Strength and Microstructural Investigation on Kenaf Fiber Reinforced Polypropylene and Low-Density Polyethylene Composites

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Abstract. Recent studies have explored the potential of using polymer and natural resources such as kenaf fiber to create new bio-composite materials with strong mechanical properties. To investigate this further, the hot press has been used for fabrication to create a bio-renewable kenaf fiber plastic composite (KFPC) with a polymer-to-fiber ratio of 30%, 50%, and 70%. Two types of polymer which are Low-Density Polyethylene (LDPE) and Polypropylene (PP) were combined with kenaf fiber and bonded with 8% Urea-Formaldehyde to enhance the bonding between the polymer and fiber. The mechanical and morphological properties of these composites were evaluated according to ASTM standards. Results have shown that the Polypropylene/Kenaf fiber composite demonstrated higher tensile and flexural strength compared to LDPE. Scanning electron microscope (SEM) analysis revealed that the composite with a composition of 70% PP and 30% kenaf fiber with 8% UF had the most uniform structure and bonding between the fiber and polymer. These findings suggest that bio-renewable composites have the potential to be used as fabrication materials in various industries. Implementing such materials may help maintain environmental sustainability, and reduce the reliance on non-renewable resources.

Keywords: Tensile, flexural, urea formaldehyde, Scanning electron microscopy, polypropylene, Low-Density Polyethylene

1. Introduction

Plastics are the most common product materials industries in Malaysia with characteristics such as lightweight, high effect opposition, and capacity to structure it into various shapes and protection from bacteria [1]. Reported a few types of plastic have been recycled such as Polyethylene (PE), High-Density Polyethylene (HDPE), Low-Density Polyethylene (LDPE), Polypropylene (PP), and Acrylonitrile Butadiene Styrene (ABS) which are able to be recycled [2]. In composite manufacturing, the wood composite industry has used forest plantation and mill residues as raw materials in recent decades. Strict harvest regulations and environmental policy pressure have resulted in a decrease in the supply of high-quality timber and an increase in costs [3]. However, reinforced plastic material creates good effects such as using maleates polypropylene as a coupling agent improved and create better mechanical properties stability compared to the non-coupled ones [4]. It was proved that applicable adhesive may be suitable to enhance the mechanical properties of the composite with a percentage of 65% and 20% with respect to PP and kenaf [5]. Also, found that 3% of MA was the best content on PP kenaf composites [6]. In another hand, found that the properties of the composite in which treated kenaf fiber with NaOH solution mixed with LDPE gain comparable mechanical properties to the percentage of fiber loading [7]. Focussing on environmental scope, the degradation of LDPE would able to perform faster degradation by its own oxidation which involves microorganisms changing and consuming polymer lead in a change of its properties. Also, believed that LDPPs are able to be mixed with polypropylene to obtain such advantages as low density, high stiffness, high softening temperature, and fine chemical inertness [9]. In another polymer, the production of polypropylene is done by the process of additional polymerization which is heat, high-energy radiation, and catalyst are combined all together with the monomer [10]. It's also good in electrical behavior which is able to manage the electrical resistivity and dielectric permittivity to enhance [11]. Nonetheless, PP widely uses in engineering applications such as automotive parts and industrial equipment [12].

Kenaf known as *Hibiscus Cannabinus* [13] is cultivated actively in Southeast Asia and East Asian countries, it is a non-wood lignocellulosic material because it is formed mainly by cellulose, hemicelluloses and lignin [14]. Agricultural fiber can be easily crushed and may be used as a substitute for wood-based raw materials. Explore the use of local natural fiber for composite boards and has an excellent potential to compete with other commercial products [15]. Moreover, kenaf has excellent physical-mechanical properties, huge application, and small production cost [16,17]. Some researchers believed that the alkaline (NaOH) treatment or Sodium Lauryl Sulfate (SLS) on kenaf fiber in a different composition might result from changes in mechanical properties. But like some other researchers might have conducted the mechanical test on the kenaf fiber by only using the initial physical form of the kenaf fiber without any additional treatment [18]. Kenaf has a good advantage compared to other lignocellulosic because of its short plantation cycle adaptability to the surrounding conditions. It's only required a lower amount of pesticides and herbicides [19]. Comparisons of the mechanical properties of kenaf fiber with other natural fibers are highlighted in Table 1. Kenaf has excellent characteristics which have approximately 295-930 MPa of tensile strength and young's modulus at 22-60 MPa compared to bamboo which has 140-441 MPa of tensile strength and young's modulus at 11-36 MPa [20].

Kenaf plastic composite is one of the alternatives to the development of a new material that was blended by using the kenaf fiber and recycled polypropylene plastic, virgin plastic, or low-cost polyethylene. These composites represented the kenaf fiber filler in a virgin plastic to create new mechanical properties from its original form [23]. Kenaf fiber plastic composite is recommended used in automotive and aerospace industries to lessen vehicle weight, car organizations have as now moved from steel to aluminum and now moving from aluminum to fiber composites for certain applications [24]. Among of components are the engine cover, running board, underbody shield, battery carriers, glove box, and instrument panel substrate [14]. In this paper, the tensile and flexural test was applied to the kenaf plastic composite, and the bonding of the composite was proven via scanning electron microscopy.

Table 1. Comparison of physical and mechanical properties based on a few types of natural fiber.

Type of fiber	Density ($g/cm3$)	Strain at Break (%)	Tensile strength (MPa)	Young's modulus (MPa)
Bamboo	0.6-1.1	1.3-8	140-441	11-36
Kenaf	1.2	2.7-6.9	295-930	22-60
Jute	1.3-1.46	1.5-1.8	393-800	10-30
Banana	1.35	5-6	529-914	27-32
Hemp	1.48	1.6	550-900	70
Pineapple	1.5	1-3	170-1627	60-82

Source: Koohestani, et al., 2018 [20]

2. Material and Methods

The composite fabrication using kenaf fiber and two different types of the polymer has been prepared (Figure 1). The performance of the composite on mechanical properties and microstructure analysis was determined.

Figure 1: Kenaf polymer composite manufacturing

2.1. Composite Preparation

Kenaf plastic composite fabrication was conducted at the Materials and Metrology Laboratory, University of Technology Sarawak. The kenaf fiber obtained from Lembaga Kenaf dan Tembakau Negara (LKTN) was oven-dried at 103±2 °C for 24 hours before grinding and sieved for 0.5-1.5 cm of fiber length. Two different types of polymers were used to fabricate the composite sample namely Low-Density Polyethylene (LDPE) and Polypropylene (PP). Then, 8% wt Urea-Formaldehyde (UF) adhesives are mixed together to improve the bonding of composite residues.

In the manufacturing process, different temperatures were applied to two selected plastic which is 210°C for PP and 190°C for LDPE. The details parameter for the kenaf plastic composite is represented in Table 2. The compositions were weighted and a composite fabrication method was done using a hot press process accordingly to the information in Table 2. In another order, the mould volume is 20 cm x 20 cm x 0.5 cm and the target density of the composite fabrication is 130 g/cm³.

Table 2. Kenaf plastic composite ratio based on two different polymers reinforce.

Type of Composites	Parameters	Composition (%)		Temperature (°C)	Time (min)	Pressure (MPa)
		Plastic Loading	Kenaf Fiber Loading (UF)			
LDPE/Kenaf Composites	LKC 1	30	62 (+8)			
	LKC 2	50	42 (+8)	190	20	5
	LKC 3	70	22 (+8)			
PP/Kenaf Composites	PKC 1	30	62 (+8)	210		
	PKC 2	50	42 (+8)		30	5
	PKC 3	70	22 (+8)			

*where LKC stands for LDPE+Kenaf composite

*where PKC stands for PP+Kenaf composite

2.2. Flexural test

A flexural test will be performed on the kenaf plastic composites and was prepared in standard ASTM D790. The specimen was cut into 125 mm x 12.7 mm x 3.2 mm. The specimens were cut and tested using a 10 kN Flexural Machine Hegewald & Peschke Inspekt 10-1. The triplicate samples have been conducted, and dimensions have been taken to each sample before the test run.

2.3. Tensile test

A tensile is used to determine the material's strength before it breaks. The kenaf plastic composite was prepared following the ASTM D638 standard, and the specimen was cut into 165 mm x 19 mm x 3.2 mm for the tensile test. The dimension is 57 mm in length, 50 mm in gauge length, and 12 mm in gauge width for the narrow section. A triplicate specimen was prepared and tested using Hegewald & Peschke Inspekt 20-1 10 kN Universal Tensile Machine.

2.4. Scanning Electron Microscopy Analysis

Scanning Electron Microscopy (SEM) was used to characterize the morphology study for each specimen with different types of plastic composites and their compositions. The composite samples of each parameter were cut into 24 mm x 10 mm x 8 mm dimensions. First, before the samples were observed, specimens must be coated using JOEL Smart Coater with a fully automated vacuum and sputtering. The purpose is to eliminate charging with non-conductive materials and enhance secondary electron emission. After that, coated samples were observed by using JOEL JCM-6000 Scanning Electron Microscope [22].

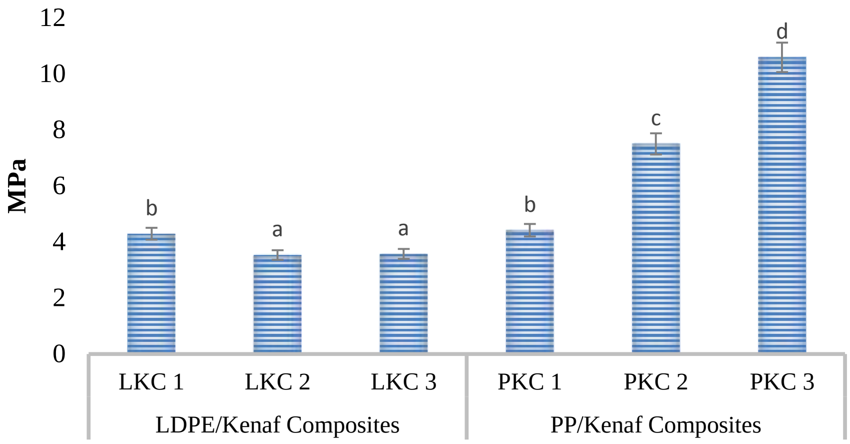
3. Results and Discussion

3.1. Tensile test determination

Figure 2 shows the average results of the tensile strength of LDPE Kenaf composites (LKC) and PP kenaf composites (PKC). Figure 2 shows that 30% of plastic content with 70% of fiber loading (LKC 1) indicates the highest tensile strength result for LDPE kenaf composite which is 4.29 MPa. While for PP, the highest tensile strength is the composite with a composition of 70% of plastic content with 30% of fiber loading which gives the result of 10.59 MPa.

LKC 1 indicates higher tensile strength compared to LKC 2 and LKC 3. The proper UF amount as a coupling agent that have match the higher fiber loading exhibits better mechanical properties due to their high stiffness and rigidity properties [25]. As observed from Figure 2, the result indicates no significant difference between LKC 2 and LKC 3 in the tensile strength. This might happen because the higher plastic content creates high surface energy between hydrophobic polymer (LDPE) and hydrophilic starch of fiber might result in a low degree of adhesion [26]. This cause a weak bonding between fiber and polymer providing structure initiation. On other hand, the higher amount of fiber content will reduce the modulus of elasticity instead of increment in tensile strength. This is due to the strong interaction between composite matrices which reduces the elasticity and limits the movement of a polymer chain, resulting in more rigid and tough composites [27].

In the cases of Polypropylene mechanical characteristics, the result of tensile strength gives a significant value as this indicates the different amounts of plastic and fiber content affect the result of its mechanical characteristics. PKC 3 indicates the highest tensile strength which is 10.59 MPa compared to PKC 1 and PKC 2 which are 4.42 MPa and 7.50 MPa, respectively. According to Figure 2, PP creates higher tensile strength when the plastic content increases. This is due to kenaf fiber disrupting the matrix entanglement chain, causing the fiber to become more congested inside the PP matrix [28] and it was affected by the variations of viscosity and porosity in the polymer kenaf fiber composite [18]. Agglomeration of fiber or fiber-fiber interaction is a possibility since it contributes to the stress concentration point, which affects the mechanical qualities and lessens the tensile strength [6,21]. The finding was supported by Roslan, 2019 [6].



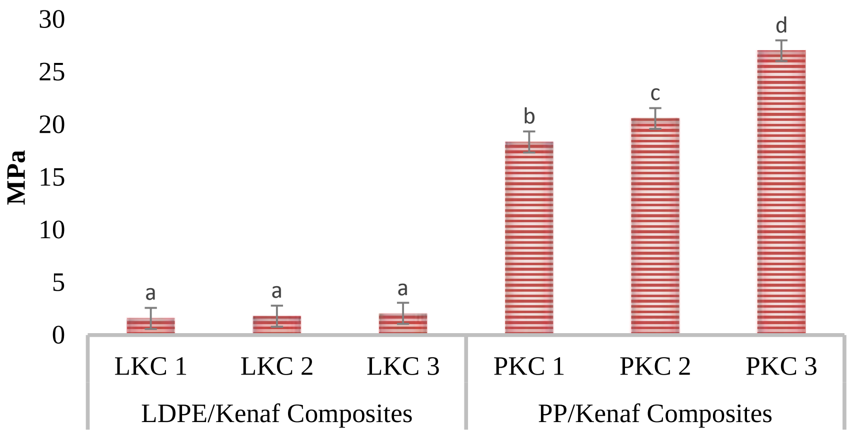
*Note: LKC is LDPE kenaf fiber composite and PKC is PP kenaf fiber composite

Figure 2. Tensile properties for two types of kenaf plastic composites.

Figure 2 indicates that the composition of 70% of polypropylene with 30% fiber exhibit the highest tensile strength which is 10.59 MPa. Theoretically, this might be due to the amount of adhesion that is constantly being applied to different types of polymer contributing greater fiber matrix interaction and chemical bonding [28]. For PP kenaf composite, the amount of 8% Urea-formaldehyde causes the fiber and polymer matrix to be perfectly bonded and has shown the compatibility of the hydrophobic polymer matrix which results in to enhance of the mechanical properties of composite material [18].

3.2. Three-point flexural determination

Figure 3 shows the results of a flexural test for the LDPE kenaf composite and PP kenaf composite. From the observation of Figure 3, it indicates that LKC 3 has the highest flexural strength which is 2.07 MPa compared to LKC 1 and LKC 2 which is 1.60 MPa and 1.81 MPa, respectively. The increased amount of plastic content exhibit a higher result of flexural strength in LDPE kenaf fiber composite. This might be due to the ductility characteristic of LDPE if compared to the higher amount of fiber which affects the brittleness of the composite [25].



*Note: LKC is LDPE kenaf fiber composite and PKC is PP kenaf fiber composite

Figure 3. Flexural test justification for two types of kenaf plastic composites.

Nonetheless, the PP kenaf fiber composite represented the Figure 3 indicates that PKC 3 exhibits the highest flexural strength which is 27.03 MPa compared to PKC 1 and PKC 3 which are 18.36 MPa and 20.59 MPa respectively. The flexural strength increases as the plastic content increases from 30%

to 70%. This outcome might be attributable to the kenaf fiber's precision, homogeneity, and attachment to the PP matrix [18,29].

Figure 3 shows the comparison of flexural strength between LDPE kenaf composite and PP kenaf composite with different plastic and fiber compositions. Indicates that the composite with the composition of 70% PP mix with 30% fiber (PKC 3) exhibits the highest flexural strength compared to other composite parameters. The figure also highlighted that the obviously that PP exhibits huge differences in flexural strength compared to LDPE. This occurrence might involve the characteristic of different type of thermoplastic which in fact LDPE has a lower density than PP, thus PP is semi-rigid, have good fatigue resistance, and is stiffer compared to LDPE [10].

3.3 Statistical Analysis of Variance (ANOVA)

Table 3 are represented the ANOVA analysis for LDPE kenaf composite (LKC) and PP kenaf composite (PKC). There is show highly significant differences between tensile and flexural with 99% probability. According to Figures 1 and 2, the results are represented there was a significant difference between LKC and PKC on the tensile and flexural tests.

Table 3. One-way ANOVA analysis for mechanical properties of plastic kenaf composite.

		Sum of Squares	df	Mean Square	F	Sig.
Tensile	Between Groups	120.139	5	24.028	495.134	.000
	Within Groups	.582	12	.049		
	Total	120.721	17			
Flexural	Between Groups	1952.371	5	390.474	560.166	.000
	Within Groups	8.365	12	.697		
	Total	1960.736	17			

Note: significant at $p \leq 0.01$

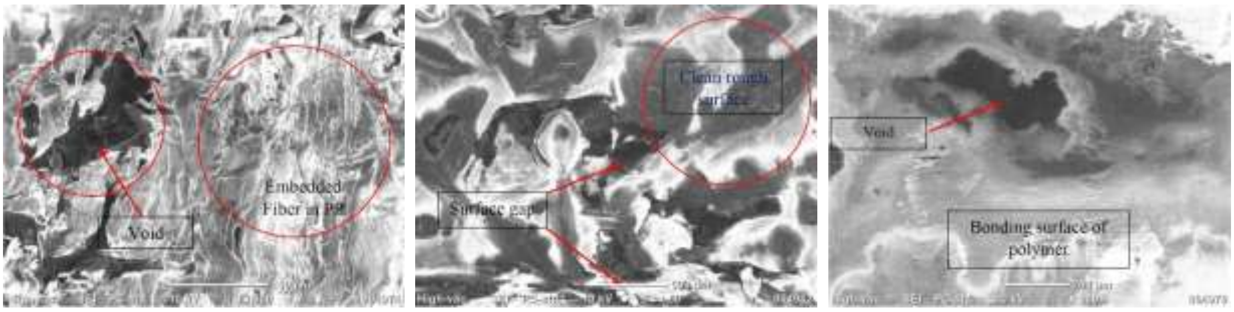
3.4 Morphological study via scanning electron microscopy

Figure 4 shows the morphological properties analysis of the LDPE kenaf fiber composite. The SEM illustrated the difference between fiber matrix interaction and plastic compositions. SEM results highlighted the presence of voids and many pulled-out of kenaf fibers as the plastic content decreased. It was clearly depicted on LKC 1 with more voids *and fiber pulled-out* found compared to the LKC 2 and LKC 3. The fiber seems to be pulled out due to the low interaction with LDPE and it may be caused to the opposite nature of hydrophilic kenaf fiber and hydrophobic plastic [26]. However, embedded fiber to the polymer matrix has been spotted which affects the tensile strength to behold out before failure [18]. Figure 4 indicates that the polymer seems to be more dispersed and fiber was embedded in LKC 3. Voids are still being spotted in LKC 2, and the addition of other surface fracture traces is due to poor bonding between fiber and polymer [26]. According to the results shows, LKC 3 has a good enough bonding between plastic and kenaf fiber; however, it still appeared to have a wide fracture surface and has become proof of weak tensile strength. This is due to the poor adhesion bonding and fiber not being fully covered with the plastic matrix [29].

Figure 5 illustrated the SEM microstructure of PP kenaf fiber composites. SEM observations indicate that the void appears to be huge in the least amount of plastic content as highlighted in PKC 1. However, Figure 5 indicates that embedded fiber in a polymer can be seen clearly in PKC 1 which might be affected by better adhesive bonding and contribute to higher mechanical properties [30]. As the plastic content increased in PKC 2, the microstructure starts to indicate a clean rough surface of polymer bonding with 50% of fiber loading. Figure 5 shows the occurrence of the void is lessened due to the proper matrix composition of polymer and fiber with reasonable adhesive propagation within the hydrogen bonding [26]. PKC 3 illustrated the good bonding of fiber plastic composite; however, it still spotted small and least void compare to PKC 1 and PKC 2. The finding was supported by PKC 3 having the highest flexural strength compared to PKC 1 and PKC 2. Nevertheless, proved that the tensile strength will decrease as fiber content increases [29]. PKC 3 also represented there was no surface fracture and fiber pulled-off detected compared to other plastic fiber compositions

LKC 1	**LKC 2**	**LKC 3**
PDPE-KF (30:70)	PDPE-KF (50:50)	PDPE-KF (70:30)

Figure 4. Scanning electron microscopy analysis for low-density polyethylene kenaf fiber composite (LKC) at magnification 100x.



PKC 1	**PKC 2**	**PKC 3**
PP-KF (30:70)	PP-KF (50:50)	PP-KF (70:30)

Figure 5. Scanning electron microscopy for polypropylene kenaf fiber composite (PKC) at magnification 100x.

4. Conclusion

The fabrication of composite material has been done successfully with findings on mechanical properties of kenaf plastic composite which is the tensile strength, flexural strength, and analysis on the microstructure of composites with different parameters of fabrications. Concluded that the PP and LDPE represented the highest tensile strength on PKC 3 and LKC 1, respectively. While PKC 3 indicated high flexural performance at a ratio of 70:30 for PP and kenaf fiber. Nonetheless, SEM analysis indicates that LKC 1 has a significant amount of void detected, however, the interaction of the bonding structure of LKC 1 is more reliable compared to LKC 2 and LKC 3. SEM analysis of PKC 3 illustrated the best distribution of polymer which indicates the highest tensile strength with a minimum amount of kenaf fiber.

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