# Effect of Addition of Micro-Sized Boron Nitride on the Mechanical Properties of the Polyester Composites

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*Abstract: Polyester-based composites reinforced with micro-sized hexagonal boron nitride (hBN) fillers were fabricated using a simple hand lay-up technique to investigate their mechanical performance. The filler content was varied from 0 to 40 wt.% to study its influence on tensile, flexural, compressive, and hardness properties. The results indicate that the incorporation of hBN significantly enhances the mechanical characteristics of polyester composites up to an optimum filler loading. Tensile and flexural strengths initially increase with hBN addition due to improved stress transfer and interfacial interactions, followed by a reduction at higher loadings because of particle agglomeration. In contrast, compressive strength and hardness show a continuous improvement with increasing filler content. The observed trends are correlated with microstructural features obtained from scanning electron microscopy. The developed composites demonstrate promising potential for structural and functional applications where improved mechanical strength and dimensional stability are required.*

*Keywords: Polyester composite; Hexagonal boron nitride; Mechanical properties; Tensile strength; Flexural strength*

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## I. INTRODUCTION

Nowadays, composite materials are everywhere as they extend their horizons in almost every branch of engineering and science. Polymer matrix composites (PMCs) are the best-established form of advanced composite materials. Of the two classes of polymers used as matrices, thermosets and thermoplastics, thermosets dominate the market for structural applications. Current research is being conducted on composite materials for thermoset as a matrix material. In the present work, polyester is selected as a matrix material and a ceramic material, i.e. boron nitride, is used as a filler material. Boron nitride has been used for the development of composite materials with polymer as a base matrix material in the past.

Agarwal and Chandrakar [1] employed epoxy as the base matrix, enhancing it with two distinct types of hexagonal boron nitride (hBN). Their approach involved integrating raw hBN in one set and silane-modified hBN in another, yielding two distinct categories of composite materials. The study demonstrated that silane-treated hBN significantly improved filler–matrix interfacial bonding compared to untreated fillers. As a result, tensile and flexural strengths showed notable enhancement, while water absorption was reduced due to improved interfacial integrity. Thermal conductivity increased with hBN loading and was further improved by silane treatment through better phonon transport across interfaces. Additionally, the dielectric constant and loss were favorably influenced, making the composites suitable for electronic and thermal management applications. Li et al. [2] used boron nitride nanosheets (BNNSs) and sphere BN (S-BN) in a polydimethylsiloxane matrix for the development of a new class of polymeric composites. The prepared BNNSs/PDMS composites exhibited an impressive thermal conductivity of 1.16 W/m-K when containing 35 wt. % fillers, a value approximately five times greater than that of pure PDMS and even surpassing the thermal conductivity of S-BN/PDMS composites. Yu et al. [3] improved the thermal conductivity of carboxylated acrylonitrile-butadiene rubber by adding the boron nitride filler, which was surface-modified with tannic acid. They decorate the surface of BN with noncovalent TA functionalization, while preserving the BN platelets' surface structure, ensuring the retention of high intrinsic thermal conductivity. Furthermore, this treatment enhances the compatibility between the filler and the matrix and promotes the formation of thermally conductive pathways within the composites.

Bashir et al. [4] used hexagonal boron nitride (h-BN) sheets that underwent functionalization using diverse amine compounds. The results demonstrate that both ortho-phenylenediamine (o-PDA)-treated o-PDA-BN and para-phenylenediamine (p-PDA)-treated p-PDA-BN when incorporated into TPU composites at a high filler loading of 45 wt. %, exhibit significantly higher through-plane thermal conductivity values of 2.06 and 1.96 W/m-K, respectively. This increase is attributed to the establishment of more effective thermal transport pathways. In contrast, composites treated with meta-phenylenediamine (m-PDA) (m-PDA-BN) at the same filler loading demonstrate a somewhat lower thermal conductivity value of 1.27 W/m-K. Wang et al. [5] studied the effect of micro- and nano-sized boron nitride particles on the microstructure, breakdown strength, and thermal and mechanical properties of epoxy resin. The analysis of breakdown strength and thermal conductivity revealed that when the composite consisted of 30 wt% micro-sized BN and 20 wt% nano-sized BN, the resulting BN/epoxy composite exhibited a substantial thermal conductivity of 1.52 W/m·K. Yu et al. [6] developed a highly thermally conductive polymer composite by building a two-level adjustable boron nitride (BN) network with leaf venation structure in an epoxy resin matrix. From the analysis of the thermal conductivity, they found that at a BN loading of 35.9 wt. %, the composite exhibits in-plane and cross-plane thermal conductivities of 10.20 W/m-K and 4.95 W/m-K, respectively. Zhou et al. [7] used a groundbreaking approach to achieving exceptional thermal conductivity in polymer composites, with substantial implications for various industries, especially electronics and thermal management. The method employed for fabricating the composites is particularly noteworthy.

Li et al. [8] present an innovative approach to enhancing the thermal conductivity of polymer composites, a development of significant importance for various applications, particularly in the field of thermal management. At a relatively low BNNS loading of 9.8 wt. %, the composite film achieved a substantial enhancement in thermal conductivity, reaching 1.62 W/m-K. He et al. [9] discussed a significant breakthrough in enhancing the thermal properties of composite materials. The researchers achieved high out-of-plane thermal conductivity by carefully aligning boron nitride nanosheets (BNNS) within an epoxy matrix using a magnetic field during the curing process. At a relatively low BNNS loading of 30 wt. %, the composite films demonstrated remarkable out-of-plane thermal conductivity values, reaching up to 7.85 W/m-K. Do et al. [10] explore the influence of different processing techniques on the thermal conductivity and mechanical properties of polymer composites containing hexagonal boron nitride (h-BN). The study is valuable as it provides insights into the most effective fabrication method for achieving the desired material properties. Jang et al. [11] offer a compelling approach to address the critical need for thermally conductive, electrically insulating materials in various applications. The study focuses on an eco-friendly and scalable method for fabricating such composites. The fabrication method presented in this research is based on a scalable solution-blending and melt-processing technique. The key advantage of this method is its eco-friendliness, as it avoids the use of toxic solvents and expensive equipment. He et al. [12] fabricated thermally conductive polymer composites using hexagonal boron nitride (hBN) as the primary filler. The study focused on optimizing filler dispersion within various polymer matrices to enhance heat transfer without compromising electrical insulation. The composites achieved an impressive thermal conductivity of 5.2

W/m·K, nearly 10 times higher than pristine polymers. Nie et al. [13] reported the development of advanced polymer composites using POSS-functionalized boron nitride nanosheets (BNNS-POSS) as fillers. By enlarging the nanosheet size and improving surface compatibility, the researchers achieved superior filler dispersion within the polymer matrix. Against this background, in the present work, a class of composite is fabricated in which the continuous phase is a thermoset polyester matrix and the discontinuous phase is micro-sized boron nitride particles. A simple hand lay-up method is used for the fabrication of composites with a wide range of filler content. The properties evaluated are tensile strength, flexural strength, compressive strength and hardness.

## II. MATERIALS AND METHODS

Unsaturated isophthalic polyester resin supplied by Carbon Black Composites, Mumbai, India, was used as the matrix material. Micro-sized hexagonal boron nitride powder served as the reinforcement. Methyl ethyl ketone peroxide (MEKP) was used as a catalyst, and cobalt accelerator was used to promote curing. The composites were fabricated using the hand lay-up technique. Predetermined amounts of hBN particles (10, 20, 30, and 40 wt.%) were mixed with polyester resin to ensure uniform dispersion. The accelerator and catalyst were added sequentially, followed by thorough mixing. The mixture was poured into silicon-coated moulds and allowed to cure at room temperature. After demolding, the specimens were post-cured for 24 hours before testing. Tensile, flexural, and compressive tests were conducted according to relevant ASTM standards using a universal testing machine. Hardness measurements were performed using a Shore-D hardness tester. For each composition, five specimens were tested, and average values were reported.

## III. RESULTS AND DISCUSSION

The variation of tensile strength of polyester/hBN composites with filler loading is shown in Figure 1. Neat polyester exhibits a tensile strength of approximately 52.5 MPa. With the incorporation of hBN particles, the tensile strength initially increases and reaches a maximum value of 63.8 MPa at around 25 wt.% filler loading.

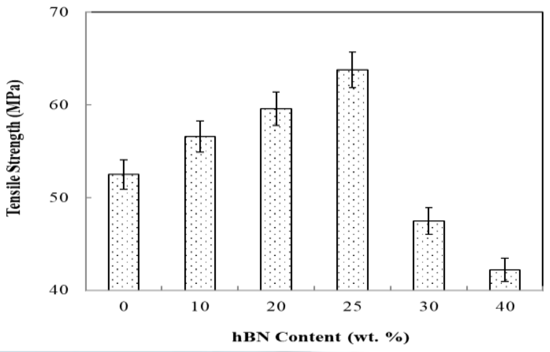

**Figure 1:** Tensile strength of polyester/hBN composites.

This improvement can be attributed to the effective stress transfer from the polyester matrix to the stiff hBN particles, provided that the particles are uniformly dispersed within the matrix. The presence of well-distributed micro-sized fillers restricts the mobility of polymer chains and delays crack initiation, thereby enhancing tensile resistance. However, beyond the optimum filler loading, a reduction in tensile strength is observed. At higher hBN contents (30–40 wt.%), particle agglomeration becomes prominent. These agglomerated regions act as stress concentrators and initiate microcracks under tensile loading. Additionally, the increase in void content at higher filler loadings weakens the matrix continuity, leading to premature failure.

Figure 2 illustrates the flexural strength variation of polyester/hBN composites with filler loading. Similar to tensile behaviour, the flexural strength initially increases with the addition of hBN and attains a maximum value of 81.2 MPa at approximately 22.5 wt.% filler content. The increase in flexural strength is mainly due to the composite system's increased stiffness and the hBN particles' resistance to bending-induced deformation. Under flexural loading, the outer surface of the specimen experiences tensile and compressive stresses simultaneously. At optimum filler content, hBN particles effectively bridge microcracks and hinder their propagation, resulting in improved load-bearing capability. However, at higher filler loadings, particle clustering and poor interfacial bonding reduce stress transfer, leading to a decline in flexural strength. The reduction is more pronounced in flexural testing compared to tensile testing due to the combined stress state involved in bending.

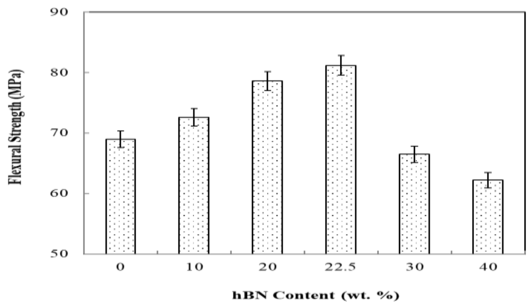

**Figure 2:** Flexural strength of polyester/hBN composites.

The compressive strength of polyester/hBN composites as a function of filler loading is presented in Figure 3. Unlike tensile and flexural properties, compressive strength shows a continuous and nearly linear increase with increasing hBN content. The compressive strength increases from 85.4 MPa for neat polyester to a maximum of 105.9 MPa at 40 wt.% hBN, corresponding to an improvement of about 24%.

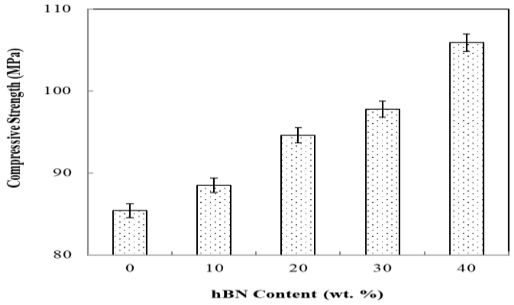

**Figure 3:** Compressive strength of polyester/hBN composites.

This continuous enhancement is attributed to the inherent high compressive strength of hBN particles and their favorable deformation behavior under compressive loading. In compression, the presence of microvoids and interfacial defects becomes less detrimental, as cracks tend to close rather than propagate. Moreover, the rigid hBN particles support the applied load and restrict plastic deformation of the polyester matrix. The increased filler content also reduces the free volume within the matrix, contributing to higher resistance against compressive deformation.

Figure 4 shows the variation in Shore-D hardness of polyester/hBN composites with filler loading. Neat polyester exhibits a hardness value of 77 Shore-D, which gradually increases with the addition of hBN and reaches a maximum value of 84 Shore-D at 40 wt.% filler content. This corresponds to an improvement of approximately 9.09%. The increase in hardness is primarily due to the presence of hard ceramic hBN particles, which offer significant resistance to localized plastic deformation during indentation. At lower filler loadings, the improvement in hardness is marginal because fewer particles are present near the surface. As the filler content increases, a greater number of hBN particles come into direct contact with the indenter, resulting in enhanced resistance to penetration. Additionally, the strong interfacial constraint imposed by the fillers limits the movement of polymer chains, thereby contributing to higher hardness values. Overall, the results demonstrate that the mechanical behaviour of polyester/hBN composites is strongly dependent on filler loading. While tensile and flexural properties exhibit optimum values at intermediate filler contents, compressive strength and hardness consistently improve with increasing hBN concentration. These trends are closely associated with particle dispersion, interfacial bonding, and the intrinsic mechanical characteristics of hexagonal boron nitride.

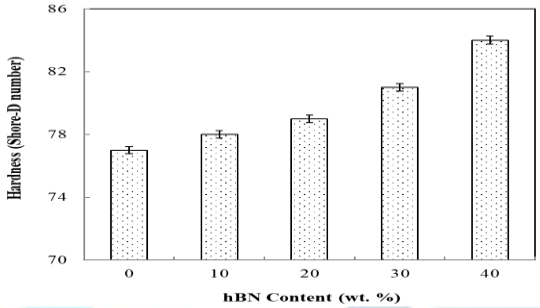

**Figure 4:** Hardness of polyester/hBN composites.

## IV. CONCLUSIONS

This experimental investigation has led to the following specific conclusions:

1. Incorporation of hBN in the polyester matrix increases the tensile strength of the material when the filler content is limited to 25 wt. % and decreases thereafter. For polyester/hBN composites, the maximum tensile strength obtained is 63.8 MPa. The elongation at the break of the matrix decreases with hBN loading. The minimum elongation at break is 1.2% for polyester at 40 wt. % hBN composites.
2. A similar trend is obtained during the evaluation of the flexural strength of the material. The flexural strength also shows an increasing-decreasing trend. However, the difference is that,

for flexural strength, the maximum value is obtained when the hBN loading is 22.5 wt. %. For the polyester/ hBN composite, the maximum flexural strength obtained is 81.2 MPa.

3. The compressive strength of the polyester/hBN composites increases linearly with the loading of the filler. The maximum compressive strength obtained is 105.9 MPa, for a filler loading of 40 wt. %.
4. The hardness of neat polyester is 77 Shore-D number, and the same increases to 84 with the addition of 40 wt. % micro-sized hBN. This shows an improvement of 9.09 % over unfilled polyester.

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