Effect of Hybridization on the Mechanical Properties of Pineapple Leaf Fiber/Kenaf Phenolic Hybrid Composites

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ABSTRACT: In this study, pineapple leaf fiber (PALF), kenaf fiber (KF) and PALF/KF/phenolic (PF) composites were fabricated and their mechanical properties were investigated. The mechanical properties (tensile, flexural and impact) of the PALF/KF/PF hybrid composites were investigated and compared with PALF/KF composites. The 3P7K exhibited enhanced tensile strength (46.96 MPa) and modulus (6.84 GPa), flexural strength (84.21 MPa) and modulus (5.81 GPa), and impact strength (5.39 kJ/m^2) when compared with the PALF/PF and KF/PF composites. Scanning electron microscopy (SEM) was used to observe the fracture surfaces of the tensile testing samples. The microstructure of the 7P3K hybrid composite showed good interfacial bonding and the addition of KF improved the interfacial strength. It has been concluded that the 3P7K ratio allowed obtaining materials with better mechanical properties (tensile, flexural and impact strengths) than PALF/PF and KF/PF composites. The results obtained in this study will be used for further comparative study of untreated hybrid composites with treated hybrid composites.

KEYWORDS: Pineapple leaf fiber, kenaf fiber, phenolic resin, hybrid composites, mechanical properties

1 INTRODUCTION

Population growth imposes an increasing demand for wood products in our daily lives, but because of current wood scarcity, such a demand cannot be fulfilled [1]. The future sustainability of wood reservoirs and environmental threats have forced the use of natural redeemable materials [2]. Huge amounts of agricultural crop residues are burned in the field because of agricultural mismanagement, which negatively affects the environment and causes air pollution [3]. These residues can be used as reinforcement or filler in polymeric materials, which can replace wood in different application areas such as construction industries. Natural fibers are easily available, cheap, renewable and biodegradable and they have good mechanical strength, low density and good acoustic properties [4]. In addition, fibers require low processing energy and impose fewer health hazards in polymer products and have a positive impact on their biodegradability [5–7] and thus help reduce carbon emissions [8].

Pineapple leaf fiber (PALF) and kenaf fiber (KF) are among the most readily available natural fibers in Malaysia, as well as other Southeast Asian countries and have the highest potential to be used as a reinforcement material in polymer composites [9, 10]. Incorporating waste fibers into polymers makes them very cost effective, enhances their thermal and mechanical properties and transforms them into green composites [11]. PALF has excellent mechanical properties due to its extraordinary chemical constituents, such as cellulose (70–82%), lignin (5–12%) and ash (1.1%) [12–14]. Like cotton and jute, kenaf (*Hibiscus cannabinus*) is an annual fast-growing plant. Morphologically, kenaf is a single, straight and branchless stalk made up of core fiber (75–60%) and bast fiber (25–40%). Bast fiber is extracted from the outer layer of the kenaf plant, whereas the inner portion is used for obtaining core fiber through the retting process [15]. Kenaf consists of 45–57% cellulose, 21.5% hemicelluloses, 8–13% lignin and 3–5% pectin [16]. Kenaf

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represents low density fibers, which is nonabrasive during processing and has good specific strength. It is used to produce light weight and high strength composites for many light-duty applications, such as in the automotive, textile, food packaging, sports and furniture industries. The matrix for the composite should be selected on the basis of the required applications. Phenolic composites are widely known for their use in construction materials and in components in the automobile sector due to their fire resistant characteristics. Natural fiber reinforced phenolic composites have the potential to work perfectly in making automotive parts. Such composites are also advantageous from an environmental point of view, and industries are more inclined towards recyclable components [17].

The hybridization of two natural fibers or a synthetic fiber with a natural one can improve the physical, mechanical and thermal properties of composites [18]. Natural fiber hybrid composites are very frequently used in the automotive industry. Hybrid natural fiber polymer composites can be designed and developed into materials with desired qualities, allowing achievement of such properties in a very economical way, which is very difficult to do with a composite containing only one type of fiber/filler dispersed in the matrix [19–21]. Besides, in hybrid composites, the strong points of one type of fiber could compensate for the drawbacks of another type of fiber, which balances the overall performance of the composite material and could be cost effective through appropriate material design [22]. Researchers investigated the hybridization of KF and wood flour fibers in various weight ratios produced by the injection molding process, and found that the KF/wood flour/PP hybrid composites had improved mechanical properties after adding the maximum proportion of kenaf fibers [19]. KF/glass fiber reinforced unsaturated polyester hybrid composites were manufactured using sheet molding compound processing in accordance with the concept of green composites and it was found that the KF/glass hybrid composite exhibited better mechanical properties and better interfacial bonding between the matrix and reinforcement compared to other composites [23]. Hybridized sisal/bamboo fiber and unsaturated polyester composites were investigated to determine the dependence of mechanical strength and water absorption on fiber length and weight fractions. The sisal/bamboo hybrid composites showed excellent tensile, flexural and impact strength and low water absorption at 20 mm fiber length [24]. Woven kenaf/Kevlar/epoxy hybrid composites were prepared by using the hand lay-up method in various weight fractions. The hybrid Kevlar/kenaf composites showed better mechanical properties compared to other hybrid composites and an excellent potential to be used for impact applications [25]. PALF and glass fiber (GF) hybrid composites were investigated to assess the relation between tensile and impact performance and various volume fractions of both types of fibers. Single fiber GF composites showed maximum tensile strength, but maximum impact was recorded for PALF/GF hybrid composites [26]. Abaca/raffia hybrid composites were fabricated by the hand lay-up process and their mechanical properties were investigated to find if such composites would be suitable for replacing conventional materials commonly used in the automobile and aerospace sectors. The researchers concluded that the hardness and shear strengths of the hybrid composites showed excellent improvement [27]. Oil palm empty fruit bunch (OPEFB) and glass fiber reinforced phenol formaldehyde hybrid composites were studied to achieve superior mechanical performance in various fiber fractions. The hybridization of glass fiber and OPEFB fiber led to better tensile, flexural and impact strengths of the composites after the glass and OPEFB fiber mats were oriented randomly as interlayers to enhance the hybrid effects [28].

Based on a literature review, the fabrication and characterization of PALF/KF filled phenolic (PF) hybrid composites has not yet been studied to our knowledge. The present work aims to develop PALF/KF/PF hybrid composites in different PALF and KF fractions and to characterize their mechanical properties (tensile, flexural and impact strengths). The properties of polymer composites are affected by fiber loading and hybridization of different types of fibers [29]. In this study, we discuss the effects of different fiber loading of KF and PALF in PALF/KF hybrid composites on their mechanical properties, such as tensile, flexural and impact strengths, and also investigate the fiber distribution, fiber pull-out and fiber/matrix adhesion qualities through SEM analysis of tensile fracture surfaces of the samples.

2 MATERIALS AND METHODS

2.1 Materials

Novolac-type phenol formaldehyde resin (Grade PH-4055) was supplied by Chemovate Girinagar, Banglore, India. PALF (*Ananas comosus*) was harvested in Indonesia and KF was harvested in Malaysia and retted.

2.2 Composite Preparation

For fabrication of the composites, PALF and KF were used as filler. PALF and KF were ground into particle sizes of 0.8–1 mm using a grinding machine; fibers

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were maintained at 6–8% moisture content. The composites developed, as well as their PALF and KF ratios in hybrid, are shown in Table 1. They were made by using the hand lay-up technique in a 15 × 15 × 3 mm stainless metal plate. The 3-mm-thick stainless metal plate was placed into a hydraulic pressure hot press at 160 °C temperature. The stainless steel plate was removed from the press after 8 min and allowed to cool at room temperature, and then samples were cut for testing according to ASTM standard.

3 CHARACTERIZATION

3.1 Tensile Test

The strength of pure PALF and KF composites and PALF/KF/PF hybrid composites were determined by using a 5kN Bluehill Instron universal testing machine. Tests were carried out according to ASTM standard D3039, using a 100 N load cell and 2 mm/min crosshead speed. The temperature was conditioned at 22 °C and the humidity to 50%. The specimens were thin rectangular strips of 120 × 20 × 3 mm width, length and thickness, respectively. The tensile strength and modulus values reported here correspond to the average of six samples.

3.2 Scanning Electron Microscopy (SEM)

A morphological investigation of the pure PALF and KF composites and PALF/KF/PF hybrid composites were performed with a Hitachi S-3400N scanning electron microscope (SEM). The SEM instrument was operated at an emission current of 58 μA and acceleration voltage of 5.0 kV; the working distance was set to 6.2 mm. Before SEM analysis, the samples were coated with gold. SEM allows microscopic analysis of broken cross sections of tensile samples on the basis of surface morphology and fiber/matrix relation.

Table 1 Formulation of PALF and KF composites and PALF/KF hybrid composites.

Type of composites	PF (wt%)	PALF (wt%)	Kenaf fiber (wt%)
PALF/PF	50	50	0
PALF/KF/PF (7P3K)	50	35	15
PALF/KF/PF (1P1K)	50	25	25
PALF/KF/PF (3P7K)	50	15	35
Kenaf/PF (KF/PF)	50	0	50

3.3 Flexural Test

Flexural tests of pure PALF and KF composites and PALF/KF/PF hybrid composites were performed using a 5kN Bluehill Instron universal testing machine at room temperature. Three-point bending tests were carried out according to the ASTM D790 standard [30]. Six specimens per test condition were tested. The crosshead speed was set to 2.0 mm/min for all tests.

3.4 Izod Impact Test

Impact strength of pure PALF and KF composites and PALF/KF/PF hybrid composites were measured using an Instron CEAST 9050 impact testing machine. For the Izod impact test, samples were cut to the dimension of 70 × 15 × 8 mm by a circular saw. For each type of composite, six identical samples were tested at ambient conditions according to ASTM D256 and their average load at first deformation was noted and tabulated as impact strength.

4 RESULTS AND DISCUSSION

4.1 Tensile Properties

Figure 1 shows the stress-strain behavior of pure PALF and KF composites and PALF/KF/PF hybrid composites. It was indicated that the increment of strain occurs when the stress is increased. The PALF/PF composite exhibited the lowest stress and strain, while the KF/PF composite showed the highest stress and strain, and the 3P7K hybrid composites ranked next to it with a slightly lower strain value. The 7P3K hybrid composite had an increased stress-strain value compared to that of the PALF/PF composite, which is explained by the fact that fiber has the capacity to

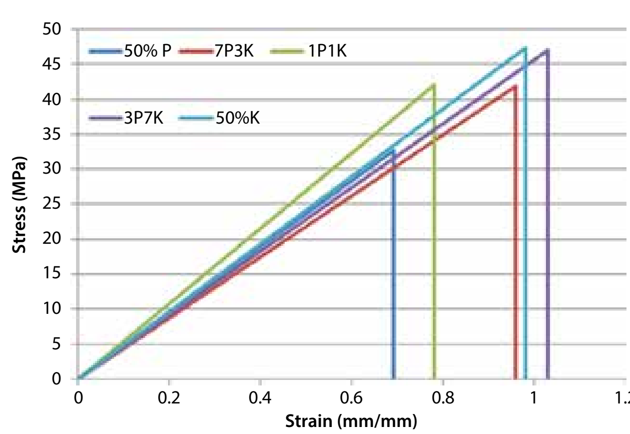

Figure 1 Tensile stress and strain curve of PALF and KF composites and PALF/KF hybrid composites.

carry the load and thus the stress is transferred from the matrix to the fiber loading [31]. In general, it shows that the percentage elongation of PALF composite is lesser than the hybrid composite as well as KF composites, which means that the hybrid composite withstands more strain than the single fiber composite before failure [32], the presence of KF contributed to an efficient load transfer from the matrix to the fibers. The 1P1K hybrid composite showed very low strain and stress value, very close to that of the 7P3K hybrid composite, which may be caused by some incompatibility within the fibers. Among all the hybrid composites, the 3P7K hybrid composite displayed a very good stress-strain response, which was similar to that of the 50% KF/PF composite, while the strain exceeded that of the KF/PF composite, because the KF composite not only presented enhanced mechanical strength, but also developed a brittle character [33]. Figure 2 illustrates the tensile strength and modulus of PALF/PF, KF/PF composites and those of the hybrid composites. It may be noted that the tensile strength and modulus of the hybrid composites were enhanced by increasing the KF ratio in the hybrid composition. The 3P7K hybrid composite showed the best tensile strength and modulus of 46.96 MPa and 6.84 GPa, respectively, among the hybrid composites; these values are very close to those for the KF composite. The tensile strength and modulus of the 7P3K hybrid composites were higher by 128.22% and 96.19%, respectively, than the corresponding values for the PALF/PF composite; while for the 1P1K hybrid composites, the same parameters achieved values which were higher by 128.8% and 94.87%, respectively, than those of the same PALF/PF composites. The performance of these hybrid materials is, however, exceeded by that of the 3P7K hybrid composite, which performed best with tensile strength and modulus values higher by 144.58% and 99.70%, respectively.

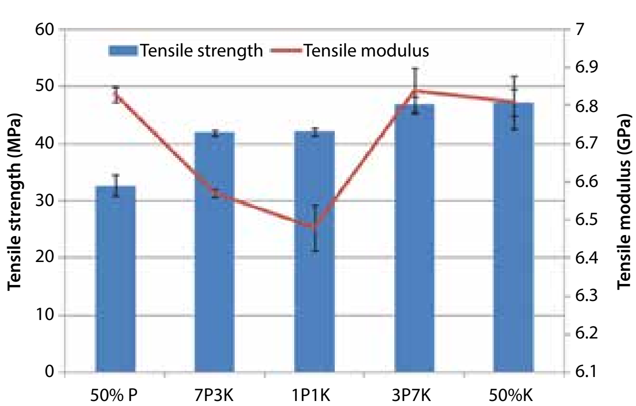

Figure 2 Tensile strength and modulus of PALF and KF composites and PALF/KF hybrid composites.

The properties of a hybrid composite are dependent on the properties of the reinforcement [34]. The mechanical properties of KF are higher than those of PALF. The extensibility of PALF is low compared with KF. When composite is deformed, both fibers bear load. However, when PALF undergoes failure, the stress is borne by the stronger KF till complete failure takes place. The fiber bundle theory is the study of tensile fracture in hybrid composites. According to this theory, weaker fibers (PALF) break first at normal strain, while stronger fibers hold the matrix and weaker fibers. Although fibers have different characteristics, they still distribute the load and contribute to making a hybrid composite stiffer [35, 26].

The improvement in the tensile strength and modulus of the 7P3K hybrid composite can be explained based on this theory, considering that the KF loading effectively transferred the load from the matrix. A number of studies [36, 37] that focused on fiber loadings in hybrid composites reported an improvement in the tensile strength of hybrid composites. The 1P1K hybrid composites exhibited low tensile strength and modulus, probably due to the hybrid ratio and the state of dispersion [26]. The presence of voids inside the composite samples also influences the tensile properties of composites [38]. The KF/PF composites showed good interfacial fiber/matrix bonding, while the 3P7K hybrid composite presented enhanced tensile strength and modulus because PALF was able to transfer the stress from the matrix, and due to this, the strain of 3P7K reached the highest value among all the composites, including the hybrid ones. Similar results on the tensile properties of hybrid composites have been reported, supporting the idea that higher fiber ratios in hybrid composites had a positive effect on tensile strength, e.g., a ratio of 4:1 of banana and sisal fiber in hybrid composites brought a significant improvement in tensile strength [39]. Another study on jute and banana fiber reinforced epoxy hybrid composites prepared with various weight ratios confirmed the improvement in the mechanical strength of hybrid composites [40].

4.2 Scanning Electron Microscopy (SEM)

The SEM micrographs of the tensile fractured surface of PALF/PF, KF/PF and hybrid composites are shown in Figure 3. The simultaneous fracture of both PALF and KF in hybrid composites can be observed, which allows analyzing the degree of adhesion between the fibers and the matrix. However, SEM fracture morphology revealed a certain extent of fiber pull-out of the PALF and KF in hybrid composites, as observed for most polymer-fiber bonding systems [22, 41, 42].

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In Figure 3a, the SEM micrograph for the PALF/PF composite reveals significant fiber pull-out, indicating poor fiber distribution within the matrix and ineffective adhesion, compared to the hybrid composites. Although the KF/PF composite in Figure 3e showed the best tensile strength among all the composites, including the hybrid ones, few fractures were noted in the KF/PF micrograph compared to the rest of the samples, which is assumed to enhance the strength of the fiber/matrix interface and allow the load to be distributed throughout the surface, contributing to an efficient stress transfer from the matrix to the fiber [43]. Hybrid composites exhibiting homogeneous distribution of fibers, fiber pull-out and void content can still be easily seen on the fractured surface.

In Figure 3b, the 7P3K hybrid composite shows very good fiber/matrix interfacial strength and the fibers appear to be distributed homogeneously. Good interfacial bonding thus enhanced the tensile strength of hybrid composites [20]. The 1P1K hybrid composite showed poor distribution of the fibers and fiber pull-out. The surface of the matrix can be clearly observed in Figure 3c as showing many voids, which may be due to the different polarities of the KF and the matrix [44]. Figure 3d shows an even distribution of the fibers and good interfacial bonding, which helped improve the tensile and flexural strength.

As could be noted in the SEM micrographs, in the PALF/PF composite the fibers were loosely surrounded with the resin and many micro-spaces could be observed in the fiber-matrix interfacial area, which indicated weak interfacial interaction between PALF and the PF matrix. Therefore, the interfacial structure of the PALF/PF composite could not transfer the stress effectively. In contrast to this, the microstructure of the 7P3K hybrid composite showed good interfacial bonding and the addition of KF improved the interfacial strength, while the 1P1K hybrid composite had a reduced tensile strength because of its heterogeneous fiber distribution.

4.3 Flexural Properties

Flexural testing is required to examine the capacity of a material to sustain bending before reaching the breaking point [25]. Flexural strength reveals the combination of tensile and compressive strength, which is directly dependent on the interlaminar shear strength, while the flexural modulus is a measurement of the composites resistance to bending deformation [45]. Thus, flexural testing is a combination of different mechanisms such as tension, compression, shearing, etc. [28].

The flexural test was conducted on the PALF/PF and KF/PF composites, as well as on the hybrid composites with various weight fractions, and the results are shown in Figure 4. The flexural strength of the hybrid composites increased with an increasing weight fraction of KF, while KF also contributed to improving the tensile modulus. Maximum flexural strength and modulus were recorded for the KF/PF composite, which means KF has good compatibility with phenolic

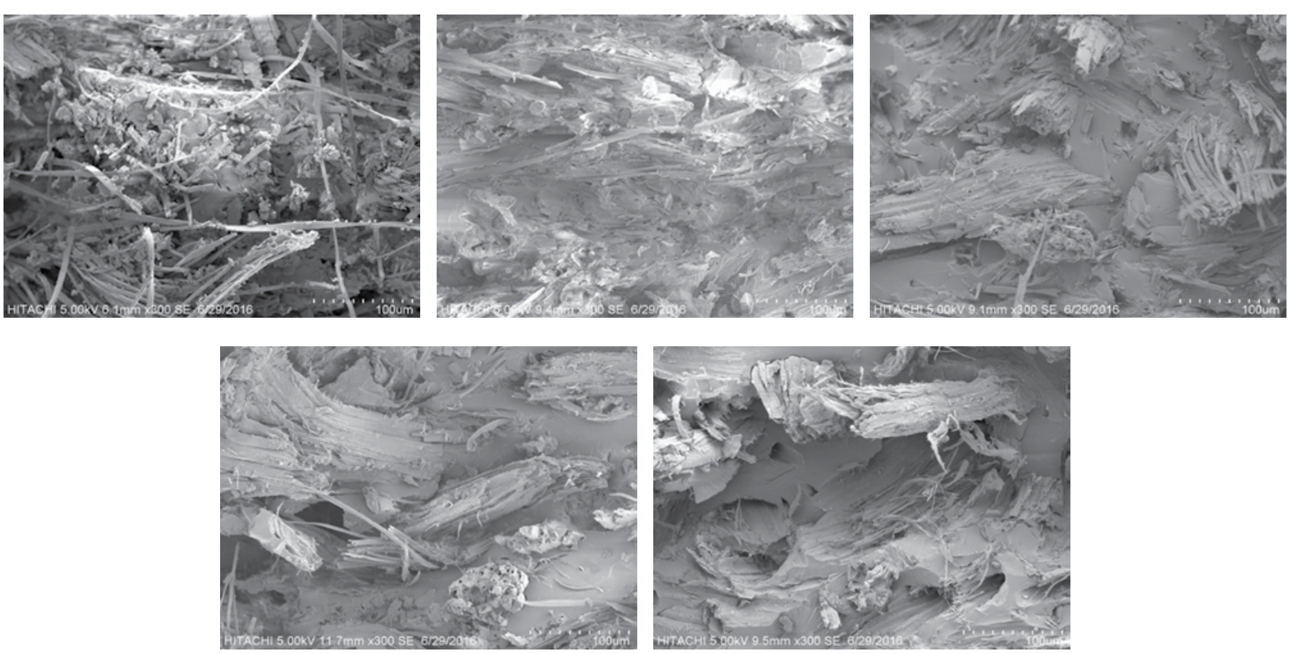

Figure 3 SEM micrographs of PALF and KF composites and PALF/KF hybrid composites.

resin in terms of flexural properties. PALF/PF showed the lowest flexural strength (81.45MPa) and the highest flexural modulus (6.42GPa). This may be due to weak interfacial bonding between the fiber and the matrix, as it has been reported that weak fiber/matrix interfacial bonding contributes to poor flexural properties [4]. The incorporation of KF in PALF/phenolic composites improved the flexural strength and after increasing KF, the flexural properties are enhanced accordingly. Figure 4 presents the flexural strength and modulus of the hybrid composites with different weight fractions in comparison with those of the PALF/PF and KF/PF composites.

For the 3P7K hybrid composite, the flexural strength increased by 108.26%, while its flexural modulus decreased by 88.47% compared to PALF composites. The flexural strength of the 7P3K and 1P1K hybrid composites was enhanced by 101.6% and 103.38%, respectively, though their flexural modulus decreased by 78.81% and 90.49%, respectively. The 3P7K hybrid composite showed the highest flexural strength and modulus among hybrid samples due to its homogeneous distribution of fiber loading. Therefore, PALF and KF allowed an efficient load distribution and PALF helped to improve flexural modulus while KF enhanced the flexural strength of hybrid composites.

Similar research [46] has been published on hybrid composites of rubber wood and empty fruit bunch fibers in different weight ratios, reporting very good flexural strength. The flexural properties of sisal and carbon reinforced unsaturated polyester hybrid composites with different fiber weight ratios have also been studied and it was found that the hybrid composites presented significantly improved flexural strength [47]. The flexural strength and modulus of banana and sisal (4:1) hybrid composites has been reported as the highest among the whole series of hybrid composites with different weight ratios [48].

4.4 Impact Properties

The impact test is used to measure the impact resistance and total energy distribution in composites before sample failure occurs [26]. Figure 5 shows the graphs of the impact strength and energy absorption of the composites and hybrid composites. The KF/PF composite and all hybrid composites presented lower impact strength and energy absorption than the PALF composites. The highest values of impact resistance and energy absorption were obtained for the PALF/PF composites, i.e., 7.05 kJ/m^2 and 63%, respectively, while the 7P3K hybrid composite showed the highest impact resistance and energy absorption among hybrid composites. The results of the Izod impact test for the hybrid composites were encouraging, revealing that hybridizing PALF with KF in all weight ratios enhanced the impact strength, compared to that of the KF/PF composite.

The impact strength and energy absorption of the 3P7K hybrid composite were very low compared to the rest of the hybrid composites, but still higher than those for the KF/PF composite by 112.29% and 158.46%, respectively. The PALF/PF composite exhibited the highest impact strength and energy absorption of 7.05 kJ/m^2 and 63%, respectively, among all composites, including the hybrid ones. PALF has a high aspect ratio, which contributed to increasing the impact strength and energy absorption in the PALF/PF composite, as well as in hybrid composites. A higher aspect ratio can provide toughness in a composite, which can be accompanied by increased fracture energy, and PALF was expected to give a higher

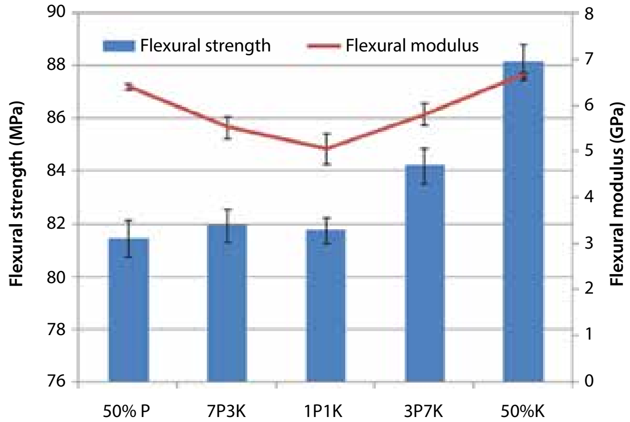

Figure 4 Flexural strength and modulus of PALF and KF composites and PALF/KF hybrid composites.

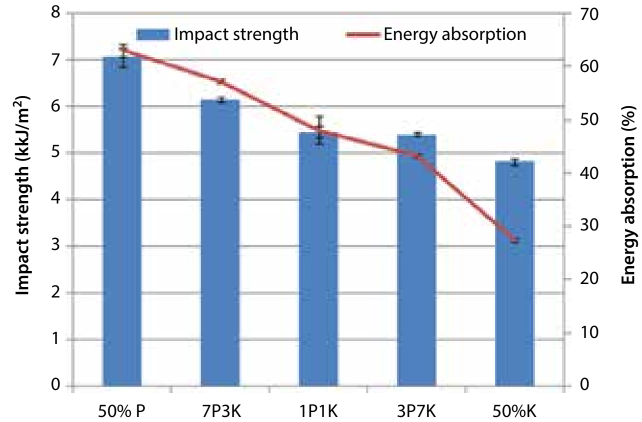

Figure 5 Impact strength and energy absorption of PALF and KF composites and PALF/KF hybrid composites.

impact behavior because of its higher cellulose content [49]. The impact strength in hybrid composites was enhanced due to the synergistic effects of the fibers; therefore, the 7P3K and 1P1K hybrid composites also had increased impact strength by 127.91% and 113.33%, respectively, compared to that of the KF composite. Energy absorption depends on the energy required to pull out fibers from the matrix and to fracture the matrix, and also shows energy distribution in attrition among fibers. The enhancement in impact strength can be related to the improvement in stress capacity, which is connected to the fiber-related mechanisms, such as fiber pull-out and load distribution [26].

5 CONCLUSION

The hybridization of PALF and KF and their incorporation into a PF matrix have improved the mechanical properties of the composites, such as tensile, flexural and impact strengths, with increasing KF loading. The PALF composite showed the lowest tensile and flexural strengths, but the highest impact strength and flexural modulus. After addition of KF up to 70% by weight, the hybrid composites showed better tensile and flexural strengths. On the other hand, PALF helped to increase the impact strength, energy absorption percentage and flexural modulus of the 3P7K hybrid composite. The SEM of the tensile fractured surfaces of PALF/PF and KF/PF composites and of the hybrid composites showed the distribution of fibers throughout the composites and the interfacial bonding between the fibers and the matrix. In the KF/PF and hybrid 3P7K composites, fibers showed very good interfacial bonding with the matrix, which indicated that KF has very good compatibility with phenolic resin. On the hand, the PALF/PF composite and the hybrid composites having more PALF by weight fraction exhibited fiber pull-out, thus revealing incompatibility with the matrix. Surface modification of PALF and KF for fabrication of PALF/KF/PF hybrid composites will provide very good interfacial strength, which will help enhance the mechanical strength of the resulting materials.

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