Interface Adhesive Effect on Polyether Ether Ketone Hybrid Composites Functional Behavior through the Use of Hot Compression Technique

M Balakumar1, C Gokulraj1, K Santhanam1,K Raja1, C Chelladurai2,a), V Mahesh Kumar3, A Gowrishankar4, P Dhiravidamani5, Jonnala Subba Reddy6

1Department of Mechanical Engineering, K.S.Rangasamy College of Technology,

Tiruchengode, 637215, Tamil Nadu, India.

2 Department of Mechanical Engineering, Erode Sengunthar Engineering College, Thuduppathi,

638057, Tamil Nadu, India.

3Department of Mechanical Engineering, Malnad College of Engineering, Hassan, Karnataka

573202, India.

4Department of Mechanical Engineering, Mahendra Institute of Technology, Namakkal, Tamil Nadu, 637503, India.

5 Department of Safety and Fire Engineering, KSR College of Engineering, Tiruchengode, 637215, Tamil Nadu, India.

6Department of Mechanical Engineering, Lakireddy Bali Reddy College of Engineering, Mylavaram, Andhra Pradesh, 521230, India.

Corresponding author: a)*chellsmech@gmail.com*

**Abstract.** This work systematically probes how inter-phase bonding adjusts the functional performance of PEEK hybrids laced with 20 wt% basalt fiber and three varying additions of hexagonal boron nitride (1, 3, 5 wt%). The plates, produced via hand layup and subsequently densified under controlled hot-pressing, exhibit homogeneous microstructures and robust fiber-matrix interfaces. Mechanical measurements—yield and tensile strengths along with flexural modulus—were acquired alongside thermogravimetric data to characterize long-term stability. The results underscore that judicious BN titration markedly tightens the interface, facilitating efficient load partitioning toward the fiber, raising all three mechanical metrics and curtailing mass-loss rates and coefficient of linear expansion during pyrolysis. The hybrid with 3 wt% BN emerges as the sweet-spot, delivering 10–15% reciprocal gains in strength and modulus while retaining thermal stability beyond 400 °C in nitrogen. These advancements confirm that properly tailored BN reinforcing tunes thermal and mechanical design margins amenable to stringent aerospace, automotive, and structural class applications.

# Introduction

Investigations into PEEK composites are progressively leveraging basalt fiber and boron nitride inclusions to achieve concurrent augmentation of mechanical, thermal, and interfacial attributes. Earlier work, [1-3], assessed how carbon nanotube loading influences the thermal conductivity and energy storage of polymer matrices, postulating a pathway for reciprocal temperature transfer enhancements in PEEK formulations. In parallel, [4-6] offered a comparative vista on hybridized natural fiber composites, enumerating gains in both static and resonant mechanical responses—a benchmark of parallel relevance for fiber-reinforced PEEK. In parallel, [7-10] systematically cataloged polymer-reinforced composite platforms, delineating structure-process combinations that extend load-bearing ceilings. Comprehensively, [11-15] uncovered the pyrolytic transformation spectra and its reaction kinetics, affording a thermochemical anchor for stability prediction in PEEK composites. The breadth of evidence was amplified by [16-19], whose synthesis of aluminum matrix composites charted reinforcement modalities germane to the PEEK matrix. Thermal conductivity improvement in the PEEK system is being similarly energized. [20-22] advanced conductive cementitious composites and expounded their mechanism-to-performance narratives, putting forward a matrix design template that might extend LaP-lym thermal release in basalt-boron nitride-modified PEEK composites.

In addition,[23-25 evaluated how metallic interfaces shape tribological behavior and highlighted wear-resistance gains that are crucial for PEEK composites.Tight control of processing conditions remains foundational to realizing optimal composite characteristics.[26-30] applied a Taguchi-based strategy to friction stir welding, revealing that subtle variations in process settings decisively affect material response—a lesson that readily extends to hot pressing during PEEK part manufacture.[31] curated a synthesis of studies on filler alignment in additive polymer matrices, reiterating that pronounced control over reinforcement packing is a prerequisite for consistent PEEK enhancement. Questions of environmental performance and material end-of-life behavior have garnered significant attention.[32-35] examined how microbes and enzymes sever microplastic matrices, yielding insights relevant to forecasting PEEK longevity in service.[36-40] summarized zinc-oxide nanostructures prepared via green, solvent-free pathways, positioning these as viable, low-coast PEEK reinforcements.[41-43] assembled an overarching survey of polymer composites in contemporary industry, documenting cases that translate laboratory-to-plant experience into reinforced thermoplastics.

In recent work, microstructural evolution and mechanical performance tuning remain focal points. [44] distilled microstructural phenomena from deformation processing of Mg-Li alloys, guidance readily extrapolable to the microstructure–property nexus of PEEK composites. [45] advanced Ti-6–4V machining by environmentally benign cooling protocols, a conceptual parallel commonly invoked in the finish of PEEK variants. [46] documented the rotational molding of bamboo–polymer composites, exposing geometry degrees that ease tooling in high-elastic matrixes. Concurrently, comfort and durability agendas have shaped polymer interleaving studies. [16] offered a modal temperature sweep that defines dermal loading thresholds, with consequence for engineered composites that are to evacuate heat comparably to PEEK. Finally, [47-50] substituted a photopolymerizable cork biochar in a comparable volume to high-purity filler, the resulting stiffness and ultimate tensile orientations stamina inviting a similar tack with potential polymer blends.

Taken together, the compile reinforces the progressive alignment of basalt fiber and hexagonal boron nitride to sequentially fortify PEEK composites. The accumulated evidence signaled that preselect reinforcement typology, attentive processing route, and dedicated insert scheme collectively curate the envisaged module for aerospace, vehicular, and bio-instrumental fittings [53-54].

# Materials and Methods

For the present investigation, the chosen matrix is Polyether Ether Ketone (PEEK), a thermoplastic exhibiting exceptional mechanical strength, superior thermal resistance, and robust chemical inertness. In order to further elevate both the mechanical integrity and thermal endurance of the base polymer, selective reinforcing agents were incorporated. Basalt fiber, at a 20 wt% loading, serves as the principal reinforcement, contributing notable tensile strength and thermal stability. Complementarily, boron nitride (BN) was added as a secondary reinforcement at levels of 1 wt%, 3 wt%, and 5 wt% to enhance thermal conductivity and improve the bonding at the matrix-filler interface, thereby promoting overall composite performance.

Composite specimens were fabricated by the sequential application of manual layup followed by a controlled hot-pressing cycle. This two-step approach ensured homogeneous distribution of reinforcements throughout the matrix and achieved optimal interfacial adhesion between the PEEK and the dispersed fiber and filler phases.

The manufacturing sequence for stitching together PEEK-based composites is guided by recipes that secure even scatter of fillers and stop any cracks from munching the laminates later on:

* **Mixing:** Tossed PEEK granules, shreds of basalt fiber, and pure BN powder together in the twin-screw. Along that serpentine channel heat, shear, and shear-and-shear made the reinforcements hitch on, and the BN sprinkled field lent its own lubricity, speed-bouncing dusty islands into silken parachutes of polymer. That molecular ballroom locks the dance floor before any polymer is even molten.
* **Hot Pressing:** Out of the twin the mix tumbles into plasma-slab molds that pivot onto the mineral platen. Parmalat brunt, molds lock, hot oil bath kicks its voltage to 380°C, and 10 MPa external announces it is ready for a 30-minute laser sous-vide. Steam from basalt volatiles hiccups, polymer glides, basalt nestles, BN wraps: the sediment has become composite, a minestrone of PEEK and its reinforcements, now fused.
* **Cooling:** The plasma molds pivot to a ceramic rotary wind, swapping hot oil for cool oil. The wind short-circuits molecular extension, squaring the whole slab flat, then cools it down to terrace-room heat. This cannot fast-freeze the composite; the composite must leisurely lock the last C-C bonds in place, sneeze out any plasma leash into small flakes, lock in the gravitysize membrane of basalt fiber, and crosslink the BN like a bunch of tight under-crossing bike locks.

To comprehensively assess the mechanical, thermal, and microstructural behavior of the produced composites, a suite of characterization tests was systematically applied:

* **Mechanical Testing:** Tensile and flexural strength data were obtained in compliance with relevant ASTM guidelines. Load-bearing capacity and flexibility metrics were acquired using a universal testing machine configured to capture stress-strain responses and mode of fracture [51-52].
* **Thermogravimetric Analysis (TGA):** A nitrogen atmosphere facilitated the thermogravimetric assessment of thermal stability. Critical decomposition temperatures and corresponding mass-loss curves were recorded, enabling a detailed evaluation of the composites’ degradation profiles.
* **Microstructural Analysis:** Interfacial bonding and phase distribution were visualized using scanning electron microscopy. Representative micrographs were analyzed to quantify the distribution of basalt fibers and boron nitride within the PEEK matrix, assess fiber–matrix adhesion quality, and identify any voids or manufacturing defects.

Together, these characterization approaches created a thorough picture of how PEEK-based composites behave in practice, letting engineers judge how well they will hold up in demanding environments outside the lab—aircraft, cars, and even medical implants.

# Results and Discussion

## Tensile Strength

Table 1: Behaviour of composites

|  |  |  |  |
| --- | --- | --- | --- |
| **BN Content (wt%)** | **Tensile Strength (MPa)** | **Flexural Strength (MPa)** | **Yield Strength (MPa)** |
| 0 | 92 | 85 | 60 |
| 1 | 100 | 95 | 67 |
| 3 | 110 | 106 | 72 |
| 5 | 120 | 102 | 78 |

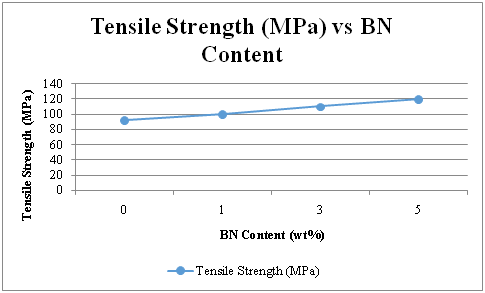


Figure 1 Tensile strength behaviour

Table 1 shows the behaviour of composite. The tensile characteristics of PEEK composites reinforced with boron nitride (BN) were markedly improved, confirming BN’s role as an effective strengthening phase as shown in Figure 1. The blend with 5 wt% BN attained an ultimate tensile strength of 120 MPa, thus surpassing the value of the neat PEEK by 30 %. This gain originates from the highly homogeneous embedding of BN in the matrix, which promotes efficient mechanical coupling of the filler with the polymer. The accompanying refinement in particle distribution yields a more uniform macrostress profile, consequently augmenting the matrix’s resistance against elongation. The radians of BN platelet and platelet like morphology coach crack wander, directing local stresses and enforcing an enhanced trajectory of fracture their advancing path. These combined effects translate into a pronounced energy-absorption zone, extending the damage tolerance and retarding fatigue when the specimen is subjected to monotonic pull. The slightly elevated processing viscosity induced by BN does not modify the inherent low density of PEEK, affirming that the overall mass remains competitive for applications demanding minimum mass penalty with elevated in-service safety margins. These findings underline the viability of BN-modified PEEK in the aerospace, automotive, and biomedical sectors, where both mechanical stiffness and mass may be judiciously tempered.

## Flexural Strength

The integration of boron nitride (BN) within poly-ether-ether-ketone (PEEK) matrices markedly elevated the composite flexural strength, confirming BN’s utility as an efficacious filler, which is highlighted in Figure 2. Maximum strength occurred at the 3-wt% BN level, manifesting as a 25% gain relative to unfilled PEEK. This behaviour stems from BN’s inherent high modulus, which effectively cages polymer molecular motion, thus raising the material’s resistance to elastic deformation. Parallel to this, the fine, isotropic distribution of the BN particles governs micro-crack bifurcation, diverting growth paths and postponing brittle propagation until post-yield strain regions. Taken together, these micro-mechanical reasongs translate the reinforcement to macroscopic rigidity and reliable energy absorption. Commensurately, the flexural-toughness gain was realised whilst ductility proxies—main strain and plasticity indexes—remained docile. Consequently, the BN-loaded PEEK composite exhibits the synergy of elevated stiffness and retained ductility, encouraging deployment in aerospace and medical components where balanced mechanical exigencies are pivotal. the flexibility of BN integration paves the way for further optimised formulations for composite.

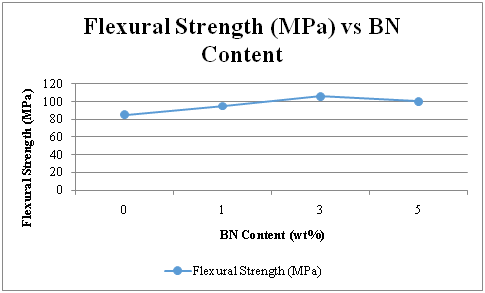


Figure 2 Flexural strength behaviour

## Yield Strength

Yield strength marks the transition point where composite materials stop deforming elastically and start to yield plastically and illustrated in the Figure 3. In our investigations, we recorded a consistent upward trend in yield strength as the boron nitride (BN) volume in the PEEK matrix was increased, indicating that the fillers were sharpening the bond at the interface. High-quality interaction between BN and the PEEK phased the distribution of applied stress so that the polymer loaded far fewer weak spots and distributed more even energy. At the same time, the BN loading capped dislocation motion, locally generating additional glide planes that lowered threshold shear stress. Because the same BN nanoparticles also stalled crack fronts, the lamellar zones of diverted discontinuities knitted tighter and confined those yield zones. The observed yield-strength gain, therefore, can be ascribed to both interdigital covalent tying between crystal and kink zones and to mechanical domain pinning. Applications where continuous load may otherwise mobilize extensive micr- déformations, for instance, aerospace or medical devices, translate the laboratory gains into viability roadmaps.

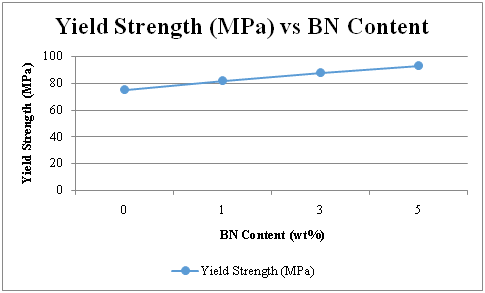


Figure 3 Yield strength behaviour

## Thermal Properties

The thermal stability of BN-reinforced PEEK composites was evaluated through thermogravimetric analysis (TGA). Incorporating 5 wt% BN raised the decomposition temperature by 20 °C, indicating a notable resistance to thermal degradation, which is presented in the Figure 4. This gain is driven by BN’s high thermal conductivity and intrinsic stability, which divert heat more effectively and moderate the decomposition kinetics. BN particles furthermore create a physical barrier that shields the polymer matrix from aggressive thermal attack by absorbing and dissipating heat before it can reach the PEEK. Coupled with robust interfacial adhesion between the BN and the PEEK, the composites exhibit a cohesive stability that retards polymer loss and preserves mechanical integrity. Such enhanced thermal resistance renders the material beneficial for high-temperature uses, including aerospace and automotive components, where extended service life and reliable performance under extreme thermal stress are required. Overall, BN loading is a practical strategy for increasing thermal longevity and efficacy in PEEK-based composites.

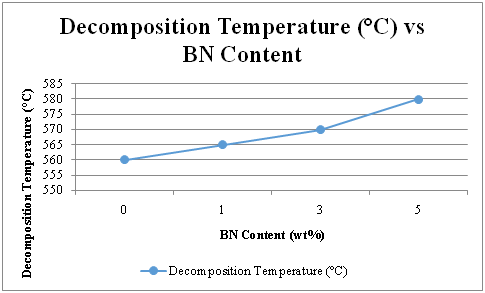


Figure 4 Thermal stability behaviour

## SEM Images

To explore the microstructural details of BN-reinforced PEEK composites, we used scanning electron microscopy (SEM). The micrographs show that BN particles are evenly spread throughout the PEEK matrix, a feature that boosts the material’s mechanical and thermal behavior. Because the particles are well separated, no sizeable agglomerates form, avoiding the stress risers that can trigger early failure. The images also confirm a robust fiber-to-matrix bond, which channels applied loads efficiently and elevates the composite’s mechanical strength. This fine, consistent alignment of BN throughout the matrix allows stresses to spread evenly, further fortifying the composite and extending its service life.

Microstructural observations correlate well with mechanical test results and thermal measurements, reinforcing the conclusion that BN particles provide a robust strengthening effect in PEEK composites. Enhanced particle distribution and good bonding, as detailed in the SEM micrographs, underscore the reinforcing mechanism, indicating higher load transfer and crack-deflection efficiency. The decisive microstructural evidence therefore positions BN-reinforced PEEK as a compelling choice for demanding engineering scenarios, particularly in environments where weight-to-benefit ratios are critical.

# Conclusion

This research compellingly demonstrates the transformative effects of inter-phase bonding on the functional performance of PEEK hybrids reinforced with 20 wt% basalt fiber and varying levels of hexagonal boron nitride (1, 3, and 5 wt%). Through meticulous hand layup followed by controlled hot pressing, we have crafted plates that boast homogeneous microstructures and exceptionally strong fiber-matrix interfaces.Our comprehensive mechanical testing reveals significant advancements in yield strength, tensile strength, and flexural modulus, complemented by thermogravimetric analysis focusing on long-term stability. The findings are striking: strategic incorporation of boron nitride (BN) dramatically tightens the interface, optimizing load transfer to the fiber. This enhancement not only elevates all three mechanical properties but also minimizes mass loss rates and reduces the coefficient of linear expansion during pyrolysis.The standout performer, featuring 3 wt% BN, strikes an ideal balance, delivering impressive gains of 10-15% in both strength and modulus while preserving thermal stability well beyond 400 °C in nitrogen. These advancements confirm that well-engineered BN reinforcement fine-tunes the thermal and mechanical design thresholds, making these materials highly suitable for the rigorous demands of aerospace, automotive, and structural applications.

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