Research Article

Mechanical, Absorption and Swelling Properties of Vinyl Ester Based Natural Fibre Hybrid Composites

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Abstract
Natural fibres such as Banana (B), Jute (J) and Kenaf (K) were hybridized in different stacking sequences in vinyl ester. The composites with hybridized fibres were tested to evaluate their tensile, flexural and impact properties. Further, they were also tested for their water absorption and thickness swelling behavior. The hybridization of the fibre mats had an encouraging outcome on the mechanical behavior. The JKBKBJ hybrid composite possessed the maximum tensile strength (34.12 MPa) while maximum stiffness of 1.667 GPa was observed for the KBJJBK hybrid composites. The observations from the flexural testing indicated that the hybrid composites resisted the flexural load for higher displacement. All the hybrid configurations presented better impact strength over the composites reinforced with kenaf and jute fibres. Among the hybrid composites investigated, the KJBBJK hybrid composite displayed highest impact strength (12.32 kJ/m^2). The improved strength, stiffness and lower moisture absorption properties make the composites with hybridized fibres a potential candidate for the light weight structural applications.

Keywords: Vinyl ester, Hybrid composites, Mechanical properties, Water absorption, Thickness swelling

1 Introduction

Use of natural fibres in polymer-based composites has gained increasing interest in the recent decades. Thanks to their comparable functional properties, easy of fabrication, abundant availability and low cost [1]–[4]. According to many researchers, there is a rapid growth in natural fibre reinforced polymer composite (NFPC) industries all over the world. A growth rate of 10% is estimated in the next 5 years mainly due to the above said advantages [5]. For instance, the different natural fibres like bamboo, coir, kenaf, sisal and hemp find their application in various sectors such as the automotive, aerospace, construction, house hold appliances etc. [6]. Various types of natural fibre-based polymer composites have earned crucial role especially in the automotive industries. Many researches have been done by most of the car companies around the world to use the NFRP in their automotive structures specifically in seats, rear window, boot area, front and

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back doors and door panels. More than the interior parts of the car, for the exterior and middle section of the body fibre embedded polymers are used widely and found more beneficial [2].

Though natural fibres have more advantages and minimal environmental damage, they are less durable than the synthetic fibres [2]. On the other hand, a single type of natural fibre reinforcement cannot offer desirable properties required for the application. To overcome the issue, hybrid composites are developed, which is a blend of two or more extra materials like natural-natural or natural-synthetic fibres embedded in the polymer matrix.

A number of studies on the performance of hybrid composites to various loads and aging conditions exist in the literature. In a study, mechanical properties of banana/jute fibre reinforced hybrid composites were examined. Hybrid composites were fabricated with different weight ratios of jute and banana fibres in epoxy matrix. From their study it was evident that up to 50% of weight ratios of banana/jute fibres, the epoxy matrix composites exhibited enhanced mechanical behaviour and low moisture uptake [7]. Cavalcanti *et al.* [8] investigated the mechanical properties of jute, sisal and curaua fibres/epoxy matrix-based hybrid composites. The inclusion of other natural fibres in jute composites resulted in improved mechanical properties. In another research, Kumar *et al.* [9] developed vinyl ester based glass/flax fibre hybrids using vacuum aided resin transfer moulding technique. The outcome of the study indicated that the tensile properties of pure woven glass fibre composites are lower than the hybrids. Glass fibre at both ends in the laminates presented high impact strength related to other positions. Zin *et al.* [10] studied the outcome of varying fibres weights on the flexural performance of banana/pineapple leaf (PALF)/glass hybrids. Increased fibre weight enhanced the flexural strength of the hybrids. The banana/glass hybrid showed the least flexural strength and the PALF-glass hybrid had high flexural strength at 40 wt.%. The flexural modulus also followed the same trend. In a recent study, the influence of random orientation and knitting pattern on the mechanical behaviour of banana/kenaf hybridized polyester composites were studied. Hybrid laminates were fabricated by hand-layup technique with dissimilar patterns. It was found that the highest mechanical strength was noted for oriented composites. Furthermore, surface modification of the natural fibre appeared to make further enhancement in mechanical strength by improving the interfacial adhesion [11]. Senthilkumar *et al.* [12] explored the result of layering arrangements of different plant fibre mats in bio-epoxy based hybrid composites. They found that the inclusion of hemp mat in the outer layer and sisal at the inner layer exhibited high flexural strength and modulus amongst other hybrids. On the other hand, hybrids consisting both sisal and hemp mates in the outer and inner layers presented high impact properties.

Based on the above studies, this work aims in the fabrication and performance analysis of vinyl ester-based hybrid bio-composites. In this work, three natural fibres viz, banana, kenaf and jute in varying sequences with either of the fibres placed in core position and other two fibres in the outer skin position were stacked to fabricate hybrid composite materials. The fabricated laminates were exposed to mechanical characterization viz., tensile, flexural and impact properties. Further, the absorption and swelling behaviour of the composites was also evaluated.

2 Materials and Methods

2.1 *Materials*

Two directional interlaced fibre mats of Banana, Jute and Kenaf fibres were provided by Go Green Products, Chennai. Vinly Ester, Co naphthenate, Ethyl methyl ketone peroxide (MKEP) and N, N-dimethylaniline were supplied by Sakthi Fibre Glass, Chennai, India and were used as the matrix material, catalyst, accelerator and promoter respectively. The salient characteristics of the fibres and the vinyl ester matrix are shown in the Tables 1 and 2.

Table 1: Salient characteristics of the fibre mats used in this study [13], [14]

Properties	Banana Fibre	Jute Fibre	Kenaf Fibre
Density (g/cm^3)	1.35	1.3	1.2
Tensile Strength (MPa)	355	700	295
Young's Modulus (GPa)	33.8	26.5	53
Elongation (%)	5.3	1.5	1.5
Cellulose (%)	60–65	64.4	53.4
Hemicellulose (%)	19	12	33.9
Lignin (%)	5–10	11.8	21.2

Table 2: Characteristics of the Vinyl ester [15]

Properties	Vinyl Ester
Density @ 20°C (g/cm^3)	1.1–1.3
Viscosity (mPa.s) @ 20°C	350–400
Tensile Strength (MPa)	75
Tensile Modulus (GPa)	3.5
Elongation at Break (%)	2.8
Flexural Strength (MPa)	110
Flexural Modulus (GPa)	3.03

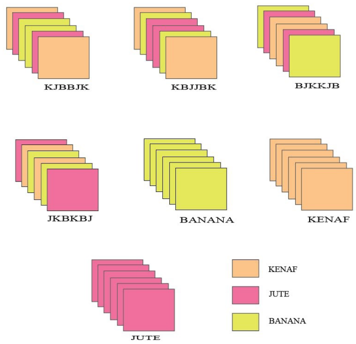

Figure 1: Layering arrangements of Banana, Jute and Kenaf fibre mats.

2.2 *Fabrication of hybrid composites*

The vinyl ester matrix solution was prepared by mixing 1% of catalyst, accelerator and promoter. Before fabrication of the composites the fibre mats were dried at 100°C for 20 min to eliminate the moistness. The Banana, Jute and Kenaf fibre mats were stacked based on chosen layering arrangement (shown in Figure 1 and abbreviated in Table 3) and was impregnated with vinyl ester matrix in a 30 cm^2 mould. The mould was then compressed at 250 bar and 100°C for 60 min in hot press. After removing from the mould, the laminates were also exposed to post curing at 100°C for 20 min. In order to have a comparison, composites with Banana, Jute and Kenaf fibre mats were also fabricated.

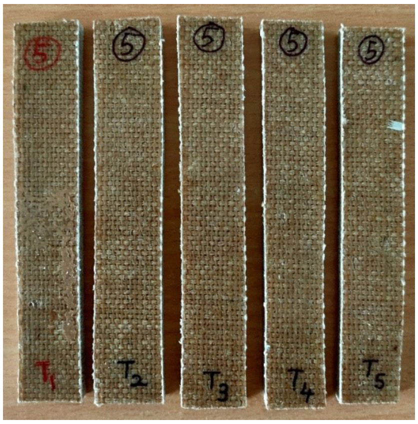

Figure 2: Sample specimen used in tensile test.

2.3 *Tensile test*

The tensile test was done as per the ASTM D3039 standard. For this an INSTRON 3382 Universal Testing Machine was used. The speed of the crosshead was maintained at 1.27 mm.min^{-1} while the gauge length as set to 50 mm. Five identical specimens with dimensions of 120 × 20 × 3 mm^3 were tested for each layering sequence and the mean values were presented. A sample specimen used in the tensile test is presented in Figure 2.

2.4 *Flexural test*

The three-point bending flexural tests was done as per the ASTM D790 standard. The conditions same as the tensile test was followed. Five identical specimens having dimensions of 120 × 20 × 3 mm^3 were tested for each layering sequence and the mean values were presented. A sample specimen used in the flexural test is shown in Figure 3.

Table 3: Abbreviations for the designated composites and hybrids

Abbreviations	Description	Fibre loading & Resin weight %
KJBBJK	Kenaf/Jute/Banana/Banana/Jute/Kenaf	Overall fibre loading –30 wt.% (Kenaf –15 wt.%, Jute –7.5 wt.% & Banana –7.5 wt.%) Vinyl ester –70 wt.%
KBJJBK	Kenaf/Banana/Jute/Jute/Banana/Kenaf	
BJKKJB	Banana/Jute/Kenaf/Kenaf/Jute/Banana	
JKBKBJ	Jute/Kenaf/Banana/Kenaf/Banana/Jute	
Banana	Pure Banana	
Kenaf	Pure Kenaf	
Jute	Pure Jute	

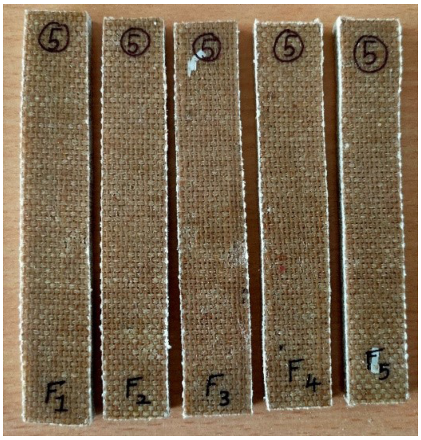

Figure 3: Sample specimen used in flexural test.

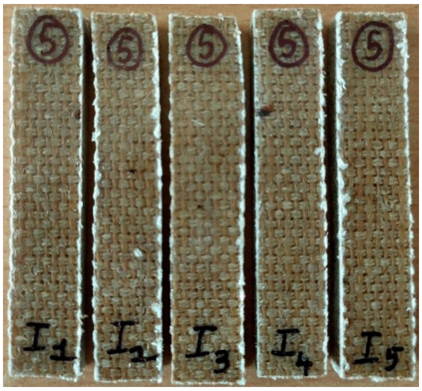

Figure 4: Sample specimen used in impact test.

2.5 *Impact test*

The impact test was conducted as per ASTM D256 standard by means of a Zwick/Roell HIT 5.5P impact tester. Five identical specimens having dimensions of 63 × 13 × 3 mm^3 were tested for each layering sequence and the mean values were presented. A sample specimen used in the impact test is presented in Figure 4.

2.6 *Water absorption*

The water absorption test was done as per the ASTM D570 standard, while the percentage water absorbed was estimated based on the equation below.

$$\textit{Water absorption}\ (\%) = \frac{W_n - W_d}{W_d}$$

The initial sample weight is W_d and weight after immersion is W_n.

2.7 *Thickness swelling*

The thickness swelling test was performed based on ASTM D570 standard. The percentage thickness swelling of the laminates was estimated based on the equation below.

$$\textit{Thickness swelling}\ (\%) = \frac{T_1 - T_o}{T_o}$$

T_o and T_1 represent the thickness before and after immersion, respectively.

3 Results and Discussion

3.1 *Tensile behaviour*

The tensile properties of the tested specimen based on the different layering arrangements are presented in Figures 5–7. From the Figure 5, it is evident that pure banana composites exhibited excellent tensile strength of 52.73 MPa while kenaf displayed the lowest strength of 9.41 MPa. The jute fibre reinforced composites displayed intermediate strength of 29.25 MPa. In case of hybrid composites, maximum tensile strength of the 34.12 MPa was observed for intercalated arrangement while the composites with kenaf as skin, jute in the subsequent layer and banana in the core (KJBBJK) displayed approximately 32 MPa followed by KBJJBK which possessed a strength of 23 MPa and 17 MPa for BJKKJB.

The % elongation of the composites shown in Figure 6 indicates that the layering sequence had considerable influence on the maximum elongation. Among the hybrid composites, composites with banana fibres in the skin (BJKKJB) displayed highest elongation followed by intercalated arrangement, KBJJBK and KJBBJK.

The advantage of hybridization can be noticed in Figure 7 which shows the Young's modulus of the investigated composites. Young's modulus was found to be in the following order: Intercalated > jute fibre composite > KBJJBK > KJBBJK > Banana fibre composite > Kenaf fibre composite > BJKKJB.

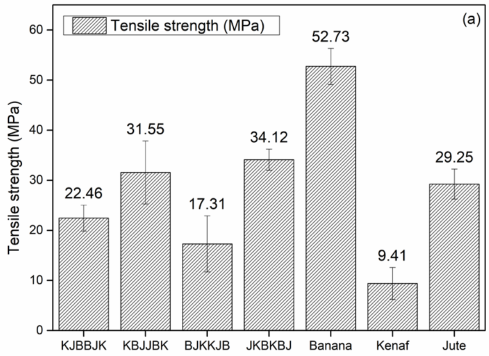

Figure 5: Tensile strength of investigated composites with individual fibres and various stacking sequences in the hybrid configuration.

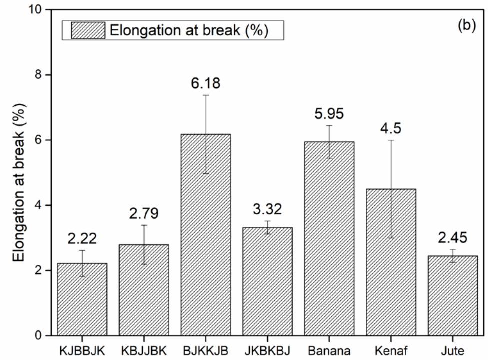

Figure 6: Elongation at break of investigated composites with individual fibres and various stacking sequences in the hybrid configuration.

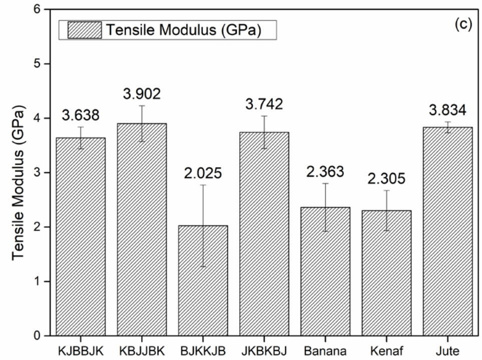

Figure 7: Tensile Modulus of investigated composites with individual fibres and various stacking sequences in the hybrid configuration.

Tensile properties of the composites is a fibre dependent property in which the inherent characteristics of the fibre such as type of fibre, fibre architecture, fibre aspect ratio, number of fibre layers, stacking sequence and fibre loading can have a predominant influence on the load bearing characteristic of the composites under tensile load. It can be noticed from Table 1 that banana fibre had the highest elongation at break. Similar characteristic was reflected by the pure banana composites and BJKKJB which has banana fabric as outer layers. On the other hand, tensile strength of the fibre reinforcement was highest for jute, followed by banana fibre and kenaf while stiffness for the jute fibres was the least among the employed fibres. Thus, the hybrid composites with various layering arrangements showed unique response to the applied load. The variation in tensile properties with respect to the stacking sequence was in corroboration to the observations from the recent studies on hybrid composites with other natural fibres [16], [17].

3.2 *Flexural behaviour*

The typical flexural load vs. displacement curve of pure kenaf, jute, banana fibre composites, and their hybrids is depicted in Figure 8. The displacement of the composites increased linearly with the applied load until fracture. The banana fibre- composites showed the maximum flexural strength among the pure kenaf, pure jute and hybrid composites. The reason for superior performance of the banana fibre under bending load is believed to be due to the greater cellulose concentration and a high L/D ratio possessed by banana fibre than the kenaf and jute fibres [12], [18].

Figure 9 depicts the flexural performance of pure composites and their hybrids. The results indicate least and maximum flexural strength for the pure kenaf and banana composites while their hybrids showed the intermediary flexural performance.

Due to the application of a three-point bending load, the top surface of the composites is exposed to compressive force, while the bottom layer is subjected to tension. Then, the axis-symmetric plane undergoes shear stresses. Thus, every composite sample will have two different failure modes, such as 1) bending failure and 2) shear failure which can influence the flexural strength of the composites [19]. In case of the hybrid composites, when the kenaf fibre was positioned at

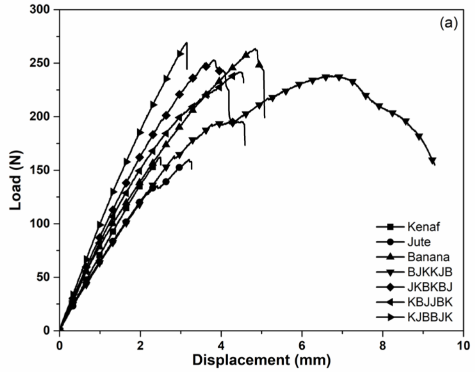

Figure 8: Flexural load vs. Displacement of investigated composites with individual fibres and various stacking sequences in the hybrid configuration.

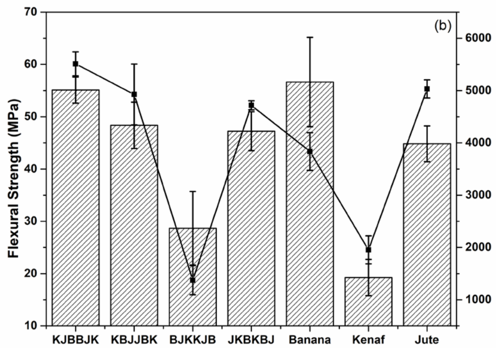

Figure 9: Flexural properties of investigated composites with individual fibres and various stacking sequences in the hybrid configuration.

the compressive & tensile sides with banana fibre at the core, the laminate exhibited higher flexural strength. This indicated that placing the kenaf fibre as skin layer and banana fibre at the centre improves the flexural properties. Conversely, when the banana fibre positioned in the skin, and the kenaf fibre at the core, flexural strength declined. Thus, altering the fibre layer sequences showed a significant change in the flexural properties. For instance, the flexural strength and flexural modulus of KJBBJK composites were 55.1 MPa and 5511.72 MPa, respectively, which was ~2-fold ~3-fold more as compared to BJKKJB. This leads us to a conclusion that outer fibre layers in the stacking sequence dictates the load bearing capability under the bending load. This observation is in agreement with a recent study in which the flexural properties of the investigated composites were dependent on the outer

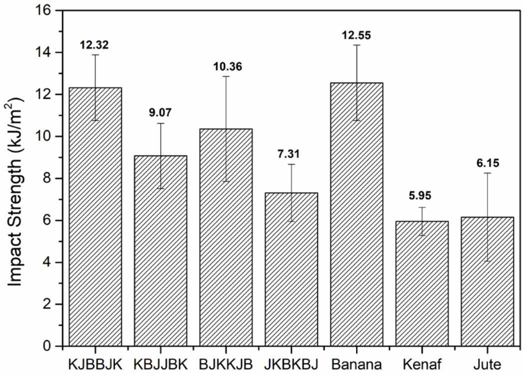

Figure 10: Impact strength of investigated composites with individual fibres and various stacking sequences in the hybrid configuration.

fibre layers in the stacking sequence [20], The trend for flexural modulus of pure and hybrid composites resembled that of the flexural strength. Thus, similar hypothesis could be applied to the flexural modulus.

3.3 *Impact behaviour*

The impact performance of pure kenaf, jute, banana fibres composites, and their hybrids is depicted in Figure 10. Banana fibre composites displayed the best impact strength among all the composites investigated. Kenaf fibre composites and jute fibre composites have lower impact strength than all the hybrid composites. However, on introducing banana fibres in different layering arrangements produced considerable improvement in the impact strength. The reason for this enhanced impact strength may be the fibre pull-out in the outer layers of the laminate which enables effective transfer of the impact energy to the core [12].

3.4 *Water absorption characteristics*

The moisture absorption characteristic of the composites relating to the immersion time is depicted in Figure 11. All the composites irrespective of the fibre type and stacking sequence absorbed moisture as could be noticed from the change in weight% over the immersion time. Moisture diffusion into the natural fibre based composites occurs due to the following reasons: 1) hydrophilicity of the biofibres which has natural affinity to moisture [21], 2) cellulose % of individual fibre which can influence the moisture

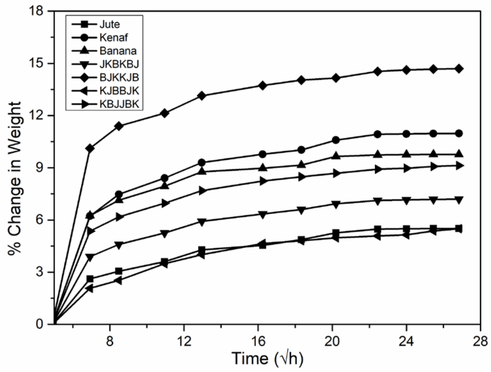

Figure 11: Moisture absorption characteristics of the investigated composites with individual fibres and various stacking sequences in the hybrid configuration.

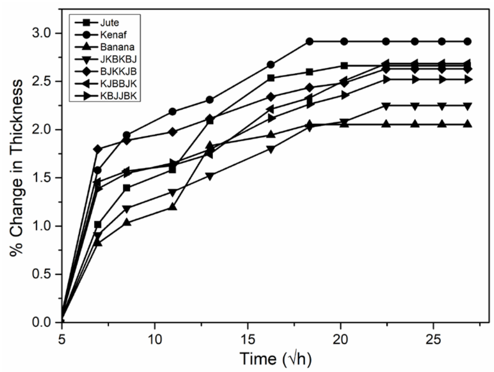

Figure 12: Thickness swelling characteristics of the investigated composites with individual fibres and various stacking sequences in the hybrid configuration.

absorption [22], [23] and 3) manufacturing defects like microcracks, voids and resin starvation areas in the composite [24].

The moisture diffusion occurred in two stages after the linear increase in the initial stage for both the composites with individual fibres and hybrid fibres. According to the literature, the two stage moisture absorption represents Non-fickian diffusion [25]. Among the composites with individual fibres, maximum % change in weight in due to moisture absorption was observed in the kenaf/vinyl ester composite (approximately 11%) followed by the banana/vinyl ester composite (approximately 10%) and jute/vinyl ester composite (approximately 6%). Introducing jute, kenaf and banana fibres altogether in the laminate was found to be beneficial for all stacking sequences except BJKKJB which showed the maximum change in weight of 16%. The moisture diffusion characteristic of the hybrids was dependent on the fibre layering arrangements. Hybrid composites exhibited maximum weight change in the following order: BJKKJB > KBJJBK > JKBKBJ > KJBBJK. The weight change due to moisture absorption in the hybrid composites was comparatively lower than the pure kenaf and banana fibre reinforced composites except BJKKJB.

3.5 *Thickness swelling characteristics*

The thickness swelling characteristics (shown in Figure 12) followed similar trend as moisture absorption with linear increase followed by two stage curve until saturation. The maximum change in thickness due to moisture diffusion into the composite was less than 3% for all the investigated composites. The intermediate values of thickness swelling % for the hybrid composites compared to the kenaf and banana fibre-based composites indicates good packing characteristic and compatibility between the subsequent fibre layers in the laminate. This is crucial for hybrid composites since the physical differences in terms of mat thickness, fibre diameter and fibre packing density within the mat between the distinctive fibre layers could create voids within the laminate. Presence of voids can lead to increased moisture diffusion into the composite due to capillary action leading to higher thickness swelling [21]. Increase in thickness % due to moisture absorption in the investigated composites occurred in the following order: Kenaf > Jute > KJBBJK > BJKKJB > KBJJBK JKBKBJ > Banana.

4 Conclusions

The mechanical properties, moisture absorption and swelling characteristics of hybrid composites having banana, jute and kenaf fibre mats in different stacking sequences embedded in vinyl ester matrix was investigated. The following conclusions were arrived: In the composites with the individual fibres, the banana composites exhibited the highest tensile strength of 52.73 MPa, while in hybrid composites, the JKBKBJ exhibited the highest tensile strength of 34.12 MPa followed by the KBJJBK with 31.55 MPa. All the hybrid composites except BJKKJB exhibited better tensile modulus compared to the pure composites.

It was observed that pure kenaf composites possessed the lowest flexural strength (18.07 MPa) and pure banana composites possessed the highest flexural strength (59.51 MPa); as expected, hybrid composites showed the intermediate flexural properties. All the hybrids exhibited better impact performance than the pure jute and kenaf composites. The maximum impact strength was exhibited by KJBBJK hybrid composites (12.32 kJ/m^2). In pure composites, Banana composites exhibited the maximum impact strength (12.55 kJ/m^2). Hybridization of jute, kenaf and banana fibres altogether in the composite was found to be beneficial in terms of water absorption characteristics for all stacking sequences except BJKKJB which showed the maximum change in weight of 16%. The maximum change in thickness due to moisture diffusion into the composite was less than 3% for all the investigated composites.

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