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Surface Hardness Evaluation of Hybrid Natural Fibre Reinforced Polymer Composites Using Shore D Testing

Sandeep Kongre[1], Kiran Kaware[2]
[1] Sandip University, Nashik, Maharashtra, India
[2]Adsul's Technical Campus, Ahilyanagar, Maharashtra, India

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ABSTRACT

Natural fibre reinforced polymer (NFRP) composites have emerged as sustainable alternatives to conventional synthetic composites because of their low density, renewable nature, biodegradability, and favourable mechanical performance. Among various characteristics, surface hardness plays a vital role in determining the wear resistance, scratch resistance, and service durability of composite components. The present study investigates the Shore D hardness behaviour of four hybrid natural fibre reinforced composite laminates fabricated with different stacking sequences of bamboo (B), sisal (S), kenaf (K), and flax (F) fibres. The laminates considered are B/S/K/F, S/K/F/B, S/B/K/F, and B/F/S/K. Shore D hardness testing was performed in accordance with ASTM D2240 using a calibrated durometer. The hardness values were measured by applying the indenter perpendicular to the composite surface, and multiple readings were recorded to ensure repeatability. The influence of fibre stacking sequence on the surface hardness of the hybrid laminates was evaluated and compared. The experimental results indicate that the arrangement of natural fibre layers significantly affects the indentation resistance of the composites due to the varying stiffness and surface characteristics of the constituent fibres. The study demonstrates that optimizing the stacking sequence can enhance the surface hardness of hybrid natural fibre composites without altering the constituent materials. The findings provide valuable insights for the design of eco-friendly composite structures intended for applications requiring improved surface durability, such as automotive interior panels, lightweight structural components, consumer products, and building materials.

Keywords: Natural fibre composites, Hybrid composites, Shore D hardness, ASTM D2240, Bamboo fibre, Sisal fibre, Kenaf fibre, Flax fibre, Stacking sequence, Surface hardness.

1. INTRODUCTION

Natural fibre reinforced polymer (NFRP) composites have gained considerable attention in recent years owing to their renewable nature, low density, biodegradability, cost-effectiveness, and favourable specific mechanical properties[1]. The increasing demand for sustainable engineering materials has encouraged researchers to replace conventional synthetic fibre composites with environmentally friendly natural fibre composites in various structural and semi-structural applications. Natural fibres such as bamboo, sisal, kenaf, and flax possess excellent strength-to-weight ratios and are abundantly available, making them attractive reinforcements for polymer matrix composites used in automotive interiors, construction materials, sporting goods, furniture, and consumer products[2].

Hybridization of natural fibres has emerged as an effective approach to overcome the limitations associated with single-fibre composites. By combining different fibres within the same laminate, it is possible to exploit the individual advantages of each fibre and achieve improved mechanical performance, dimensional stability, and durability. Bamboo fibre offers high stiffness and good impact resistance, sisal fibre provides excellent tensile strength and toughness, kenaf fibre contributes to lightweight characteristics and good mechanical properties, while flax fibre exhibits superior specific strength and low density. The arrangement or stacking sequence of these fibres within a composite laminate significantly influences its overall performance because each fibre layer experiences different loading conditions during service[3].

Among the various properties of composite materials, surface hardness is an important parameter that determines the resistance of a material to localized plastic deformation, indentation, scratching, and abrasion. Components with higher surface hardness generally exhibit improved wear resistance, dimensional stability, and longer service life under repeated contact loading. Shore D hardness testing is one of the most widely adopted methods for evaluating the hardness of rigid polymers and fibre reinforced polymer composites. The test is simple, rapid, non-destructive, and standardized under ASTM D2240, making it suitable for assessing the surface characteristics of composite laminates[4].

Several researchers have investigated the mechanical behaviour of natural fibre composites; however, studies focusing on the influence of fibre stacking sequence on the Shore D hardness of hybrid natural fibre composites

remain limited. Since the outermost fibre layers directly interact with the indenter during hardness testing, the arrangement of different natural fibres can significantly affect the measured hardness values[5], [6]. Understanding this behaviour is essential for designing composite structures with improved surface durability for engineering applications.

In the present investigation, four hybrid natural fibre reinforced epoxy composite laminates with different stacking sequences, namely Bamboo/Sisal/Kenaf/Flax (B/S/K/F), Sisal/Kenaf/Flax/Bamboo (S/K/F/B), Sisal/Bamboo/Kenaf/Flax (S/B/K/F), and Bamboo/Flax/Sisal/Kenaf (B/F/S/K), were fabricated and evaluated. Shore D hardness testing was carried out in accordance with ASTM D2240 using a calibrated durometer. The primary objective of this study is to examine the influence of fibre stacking sequence on the surface hardness of hybrid natural fibre composites and identify the laminate configuration that provides superior indentation resistance. The outcomes of this work are expected to contribute to the development of sustainable composite materials with enhanced surface performance for automotive, construction, and lightweight engineering applications.

2. MATERIALS AND METHODS

2.1 Natural fibre Materials

In the present investigation, four natural fibres, namely bamboo (B), sisal (S), kenaf (K), and flax (F), were used as reinforcements for the fabrication of hybrid natural fibre reinforced epoxy composites. These fibres were selected because of their renewable nature, low density, biodegradability, high specific strength, and excellent mechanical properties. Hybridization of these fibres improves the overall performance of the composite by combining the unique characteristics of each constituent fibre[7]. Bamboo fibre provides high stiffness and excellent structural stability, while sisal fibre contributes good tensile strength, toughness, and abrasion resistance. Kenaf fibre is lightweight and possesses favourable mechanical properties with good compatibility with polymer matrices. Flax fibre exhibits high specific strength and modulus, making it suitable for enhancing the structural performance of composite laminates. Four different fibre stacking sequences were considered in this investigation: B/S/K/F, S/K/F/B, S/B/K/F, and B/F/S/K, to evaluate the influence of fibre arrangement on the Shore D hardness of hybrid composites[7].

2.2 Matrix Material

The matrix material used in the present investigation was LY556 grade epoxy resin cured with HY951 hardener. The resin-hardener system was procured from Herenba Instruments, Chennai, Tamil Nadu, India. LY556 epoxy resin was selected because of its excellent mechanical strength, low curing shrinkage, superior adhesion to natural fibres, good chemical resistance, and ease of processing. HY951 is an amine-based curing agent that provides effective cross-linking with epoxy resin, resulting in improved mechanical properties and dimensional stability of the composite laminates. The epoxy resin and hardener were mixed according to the manufacturer's recommended mixing ratio to ensure complete curing and uniform dispersion throughout the laminate. The epoxy matrix effectively bonded the bamboo, sisal, kenaf, and flax fibres, facilitating efficient load transfer between the reinforcement and matrix during service. The Summary of the materials are given in Table 1.

Table 1. Materials used for composite fabrication

Material	Specification
Reinforcement fibres	Bamboo (B), Sisal (S), Kenaf (K), Flax (F)
Matrix	LY556 Epoxy Resin
Hardener	HY951
Supplier	Herenba Instruments, Chennai, Tamil Nadu, India

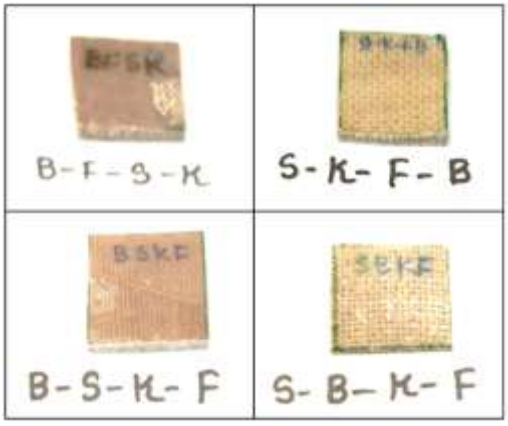


Figure 1 Various Fiber combinations

2.3 Shore D Hardness Testing

The Shore D hardness test was carried out to evaluate the surface hardness of the fabricated hybrid natural fibre reinforced epoxy composite laminates in accordance with ASTM D2240, the standard test method for determining the hardness of rigid plastics using a durometer. Shore D hardness is a measure of a material's resistance to localized indentation and is widely used to assess the surface strength, wear resistance, and durability of polymer composites. The hardness measurements were performed using a calibrated Shore D durometer consisting of a hardened steel indenter, a pressure foot, a calibrated spring mechanism, and a graduated scale ranging from 0 to 100 Shore D. During testing, the durometer was positioned perpendicular to the specimen surface, and uniform pressure was applied until the pressure foot made complete contact with the specimen. The hardness value was then recorded directly from the calibrated scale after the specified dwell time in accordance with ASTM D2240.
Prior to testing, the composite specimens were prepared with smooth and flat surfaces to ensure accurate indentation measurements. The dimensions and weight of the test specimens were measured using a digital vernier caliper and an electronic weighing balance, respectively. To improve the reliability and repeatability of the experimental results, three indentations were made at different locations on each specimen while maintaining sufficient spacing between adjacent indentation points to avoid the influence of previous impressions. The hardness values obtained from the three measurements were recorded, and the average Shore D hardness was calculated using the arithmetic mean.
The average Shore D hardness, H_{avg}, was determined using the following equation:

$$H_{avg} = \frac{H_1 + H_2 + H_3}{3}$$

Where: H_1 = Hardness value obtained from the first indentation, H_2 = Hardness value obtained from the second indentation, H_3 = Hardness value obtained from the third indentation.
The Shore D hardness values obtained from the experimental investigation were subsequently used to compare the influence of different fibre stacking sequences on the surface hardness characteristics of the hybrid natural fibre reinforced epoxy composites. Figure 2 shows the Shore D hardness test illustrating indenter penetration into the polymer composite specimen and the corresponding Shore D hardness measuring instrument.

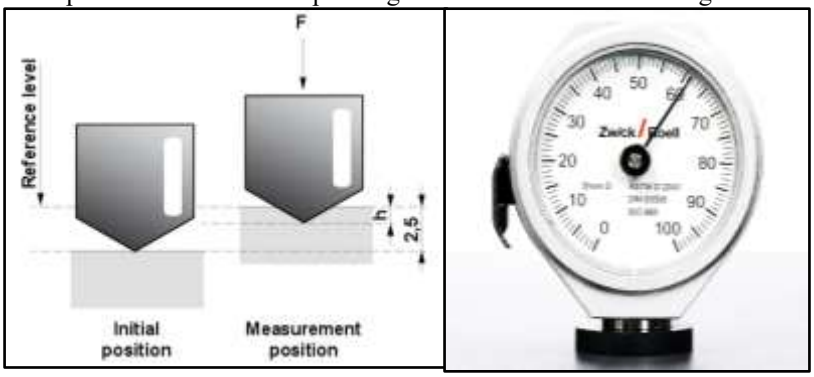


Figure 2 Shore D hardness test illustrating indenter penetration into the polymer composite specimen and the corresponding Shore D hardness measuring instrument.

3. RESULTS AND DISCUSSION

The Shore D hardness test was conducted in accordance with ASTM D2240 to evaluate the surface hardness of the fabricated hybrid natural fibre reinforced epoxy composite laminates. Shore D hardness represents the resistance of a material to localized indentation and is an important indicator of surface durability, wear resistance, and structural integrity. Three indentation readings were recorded for each specimen, and the average hardness value was calculated to improve the accuracy and repeatability of the experimental results. All specimens had nearly identical dimensions, with lengths ranging from 32.08 to 32.68 mm, widths from 31.98 to 33.46 mm, and thicknesses between 3.58 and 3.92 mm. The specimen weights varied from 3.949 to 4.720 g, indicating uniform fabrication of the hybrid composite laminates. The physical dimensions and weight of the test specimens are presented in Table 2. The Shore D hardness values obtained from three indentation measurements and their corresponding average values are presented in Table 3. The comparative average Shore D hardness values for all laminate configurations are illustrated in Figure 3.

Table 2. Properties of Shore D Hardness Test Specimens

Sr. No.	Material	Length (mm)	Width (mm)	Thickness (mm)	Weight (g)
1	S-B-K-F	32.48	32.18	3.84	3.998
2	B-S-K-F	32.08	32.48	3.86	4.720
3	S-K-B-F	32.36	31.98	3.92	3.949
4	B-F-S-K	32.68	33.46	3.58	4.032

Table 3. Shore D Hardness Test Results

Sr. No.	Material	Indentation 1	Indentation 2	Indentation 3	Mean Shore D Hardness
1	S-B-K-F	84	87	83	**85**
2	B-S-K-F	86	81	81	**83**
3	S-K-B-F	82	83	82	**82**
4	B-F-S-K	85	83	85	**84**

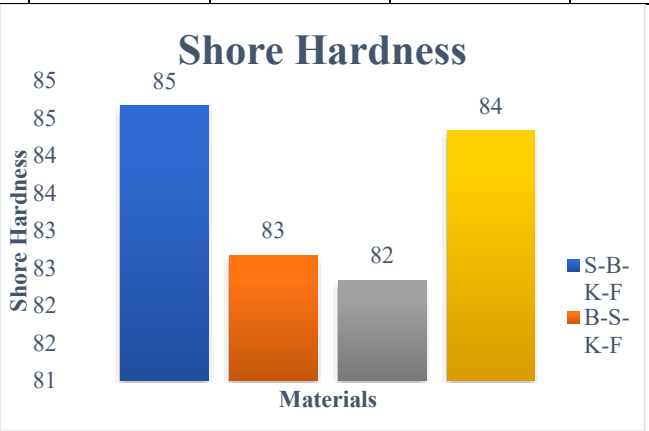


Figure 3. Comparative Analysis of Shore D Hardness of Hybrid Natural Fibre Reinforced Composite Laminates

The Shore D hardness results indicate that the fibre stacking sequence influences the surface hardness of the hybrid natural fibre reinforced epoxy composites. The average hardness values ranged from 82 to 85 Shore D, demonstrating that different fibre arrangements produce variations in resistance to localized indentation. Among the tested laminates, the S-B-K-F configuration exhibited the highest average hardness value of 85, indicating superior resistance to indentation. This may be attributed to the sisal fibre as the outermost layer, which provides a stiff surface and improves the load-bearing capability during indentation. The B-F-S-K laminate recorded the second-highest hardness (84), suggesting that bamboo fibre on the outer surface also contributes to enhanced surface hardness because of its rigid fibre structure.

The B-S-K-F and S-K-B-F laminates exhibited average hardness values of 83 and 82, respectively. The slight reduction in hardness can be attributed to differences in the internal fibre arrangement, which influence stress distribution and load transfer beneath the indenter. Overall, the results demonstrate that the outermost fibre layer and stacking sequence significantly affect the Shore D hardness of hybrid natural fibre composites. Proper selection of the fibre arrangement can improve the surface hardness and indentation resistance of the laminates, making them suitable for applications requiring enhanced wear resistance and surface durability.

4. CONCLUSION AND FUTURE SCOPE

The Shore D hardness test was carried out to evaluate the effect of fibre stacking sequence on the surface hardness of hybrid natural fibre reinforced epoxy composites. The experimental findings reveal that the arrangement of fibre layers plays a crucial role in determining the indentation resistance and overall surface durability of the composite laminates. All fabricated laminates exhibited high Shore D hardness values, demonstrating their potential for lightweight structural and wear-resistant engineering applications.

- The Shore D hardness of the hybrid natural fibre reinforced epoxy composites ranged from 82 to 85, indicating good surface hardness for all laminate configurations.
- The S-B-K-F laminate exhibited the highest Shore D hardness (85), followed by B-F-S-K (84), B-S-K-F (83), and S-K-B-F (82).
- The results confirm that the fibre stacking sequence has a significant influence on the surface hardness of hybrid natural fibre reinforced epoxy composites.
- Laminates with sisal and bamboo fibres positioned as the outermost layers exhibited greater resistance to indentation than the other stacking arrangements.
- The findings demonstrate that optimizing the stacking sequence effectively enhances the surface hardness of hybrid natural fibre composites, making them suitable for lightweight engineering applications requiring improved wear resistance, surface durability, and longer service life.

Future Scope

The present study demonstrates that the fibre stacking sequence significantly influences the Shore D hardness of hybrid natural fibre reinforced epoxy composites. Although the optimized laminate exhibited superior surface hardness, further investigations can be undertaken to improve the overall performance and expand the application potential of these sustainable composite materials. Future research may focus on the following aspects:

- Investigate the influence of different fibre volume fractions and laminate thicknesses on the Shore D hardness and overall performance of hybrid composites.
- Evaluate additional mechanical properties such as tensile strength, flexural strength, impact resistance, and wear behaviour of the optimized laminate to assess its comprehensive structural performance.
- Study the effect of chemical treatment of natural fibres on fibre–matrix interfacial bonding, surface hardness, and long-term durability of the composites.
- Perform microstructural analysis using Scanning Electron Microscopy (SEM) to correlate indentation behaviour with fibre distribution, matrix adhesion, and failure mechanisms.
- Explore the suitability of the optimized hybrid composites for automotive, construction, marine, and consumer product applications where lightweight, durable, and environmentally sustainable materials are increasingly required.

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