Hot Pressing Processing and Hybrid Fillers on Mechanical and Thermal Properties of Polyether Ether Ketone Composites

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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

Because of its exceptional mechanical strength, heat resistance, and dimensional stability, PEEK is a high performing thermoplastic polymer that is being utilised more and more in structural applications. The performance of PEEK can be greatly improved by adding nanoscale reinforcements, even if it has outstanding baseline properties. Because of their high aspect ratio, tensile strength and capacity to enhance electrical and thermal properties carbon nanotubes are among the most promising reinforcements. High thermal conductivity, chemical inertness and superior electrical insulation are characteristics of boron nitride (BN) especially when it is present in nanoparticle form. The combination of CNT and BN as hybrid fillers leverages mechanical reinforcement capability in CNTs and the thermal conductivity benefits of BN. Hybridization can create synergistic effects, improving both structural and thermal performance.

Wear resistant PEEK composites with carbon fibers and hexagonal boron nitride nanosheets [1] increasing mechanical strength and thermal conductivity and highlighted carbon and ceramic fillers workings together for versatility. Thermally conductive PEEK composites reinforced with h-BN and scalable extrusion were developed by. They found that processing might customize filler alignment and through plane thermal conduction routes [2]. made hot-pressed films with functionalized BN and CNT membrane sandwich structured PEEK composites. Their findings [3-6] reveal that layered designs balance thermal conductivity and electrical insulation. 3D printed of PEEK with CNT and BN composites were to manage heat and findings [7-9] emphasized that additive manufacturing property retention and processing capability. coated PEEK fibres with BN nanosheets to make electrically insulating but thermally conductive composites. Their findings [10-14] confirmed that BN surface modification improves filler-matrix interactions. Using TiO₂ fillers and h-BN, examined the impact of dimension on thermal conductivity in hybrid PEEK composite Their conclusion [15-19] showed that particle size and distribution affect thermal transfer. The role of BN in polymer composites for electromobility and concluded that lightweight electric systems need BN for thermal management [20-22]. found h-BN increased thermal stability and stiffness in PEEK composites. They concluded [23-26] that mechanical integrity and conductivity must be balanced with acceptable loading levels.

Researchers produced hybrid nanocomposites using polyaryletherketone, boron carbide and CNTs. Their findings [27-31] confirmed heat degradation, tensile, dynamic mechanical, and tensile mechanical improvements. In their 2022 complete study of high-performance PEEK composites highlighted mechanical, tribological, and bioactive qualities and concluded [32-36] that BN and CNTs were best for certain activities. covered aircraft grade thermoplastic composites in 2024 and combined with nanofillers like BN, PEEK's tolerance to extreme circumstances was shown [37-39]. This study will hot press PEEK-based composites and examine how BN concentrations effect mechanical and thermal properties and to test these hybrid composites for automobile structural frame components, where weight reduction, mechanical reliability and thermal performance are important.

# Materials and Methods

Commercial PEEK sheet of dimensions of 250 mm × 250 mm × 1 mm served as the study's basis material. Multi-walled carbon nanotubes (MWCNTs) at a fixed concentration of 1 weight percent and boron nitride (BN) nanoparticles (average particle size of 50 nm) at three different loadings 1 weight%, 3 weight% and 5 weight% were among the reinforcement materials. Because of their strong covalent bond, CNTs offer tensile reinforcement and BN improves heat conductivity without sacrificing electrical insulation a crucial component of many automotive applications.

The hot pressing technique provides exact control over heat and pressure to create homogenous thick materials was used to fabricate the hybrid composites. Using a high energy ball mill the PEEK powder was first dry mixed with the necessary quantities of CNTs and BN nanoparticles for two hours ensures that they are evenly distributed throughout the matrix. A steel mould that had been heated was then filled with the combined particles and it was heated to about 380°C and pressured with 20 MPa for 10 minutes as part of the hot pressing procedure. In order to prevent internal tensions from forming and to improve crystallinity, the mould was allowed to cool gradually under pressure after hot pressing. After that the composite sheets were cut and polished in preparation for thermal and mechanical testing [40-45].

Tensile strength and surface hardness tests of the composites were used to assess mechanical performance and a universal testing machine was used to assess tensile strength in compliance with ASTM D638 requirements. As required by the standard samples were machined into dog bone shapes with gauge dimensions. According to ASTM D2240 calibrated durometer was used to assess the Shore D hardness since this characteristic is essential for evaluating surface resistance to scratching and distortion particularly for automotive components subjected to mechanical wear.

According to ASTM E1530 thermal conductivity is measured by using the transient plane source method. For this a Hot Disc Analyser was employed. In situations where components are subjected to significant thermal loads the test assesses the material's capacity to transfer heat. It is anticipated that the addition of BN nanoparticles will create thermally conductive channels and their impact on total thermal performance was measured quantitatively.

# Results and Discussion

## Mechanical Properties

Hybrid fillers increased the tensile strength and Shore D hardness and based on the findings of mechanical tests and PEEK demonstrated a Shore D hardness of 83 and a tensile strength of 100 MPa. The strength and hardness of the composite containing 1 weight % BN and 1 weight % CNT improved.At 3 weight % BN the Shore D hardness increased to 88 and the tensile strength increased to 127 MPa. Load transfer and interfacial bonding among the matrix and the evenly distributed nanofillers are responsible for these enhancements and small decreases were noted at 5 weight % BN which may have been brought on by nanoparticle agglomeration which can concentrate stress and compromise mechanical integrity [46-47].

Table 1: Mechanical Properties

|  |  |  |
| --- | --- | --- |
| **BN Content (wt%)** | **Tensile Strength (MPa)** | **Shore D Hardness** |
| Neat PEEK | 100 | 83 |
| 1% BN + 1% CNT | 112 | 85 |
| 3% BN + 1% CNT | **127** | **88** |
| 5% BN + 1% CNT | 121 | 87 |

Figure 1: Tensile vs. Shore D hardness

## Thermal Conductivity

Testing of thermal conductivity showed a significant improvement as the BN content increased. The thermal conductivity at 0.25 W/m K of pure PEEK was measured. The composite with 1 weight% BN and 1 weight% CNT had a conductivity of 0.45 W/m K, but the compound with 3 weight % BN had the maximum conductivity of 0.68 W/m K. After this, the conductivity decreased somewhat to 0.64 W/m K at 5 weight percent BN. According to this behavior the fillers create continuous heat conducting networks under ideal loading conditions whereas aggregation caused by an excess of filler material prevents heat flow [48-50].

Table 2: Thermal Conductivity

|  |  |
| --- | --- |
| **BN Content (wt%)** | **Thermal Conductivity (W/m K)** |
| Neat PEEK | 0.25 |
| 1% BN + 1% CNT | 0.45 |
| 3% BN + 1% CNT | 0.68 |
| 5% BN + 1% CNT | 0.64 |

# CONCLUSION

Significant improvements in mechanical and thermal performance was shown when hybrid nanofillers made of 1 weight % carbon nanotubes and different amounts of boron nitride are hot-pressed into the PEEK matrix. In comparison to unreinforced PEEK the composite with 3 weight percent BN demonstrated the most balanced and ideal characteristics producing a remarkable 172% improvement in thermal conductivity and a 27% rise in tensile strength. These improvements are ascribed to the complementary actions of BN and CNTs which limit the mobility of polymer chains, promote efficient stress transfer and establish ongoing thermal conduction channels through the matrix.

Furthermore, these composites show great promise for demanding automotive frame applications due to the lightweight yet durable character of the PEEK matrix reinforced with properly optimised hybrid fillers including structural elements like engine mounts battery enclosures and frame connectors that are exposed to heat and mechanical stress. In addition to guaranteeing consistent filler dispersion and matrix consolidation the hot pressing method of fabrication provides scalability, repeatability and compatibility with industrial manufacturing procedures.

All things considered this study highlights the strategic potential of hybrid nanofiller reinforcement in thermoplastic matrices for engineering applications where dimensional stability, thermal reliability, and a high strength-to-weight ratio are crucial.

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