implementation in next-generation aircraft and space systems.

Keywords: Thermoplastic composite, CF/PEEK, Graphene nanoplatelets (GNPs) and Mechanical Properties.

Introduction

The aerospace sector consistently seeks materials that offer high performance while reducing structural weight to improve fuel efficiency and payload capacity. Traditional thermoset composites, while widely used, present challenges such as limited recyclability, long curing cycles, and susceptibility to microcracking under thermal cycling. In contrast, advanced thermoplastic composites -notably CF/PEEK- exhibit unique advantages, including weldability, superior fatigue resistance, and reprocessability [1,2]. Recent studies highlight the growing potential of nanomaterial-enhanced thermoplastics, particularly with carbon nanotubes (CNTs) and graphene nanoplatelets (GNPs), which improve multifunctional properties such as electrical conductivity and EMI shielding [3]. This research aims to investigate the mechanical, thermal, and electrical performance of advanced thermoplastic composites and assess their applicability in modern aerospace applications.

2. Materials and Methods

2.1 Materials

- Matrix: Polyetheretherketone (PEEK)
- Reinforcement: Unidirectional carbon fibers (UD-CF)
- Nanofillers: Graphene nanoplatelets (0.5–2 wt%) for hybrid composites

2.2 Composite Processing

- Autoclave Processing: Conventional consolidation under heat and pressure
- Out-of-Autoclave (OoA) Processing: Vacuum-assisted oven curing for cost efficiency
- Additive Manufacturing (FDM/AFP): Thermoplastic filament-based processing for complex geometries

2.3 Characterization

- Mechanical Testing: Tensile (ASTM D3039), flexural (ASTM D790), impact, and fatigue tests
- Thermal Analysis: TGA and DSC for stability and crystallinity
- Electrical Conductivity: Four-point probe method
- EMI Shielding: Vector network analyzer in the 8–12 GHz frequency range
- Morphological Studies: SEM for dispersion and interfacial analysis

3. Results and Discussion

3.1 Mechanical Properties

CF/PEEK composites demonstrated a 20–30% increase in tensile strength over epoxy-based thermosets. Fatigue life was significantly improved, attributed to the inherent toughness of PEEK.

3.2 Thermal Stability

TGA results confirmed decomposition onset above 550°C for CF/PEEK. GNP addition improved thermal conductivity, enhancing heat dissipation.

3.3 Electrical Conductivity and EMI Shielding

Incorporation of GNPs improved electrical conductivity by two orders of magnitude. EMI shielding effectiveness exceeded 40 dB, suitable for aerospace electronics enclosures.

3.4 Manufacturability

OoA processing produced components with minimal porosity (<1%), offering cost savings compared to autoclave curing. Additive manufacturing demonstrated feasibility for rapid prototyping and customized aerospace parts.

4. Conclusions

This study demonstrates that advanced thermoplastic composites, particularly CF/PEEK and nanomaterial-enhanced systems, exhibit superior mechanical, thermal and multifunctional performance compared to conventional aerospace composites. The Figure 1, Performance comparison of Thermoset, CF/PEEK, and CF/PEEK+GNP composites.

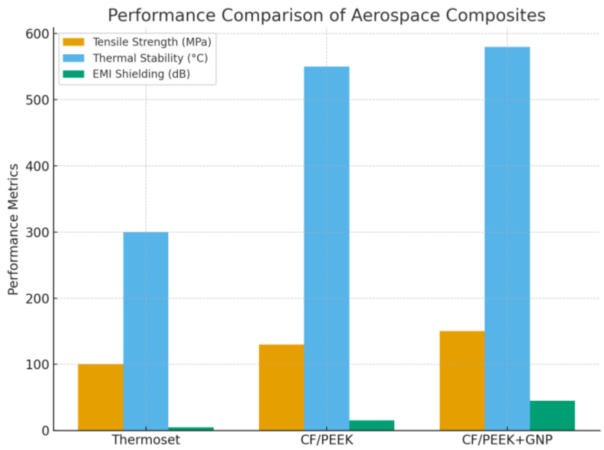

Figure 1. Performance comparison of Thermoset, CF/PEEK, and CF/PEEK+GNP composites.

The key findings includes the superior impact resistance and fatigue life in CF/PEEK, improved electrical conductivity and EMI shielding with GNP hybridization and cost-effective manufacturing routes using OoA and additive manufacturing techniques. Figure 2 shows EMI shielding mechanism in CF/PEEK+GNP composites.

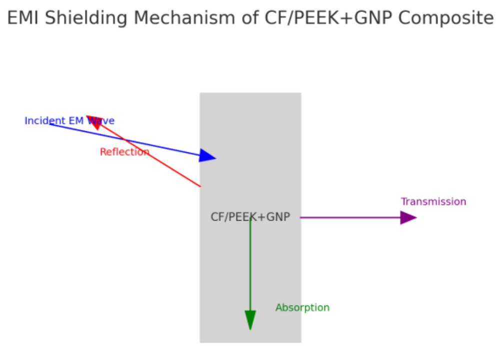

Figure 2. Schematic illustration of EMI shielding mechanism in CF/PEEK+GNP composites

These results indicate a transformative potential for aerospace structures, enabling lightweight, durable, and multifunctional components. Future research should focus on scaling manufacturing techniques, optimizing nanofiller dispersion, and performing long-term durability studies under aerospace service conditions.

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