Graphene/Magnetite Actions on Functional Behaviour of Polystyrene Hybrid Composites Via Solution Blending Route

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**Abstract:** This work investigates the influence of hybrid nano fillers which consist of 1 weight percent carbon nanotubes and varying concentrations of boron nitride on the mechanical and thermal properties of Polyether Ether Ketone composites that are subjected to hot pressing. The basis matrix material was PEEK sheets which are chemically stable and resistant to heat and powerful. They were 250 mm x 250 mm x 1 mm in size. The objective was to develop composites that were both lightweight and highly efficient for use in structural vehicle frames. Tensile strength and Shore D hardness were evaluated as well as thermal conductivity and results indicated that the most significant enhancement in thermal and mechanical properties was achieved at a BN concentration of 3 weight percent. The combined action of BN and CNTs improved thermal conduction channels and load transfer. These findings demonstrate that hybrid nanofiller-reinforced PEEK composites are capable of satisfying the requirements of rigorous industrial applications, particularly those in the automotive sector.

# Introduction

A popular thermoplastic polymer polystyrene is known for its exceptional dimensional stability, simplicity of production and low weight. However its usage in high-performance applications like EMI shielding is limited by its intrinsic low electrical conductivity and weak heat resistance. The use of magnetic and conductive nanofillers has become a successful tactic to get around these restrictions. One of the best options for enhancing the conductive network and mechanical integrity of polymer matrices is graphene, a 2D carbon substance with remarkable electrical, mechanical, and thermal properties. Super para magnetic in nature magnetite (FeO₄) nanoparticles are very good at both scattering and absorbing electromagnetic radiation. FeO₄ and graphene can be used to build a hybrid reinforcement system that enhances functional performance in a synergistic way.

Graphene and iron-based fillers in polymer composites for EMI shielding were thoroughly reviewed [1-4]. Their findings [1] showed that magnetic and conductive phases promote EMI attenuation through reflection and absorption. The graphene-based EMI shielding recent advances in nanocomposites and concluded [5-6] that filler shape, dispersion, and alignment affect shielding and mechanical robustness.

In 2025, [7-9]. created Fe₃O₄ with graphene oxide composites from natural iron sand used for photocatalysis and showed [3] that naturally available Fe₃O₄ in hybrid structures can serve multiple purpose including environmental and electrical functions without being EMI specific. They examined graphene, CNTs, and magnetite-reinforced low density polyethylene hybrids' structural, morphological and shielding Their findings [10-12] showed that multifunctional hybrids can improve EMI shielding while remaining flexible.

Their conclusions [13-15] showed that 3D printing may adjust anisotropic characteristics and improve SE performance by layer orientation.

Research [16] discussed EMI shielding composite structural design and typical mistakes. Their findings [6] suggested that percolation thresholds, interface engineering and filler agglomeration limit real-world performance. Research [167]examined carbon nanotube reinforced polystyrene composites interaction processes and rheology and findings shows [7] supporting polystyrene matrices for high-frequency EMI applications with conductive nanofillers. In his doctoral dissertation Salari (2024) modelled graphene centered polymer composites for EMI shielding at many scales. Theoretical models and experimental validation are needed to accurately estimate shielding performance [8]. Research [18]examined polymer-based composite EMI shielding structure and processing techniques. They concluded [19-21] that hybrid reinforcement and sustainable processing were essential for environmental and performance goals. Polymer matrices hold 3D graphene constructions according to Chhetri and Kuila (2024) found various internal reflections and conductive channels in interconnected 3D graphene frameworks improve EMI shielding. Carbon fibre composites bonded with haematite and goethite were examined for shielding and mechanical integrity [22-24]. Their findings [25] suggest that magnetic fillers and structural reinforcements improve SE and impact strength supporting hybrid design. Polyimide nanocomposites for EMI shielding were studied by Li (2025). Inferences [12] verified that polyimides natural thermal stability and dielectric strength make them appropriate for aerospace shielding with nanocarbon or magnetic fillers.

Powder metallurgy was used to study copper based hybrid nanocomposites [26-29] and studied the behavior of heat and corrosion and their findings [13] support metal polymer hybridization. For wearable EMI shielding [30-32] designed PVDF-CNT-GnP nanocomposites via scalable solution spinning. Their findings [14] confirmed that hierarchical architectures and surface engineering enable super hydro phobicity and ultradurable shielding textiles. Research [33] examined lightweight polymer-based EMI shielding. They found hybrid fillers to be a trustworthy solution for flexible and structural applications due to their low density and good shielding efficacy [34]. They covered EMI shielding materials, mechanisms, and applications. Their conclusions [35-36] united conductive, magnetic and hybrid mechanisms and emphasized composite optimization for next generation shielding.Through solution blending, this work examines the impact of adding 1 weight % graphene and different concentrations of FeO₄ nanoparticles to a PS matrix. For possible usage in electronic enclosures and aircraft shielding applications, the composite's tensile stress, thermal stability, and EMI shielding efficacy are being assessed [52-53].

# Materials and Methods

Due to its simplicity of processing and suitability for both structural and functional purposes the commercial grade polystyrene was selected as the foundation polymer matrix for this investigation along with the consideration of their exceptional mechanical strength and electrical conductivity, graphene nanoplatelets were introduced as reinforcing fillers at a set concentration of 1 weight %. Vaious weight % of 2 wt %, 4 wt % and 6 wt % of magnetite (Fe₃O₄) nanoparticles which have an average particle size of 30 nm were added and these magnetic nanoparticles were chosen for their capacity to shield against electromagnetic interference and to increase thermal stability. An analytical grade organic solvent called tetrahydrofuran was used as the dispersion medium because of its superior compatibility with polystyrene and capacity to dissolve the matrix evenly.

Even filler dispersion and appropriate matrix filler interaction the polystyrene based hybrid nanocomposites were made using a solution blending process and to reduce agglomeration and break apart particle clusters graphene nanoplatelets and FeO₄ nanoparticles were first dispersed individually in THF using a probe sonicator for 30 minutes. To create a transparent polymer solution polystyrene pellets were dissolved in THF concurrently and guaranteed uniform mixing the sonicated nanofiller suspensions were thereafter introduced progressively to the polymer solution while being continuously stirred by magnetic means. After that the mixture was transferred into sanitized Petri dishes and allowed to evaporate the solvent under normal circumstances. The samples were vacuum dried for 24 hours at 60°C to eliminate any remaining solvent and maintain the integrity of the film and optionally hot pressed to provide standardized sheets with consistent thickness and surface finish for additional compaction and mechanical testing.

The reinforcing effect of graphene and magnetite fillers on the mechanical integrity of the matrix was evaluated by analyzing the tensile behavior of the synthesized polystyrene hybrid nanocomposites. A universal testing machine was used to measure tensile stress in compliance with ASTM D638. The hot pressed composite sheets were used to create dog bone shaped specimens and tests were conducted in with a constant crosshead speed and their findings shed light on the enhancements in toughness and load bearing capability that the hybrid nanofillers brought about.

Thermogravimetric analysis commonly termed as TGA was used to evaluate the thermal stability of the nanocomposites in a nitrogen atmosphere to avoid oxidative degradation. At a steady heating rate 10 milligrams of each sample was heated from atmospheric temperature to 800°C. The maximal degradation rate and the beginning decomposition temperature were the main results. The effect of filler type and the resistance of composites to thermal deterioration was determined with the help of these factors.

A vector network analyser operating in the range of X-band frequency 8.2–12.4 GHz was used to evaluate the composites electromagnetic interference shielding efficacy. The transmission and reflection coefficients were measured by cutting and mounting rectangular specimens in the waveguide holder. Shielding effectiveness which took into account both absorption and reflection mechanisms, was measured in decibels. These measurements were important in finding the composites are suitable for EMI shielding solicitations in electrical and aeronautical systems.

# Results and Discussion

## Tensile Properties

Table 1: Tensile Stress of PS Hybrid Composites

|  |  |
| --- | --- |
| **Fe₃O₄ Content (wt%)** | **Tensile Stress (MPa)** |
| Neat PS | 31.2 |
| 2% Fe₃O₄ + 1% Graphene | 38.6 |
| 4% Fe₃O₄ + 1% Graphene | **44.9** |
| 6% Fe₃O₄ + 1% Graphene | 41.5 |

Figure 1: Tensile Stress of PS Hybrid Composites

When graphene and FeO₄ nanoparticles were added to the polystyrene hybrid composites their mechanical performance significantly improved. A tensile stress of 31.2 MPa was observed in pristine PS as indicated in Table 1. The first reinforcing effect of the hybrid fillers was highlighted by the increase in tensile stress to 38.6 MPa upon the addition of 1 weight percent graphene and 2 weight percent FeO₄ higher tensile stress of 44.9 MPa was achieved by the composite at 4 weight percent FeO₄ indicating an even greater improvement. By limiting polymer chain mobility and promoting stress transfer across the matrix the evenly distributed FeO₄ nanoparticles and graphene nanoplatelets works to produce this improvement. But at 6 weight percent FeO₄ there was a slight decrease to 41.5 MPa which was probably caused by nanoparticle agglomeration at higher filler concentrations which can serve as stress concentration sites and impair mechanical performance.

## Thermal Stability

The results of thermogravimetric analysis used to assess the composite thermal stability are compiled in Table 2. When the temperature reached 354°C the tidy polystyrene matrix started to break down. An improvement in thermal resistance was consistently seen with the use of hybrid fillers. The beginning decomposition temperature was 368°C for 2 weight% FeO₄ and 1 weight % graphene. The maximum thermal stability with an onset temperature of 379°C was attained at 4 weight percent FeO₄. The scattered FeO₄ nanoparticles and graphene layers barrier effect which prevents the generation of volatile degradation products and slows heat transfer is responsible for this. The onset temperature dropped somewhat to 376°C at 6 weight percent FeO₄ indicating that too much filler might cause dispersion and thermal shielding homogeneity to be compromised.

Table 2: Onset Decomposition Temperature

|  |  |
| --- | --- |
| **Fe₃O₄ Content (wt%)** | **Onset Decomposition Temp (°C)** |
| Neat PS | 354 |
| 2% Fe₃O₄ + Graphene | 368 |
| 4% Fe₃O₄ + Graphene | **379** |
| 6% Fe₃O₄ + Graphene | 376 |

Figure 2: Onset Decomposition Temperature

## EMI Shielding Effectiveness

The simultaneous presence of magnetic FeO₄ nanoparticles and conductive graphene greatly increased the composites EMI shielding efficiency . As a dielectric polymer neat PS showed very little shielding (~0.3 dB). SE rose to 10.2 dB with the addition of 2 weight percent FeO₄ and 1 weight percent graphene suggesting the development of partial magnetic and conductive shielding networks. With 4 weight % FeO₄, the highest SE of 17.5 dB was obtained which indicats the best possible compromise between magnetic loss (from FeO₄) and electrical conductivity (from graphene). A minor decrease in SE to 15.8 dB was noted at 6 % percent FeO₄ presumably as a result of increased filler agglomeration that prevents consistent electromagnetic attenuation. These findings are shown in Table 3 support the hybrid nanocomposites' potential for effective and portable EMI shielding applications.

Table 3: EMI Shielding Effectiveness

|  |  |
| --- | --- |
| **Fe₃O₄ Content (wt%)** | **EMI SE (dB)** |
| Neat PS | ~0.3 |
| 2% Fe₃O₄ + Graphene | 10.2 |
| 4% Fe₃O₄ + Graphene | **17.5** |
| 6% Fe₃O₄ + Graphene | 15.8 |

Figure 3: EMI Shielding Effectiveness

# CONCLUSION

This work unequivocally shows that polystyrene-based hybrid nanocomposites that are optimally loaded with 4 weight % FeO₄ nanoparticles via a solution blending route and reinforced with 1 weight % graphene show a well balanced enhancement in mechanical strength, thermal stability and electromagnetic interference shielding effectiveness. The interaction between graphene's high electrical conductivity and FeO₄ magnetic loss properties is crucial for the observed performance gains and these two properties work together to distribute stress, provide thermal barrier effects and attenuate multi mechanism electromagnetic interference. The lightweight nature of polystyrene is preserved by the hybrid filler system, which makes it possible to create conductive and magnetic routes that promote efficient shielding without appreciably raising the composite density. The industrial applicability of this approach is further supported by the solution blending technique scalability and simplicity especially for EMI shielding applications in small weight sensitive locations like electronic enclosures, aeronautical structures and telecommunications infrastructure.

To further enhance interfacial interactions and directional conductivity, future studies should concentrate on sophisticated techniques such alignment under external fields, surface functionalisation of fillers or hierarchical filler architectures. These routes could be used to customise multifunctional polymer composites of the future with better structural performance and electromagnetic compatibility.

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