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Mechanical properties of kenaf/polypropylene composite: An investigation

X.H. Loh*, M.A. Mohd Daud and M.Z. Selamat

Centre of Advanced Research Energy (CARE), Faculty of Mechanical Engineering,
Universiti Teknikal Malaysia Melaka, 75450 Ayer Keroh, Melaka, Malaysia.
*Email: xiaohui0505_venusloh@hotmail.com
Phone: +6062346753; Fax: +6062346884

ABSTRACT

At present, the applications of natural fibre composite in daily life products have become a norm. Therefore, studies on various combinations of natural fibre and filler have been carried out by researchers worldwide. In this study, kenaf/polypylene composite had been tested on Izod impact strength (ASTM D256) by varying fibre weights and lengths, besides being subjected under various impact angles. Impact strength of composite was determined from the average of five specimens. Besides, maleic anhydride-grafted-polypropylene was premixed with polypropylene using an internal mixer to enhance surface contact between fibre and matrix. On top of that, hardness and density tests were conducted to identify the physical properties of the samples. Other than that, digital microstructure observation was carried out to visualize the bonding surface between fibre and matrix. Next, the design of experiment analysis was employed to examine the relationship between impact angles, fibre weights, and fibre lengths. From the Izod impact test outcome, higher fibre length had been found to improve impact properties of composite. However, stress distribution of fibre at a shorter length was more significant for lower impact angle. Therefore, sample with fibre length of 1 cm and loading 30 wt.% had been confirmed as the best sample with excellent impact properties at various impact angles. Meanwhile, the microstructure of the sample demonstrated that the fibre displayed good surface coverage with the addition of maleic anhydride-grafted-polypropylene into polypropylene. Lastly, prediction of impact behaviour for kenaf/polypropylene composite was carried out by applying the formula obtained to factorial analysis generated by Minitab software.

Keywords: Kenaf; polypropylene; impact strength; DOE.

INTRODUCTION

Recent developments in finding replacement materials for synthetic fibre have focused on natural fibres. Natural fibres have successfully attracted the attention of manufacturers and researchers due to its countless advantages over conventional material used in the similar sector, as reflected in the automobile industry [1-3]. Besides improving mechanical strength, natural fibres also offer many other desirable characteristics, such as aesthetic, acoustic insulation, aging resistance, and odourless. It is also displays non-brittle fracture on impact characteristics, which is an important requirement for passengers compartment [4, 5]. Nonetheless, limited thermal stability of natural fibre has squeezed down the selection of thermoplastics that can be used as matrix. Degradation of natural fibre, however, only takes places when the temperature hits 200 ºC. Therefore, processing parameters, such as range of temperature and duration, need to be chosen carefully in order to generate an excellent product [5]. Natural fibre contains a huge amount of hydroxyl group; which makes it polar and hydrophilic in nature [6-9]. Hence, surface treatment has to be carried out first before proceeding with other processes to avoid the properties of natural fibre from being impaired [10]. Besides, several types of treatments in a comprehensive review pertaining to natural fibres [11]. For instance, maleic anhydride-grafted-polypropylene (MAPP) has been found suitable to function as a coupling agent for polypropylene (PP). This is because; addition of MAPP into composite enhances the adhesion between matrix and fibre. Although the presence of MAPP is desirable, excessive amount of MAPP can drag the mechanical performance of composite. In fact, the most suitable amount is 3%, as suggested by [8, 12-15], and it can be blended into polymer matrix using an internal mixer. According to Lembaga Tembakau & Kenaf Negara, kenaf, or its scientific name, *Hibiscus cannabinus L.,* belongs to the Malvaceae family and it originates from Africa [16]. It is an annual fibre crop with a fast growing rate under a wide range of temperatures and it can exceed the height of 3.7-4.3 m within four weeks upon planting. Moreover, it has strong CO_2 absorption ability [17]. The kenaf stalk consists of bast as the outer layer and core as the inner of the plant [16, 18-20]. For better mechanical properties requirement, bast is more suitable because it has more cellulose to contribute in absorbing energy. Meanwhile, Akil et al. [11], have discovered that the tensile strength of kenaf fibre can reach up to 930 MPa. On the other hand, polypropylene (PP) is commonly used for plastic mouldings, stationary folders, packaging materials, plastic tubs, non-absorbable sutures, diapers, and so on. PP can be degraded when exposed to ultraviolet radiation from sunlight and it oxidises at high temperatures. In fact, the potential to degrade PP using microorganisms is under investigation [21].

In addition, Hao et al., [22] revealed that the manufacturing condition of kenaf/polypropylene composite affected the mechanical properties, the thermal stability, and the acoustical behaviour of end–use products. For that study, kenaf fibre was mixed with polypropylene in 50/50 weight ratio. It was found that processing parameter influenced the outcomes of testing. For instance, samples that exhibited high impact energy and great sound absorbers were those that had been exposed to a temperature of 200 ºC and processing time 60 s with 9.8 kJ/m² for 5/200 sample. Meanwhile, Bernard et al., (2011) [23] determined the influence of processing parameters, especially temperature and feeding rate, during compression moulding, which affected the mechanical properties of unidirectional kenaf/polypropylene composite. Furthermore, higher temperature (190 ºC -240 ºC) generated more molten form of polypropylene. Besides, several other optimum parameters were determined by testing over varying temperatures and barrel speed. The highest impact strength obtained for unnotched sample was 510 J/m at 200 ºC and 16 Hz, but a decrease was noted for 210 ºC onwards. On the other hand, Oksman et al., [24] produced composite with flax and PLA with the addition of triacetin, in which the highest impact strength obtained was 12 kJ/m². Besides, Kord et al., [25] examined the composite on sawdust and PP with the addition of MAPP, whereby the highest impact strength obtained was 19.5 J/m at 50wt.% fibre. As such, this paper mainly focuses on the impact strength absorbed by kenaf/polypropylene (K/PP) composite from different impact initiate angles with different fibre lengths and ratios. Next, the main factor in driven mechanical strength of composite is identified by using factorial design in the design of experiment analysis. The outlined factors are fibre length, fibre ratio, and impact height, whereas the physical properties of composite are identified from hardness and density tests. Finally, digital microscope (Dino Lite) was used to observe the structure that forms between the bond within the composites.

EXPERIMENTAL SET UP

Raw material
Kenaf fibre used in this research was obtained from harvest plant in Kelantan. Meanwhile, polypropylene (PP) and maleic anhydride-grafted-polypropylene (MAPP) were bought from Polyscientific Enterprise Sdn. Bhd.

Preparation of Material
Kenaf fibre was cut into desired length; namely 1 cm, 2 cm, and 3 cm, using scissors, as displayed in Figure 1. First, PP was premixed with MAPP using internal Mixer with a fixed amount of 3%. The mixing parameter was set at temperature 190 ºC, rotating speed 60 rpm, and mixing for 7 minutes. The mixing products were crushed into smaller granules form using a crusher for easier weight management and material arrangement process when the materials were placed inside the mould. Kenaf fibre, PP and MAPP were weighed before they were placed inside the mould, as presented in Figure 2. The percentages of weight for kenaf fibre had been 10 wt.%, 20 wt.%, 30 wt.%, and 40 wt.%. Besides, 0% fibre was prepared as control. Table 1 shows the denotation of sample test. The materials placed inside the mould were stacked alternately. First, premixed granules of PP and MAPP were sprinkled at the base of the mould, followed by kenaf fibre, and then, granules of premixed PP were sprinkled again. This alternate sequence was repeated until the mould was full. The average thickness of the samples was 6.4 mm, as illustrated in Figure 3.

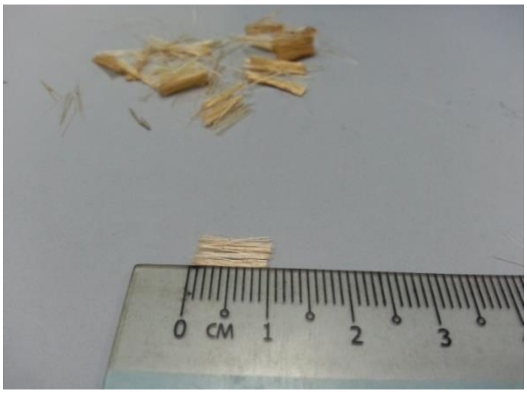


Figure 1. 1 cm of cut kenaf fibre.

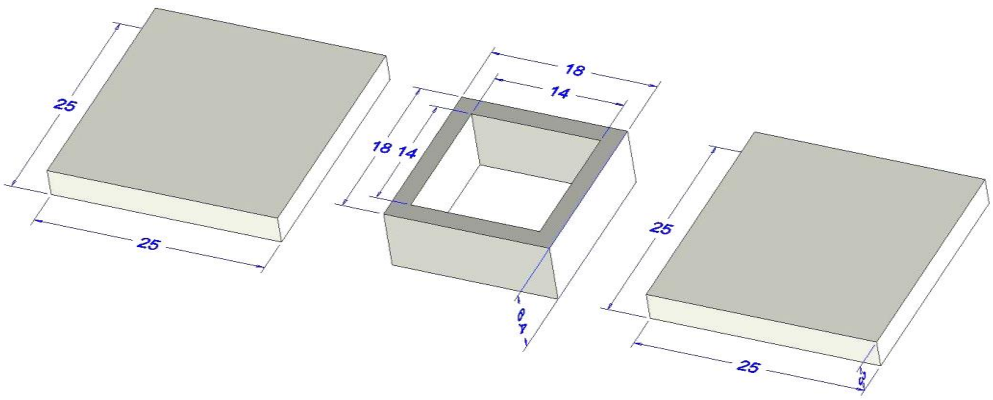


Figure 2. Carbon steel mould used in producing sample

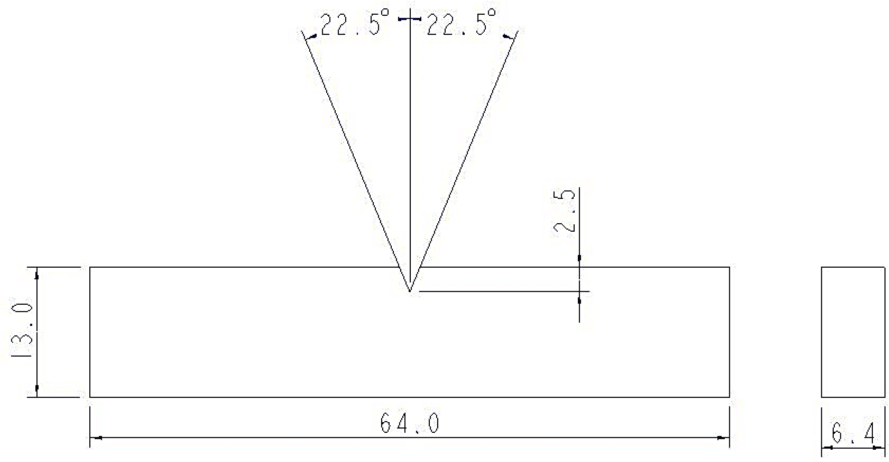


Figure 3. Izod notched sample dimension.

Table 1. Denotation of sample test.

Kenaf (wt%)	Polypropylene(wt%)	1cm	2cm	3cm
0	100	A0	B0	C0
10	90	A1	B1	C1
20	80	A2	B2	C2
30	70	A3	B3	C3
40	60	A4	B4	C4

In addition, the parameters that had been used to produce the sample are: temperature at 190 ^{0}C, preheat for 5 minutes, pressure at 100 kg/cm^2, hot press for 6 minutes, and cooling at cooling platform for 15 minutes. For example, Tengku Faisal et al., [26] used hot press stage involving a preheat stage at 180 ^{o}C and 150 kg/cm^2 for 6 minutes, followed by compressing for 3 minutes at the same temperature, and lastly, cooling for 2 minutes. The parameters chosen had been dissimilar because the authors dealt with mould material and hot press machine after performing some trials before producing the actual sample for test. The samples were cut into a particular size in accordance to ASTM D256 [27], which is 13 x 64 x 6.4 mm (notched Izod impact sample), as illustrated in Figure 3. Meanwhile, hardness and density tests were performed based on ASTM D2240 [28] and ASTM D792 [29] respectively to identify the physical properties of the sample. Other than that, results of impact testing were visualized by using full factorial design in DOE analysis.

Izod Impact Test

The major characteristics of composite that can be measured from this testing is resistance towards impact from a swinging pendulum. Izod impact test is defined as the kinetic energy needed to initiate a fracture and to further propagate it until the specimen is broken. Specimens are notched before testing to avoid deformation upon impact. This test is rapid and applies easy quality control check to determine if a material meets specific impact properties or to compare materials for general toughness. Toughness of structural material can be identified by measuring impact energy absorbed by it until yield [30]. The result derived from Izod impact test is impact energy, which is expressed in J/m or ft.lb/in. Next, impact strength is calculated by dividing impact energy in J or ft.lb by the thickness of the specimen. The result is normally the average value of 5 specimens. Moreover, it is understood in a way that the higher the resulting numbers, the tougher the material [27]. In order to study toughness of composite, three impact angles were selected, namely: 120°, 135°, and 150°.

Design of Experiment

Design of experiment (DOE) helps to outline the effect of input variables on output variables at one time. Users are able to determine series of runs, or tests that provide significant effect on the input variables. Data are collected based on every run set at the beginning of testing. DOE is a superior tool in determining process conditions and product components, which gives impact on quality, and hence, identify the factors setting that can optimize results. In this study, full factorial design was selected as the analysis tool. This is because; limit is not set to each factor levels pre-set in experiment, hence it is able to run analysis on all combinations of factor levels. For instance, the main factors in this study are outlined in Table 2. Therefore, the full factorial design involves the analysis for all the selected factors and levels.

Table 2. Factors and levels.

Factors	Levels				
Fibre Ratio (%)	0	10	20	30	40
Fibre Length (cm)	1	2	3		
Impact Degree (°)	120	135	150		

RESULTS AND DISCUSSION

The impact strength (kJ/m²) was obtained by dividing impact value with sample area below notch, as stated in ASTM D256 [28]. In fact, Figure 4 shows that composite subjected to lower impact angle or 120° displayed higher impact strength. When the pendulum is placed at a higher angle, more potential energy is stored. So, when released, higher energy is produced and the composite needs to absorb more impact energy [28]. Therefore, lower impact angle indicates lower energy and thus, composites can absorb more energy compared to higher impact angle. Furthermore, Figure 4 portrays three different impact heights that demonstrate three different levels of impact strength responses from testing. At angle 120°, the highest impact strength 353.18 kJ/m² was found at sample I/1/20. By observing the trend of impact strength by different fibre lengths denoted with 1, 2, and 3 respectively, impact strength increased with fibre loading, but it dropped at 40 wt.%. I/0/0 with 0 wt.% fibre loading, which implies improvement of impact strength with the presence of kenaf fibre. Nonetheless, decrement of impact strength was observed in samples I/2/40, I/3/30, and I/3/40, which might be due to insufficient wettability between matrix and fibre. Hence, these samples resulted in poor interfacial adhesion between the interface [31-33].

Meanwhile, at angle 135°, the highest impact strength, 174.21 kJ/m², was noted in sample I/1/30. For all various fibre lengths from 1 cm to 3 cm, the impact strength of samples exhibited optimum strength at 30 wt.%. This finding is in agreement with that of previous study by using flax and cordenka as natural reinforced fibre [33]. Besides, by comparing the result obtained for I/0/0 with zero presence of fibre, other samples enhanced with fibre loading showed improved impact strength, as depicted by Hamma et al., [34]. Furthermore, at angle 150°, the highest impact strength, which was 53.3 kJ/m², had been displayed by sample I/3/30. By viewing the impact strength pattern among the samples, increased fibre loading improved the performances of the samples until they reached the optimum performance at 30 wt.%. Samples I/1/30 and I/2/30 showed the highest impact strength with similar fibre length of 35.17 kJ/m² and 42.32 kJ/m² respectively. Besides, Mueller revealed that the impact strength on flax, hemp, and kenaf reinforced with PP had been 33kJ/m², 25 kJ/m², and 27 kJ/m² at the processing temperature of 190 ºC respectively [35]. On the other hand, Rassmann et al., found that the impact strength of composite had been the highest for 30 wt.% fibre loading group between 36 kJ/m² and 41 kJ/m² in investigating processing conditions of composite by varying fibre moisture content, mould temperature, and pressure [36]. Meanwhile, Hao et al., obtained the highest impact strength at 9 kJ/m² for kenaf reinforced PP sandwiched composite processed at 200 ºC for 60s subjected to 0.5 MPa [22]. In fact, Deng et al., assert that the addition of MAPP helps to improve surface bonding between fibre and matrix [37, 38].

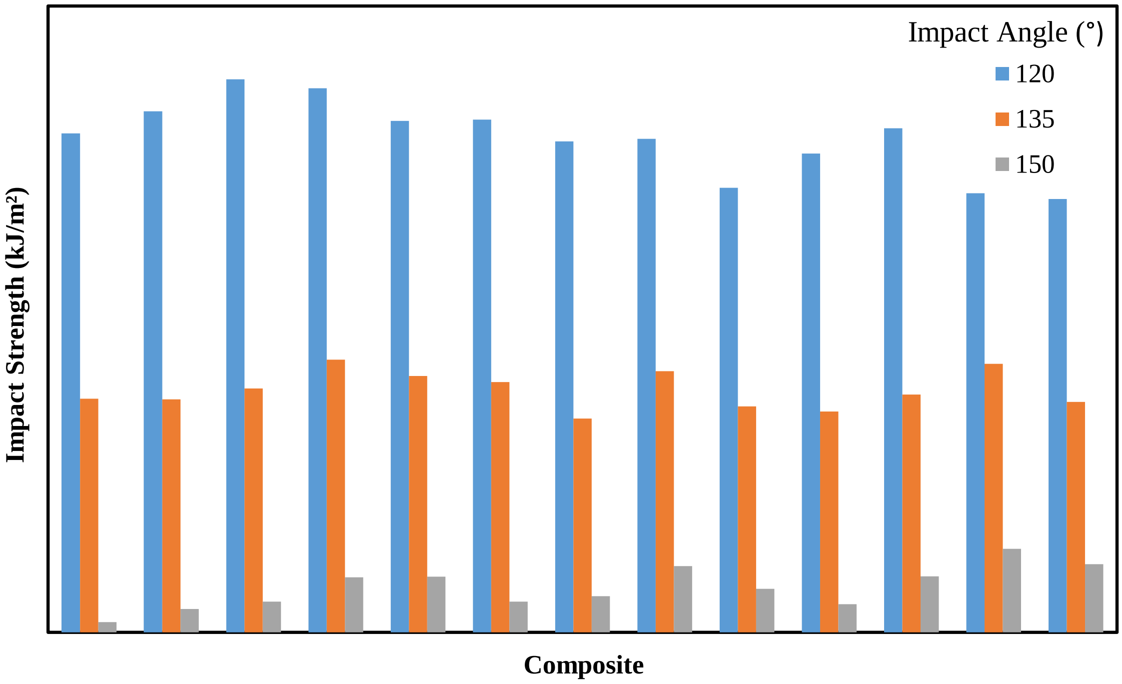


Figure 4. Impact strength for K/PP composite at different impact angles.

After results were collected from impact test, they were analysed by using full factorial design in Minitab software. Figure 5 shows the main effects from each factor, namely fibre length, ratio, and impact angle. Fibre ratio at 30% for all fibre lengths gave the highest effect in determining impact strength. This means; the optimum fibre ratio for composite is 30% and it bonds well with compatibilizer enhanced matrix. For instance, Shekel et al., [39] found that the optimum fibre loading for composite was at 30% when tensile strength was the highest at this point and exhibited a slight decrease in impact strength compared to other fibre loadings. Meanwhile, Sawpan et al., [40] discovered that increment in fibre loading enhanced fibre impact absorbance, in which the fibre loading ranged from 10% until 30%. Furthermore, Figure 5 shows that fibre length at 1 cm gave the optimum impact strength due to adhesion between fibre and matrix which had been more compact as it obtained higher mean impact strength [41]. This is because; at 1 cm, more fibre was present in the same mould compared to that of 2 cm and 3 cm fibre.

However, fibre length at 2 cm and 3 cm also contributed good bonding between fibre and matrix as they both attained the mean strength. Hence, the amount of fibre improves the strength of composite, whereby higher fibre ratio produces better composite [41]. In other words, for the same weight of fibre, different fibre lengths have different amount of fibre and that aspect is significant on fibre alignment and compact level for the composite [42, 43]. Impact angle shows significant impact gap for each different angle as impact height. Lower angle gives large impact strength absorbed. This indicates that kenaf/polypropylene composite can withstand more sudden impact at lower impact angle or height if collision happens [27]. Nevertheless, the mean impact strength absorbed composite at 150° was 25.94 kJ/m² and this is comparable with [23]. For instance, the impact strength of K/PP composite had been higher than the best result obtained in K/PLA, which was 19 kJ/m² [24]. Meanwhile, one found long hemp fibre reinforced with PLA composite appeared to be optimum at 35% with impact strength of 7.4kJ/m² [40].

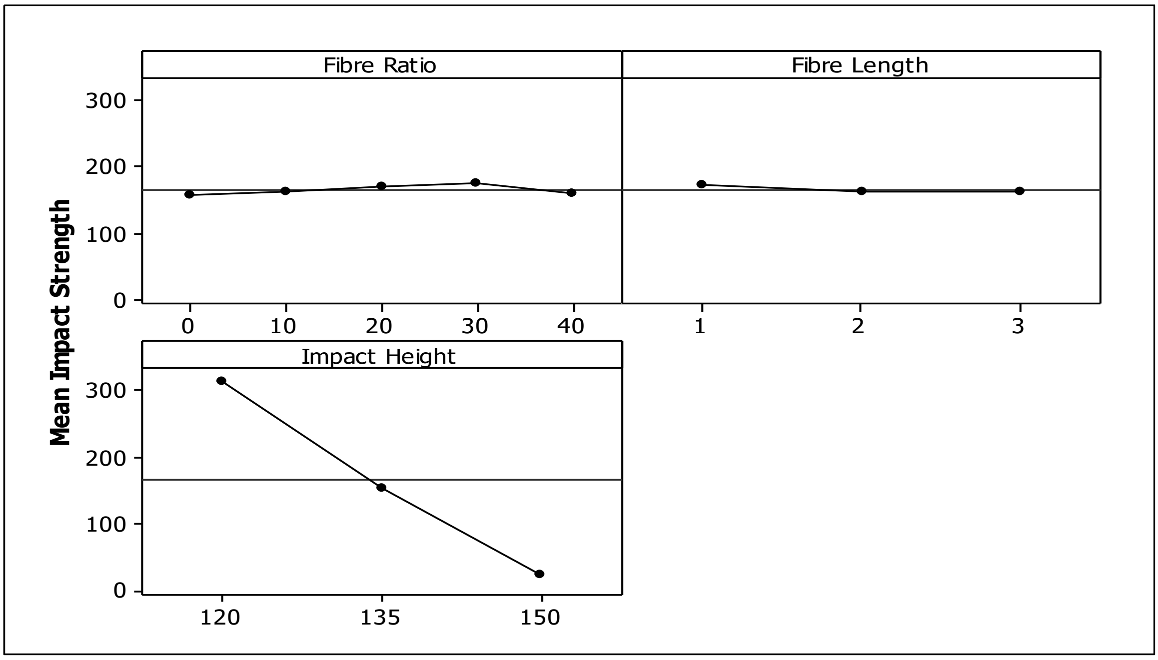


Figure 5. Main effects plot for impact energy.

Meanwhile, Figure 6 presents the interrelationship of factors visualized using Pareto chart. It shows either factors or combination of factors influences the outcome of this experiment. Any effect extended from the reference line is considered as significant to the outcome of the experiment. Impact height gives the biggest influence on composite impact strength. Therefore, the impact angles are released and go through changes from potential energy to kinetic energy, which generates varied momentum to hit the sample [28]. Besides, the tendency of the sample to absorb kinetic energy displays its strength at a sudden shock. This is followed by the interrelationship between fibre ratio with impact height and fibre length with impact height. Hence, it can be related to bonding situation within the composite, as discussed above. Third, when combining all of factors set at the beginning of the experiment, these interrelationships reflect significant outcomes.

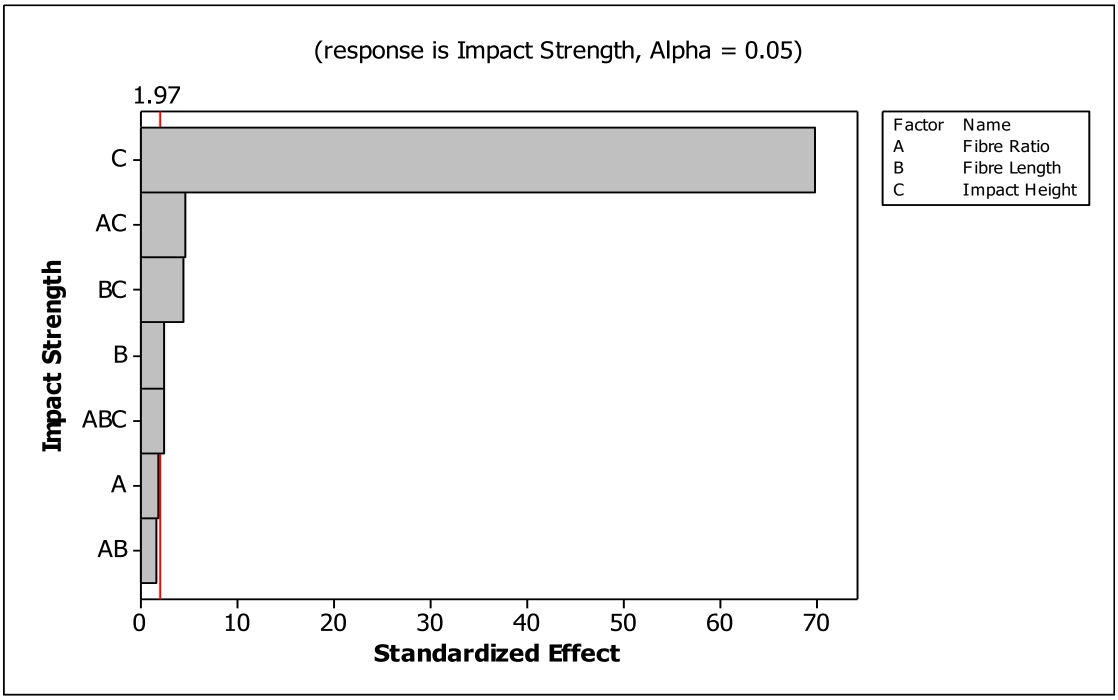


Figure 6. Pareto chart of the standardized effect.

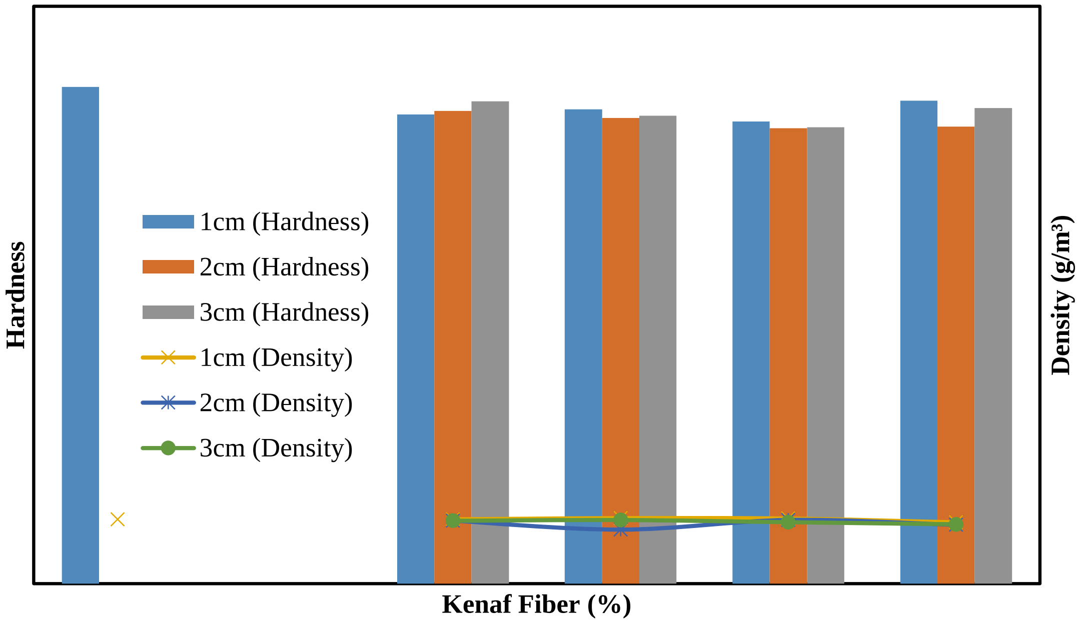


Figure 7. Shore hardness and density for samples.

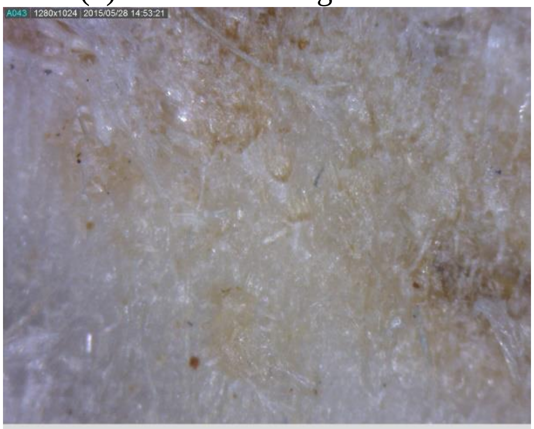
The physical properties for the samples, such as hardness and density, are presented in Figure 7. Random distribution inside the composite led to inconstant values of hardness at each point. Therefore, hardness value is the average of ten repetitions from various points on the surface of the sample. The hardness value for I/0/0, which functioned as control, was 68.8 because it was filled with zero fibre. This is because; polymers have higher hardness value because of their own properties [41]. The highest hardness for fibre filled sample was I/1/40 with 40% fibre weight and 1cm fibre length.

This is because; the sample had the most compact fibre arrangement with the most fibre amount among all samples.

(a) under x50 magnification

(b) under x200 magnification

(a) under x50 magnification



(b) under x200 magnification

Figure 8. Microstructure (a)-(b) I/1/40 and (c)-(d) I/3/40.

Meanwhile, the density test took into account the average of four readings of each sample. Due to the coverage of PP on fibre, water absorbility of fibre was reduced. The density of all samples, which ranged between $8x10^{-4}$ kg/m³ and $9x10^{-4}$ kg/m³, demonstrated constant behaviour. Besides, the addition of compactibilizer MAPP limits the bonding of –OH group of fibre when submerged inside distilled water [43]. Observation of samples had been done by using Dino Lite, whereby it is obtained from fracture surface after Izod impact test. Dino lite digital microscope is a very user friendly image capturing device. The maximum resolution is 230 times magnification. To begin observation, Dino Lite was clamped on a stand to get a static and stable condition, especially to avoid shaky images when capturing the surface of the samples. Next, the sample was placed under lens and images were captured. Users are able to adjust to obtain suitable resolution of image. In this study, composites that were selected to undergo microstructure had been I/1/40 and I/3/40, as shown in Figure 8. This figure indicates the difference in the amount of fibre present between these two composites under 50x and 200x magnification. Although both samples had equal fibre percentage, different fibre lengths were applied; I/1/40 had 1 cm and I/3/40 had 3 cm, which affected the compact level of composite [44]. Hence, when performing impact test, least fibre amount sample displayed low absorbance of impact strength. On the other hand, high fibre amount sample had the tendency to absorb water during density test, but equal coverage of matrix prevented high suction of water. Besides, Figure 6 shows almost constant density value for all samples. In addition, the presence of fibre improved ductility of PP other than turning into an interfacial material inside the composite. Interfacial bonding between fibre and matrix is a significant factor to determine the mechanical strength of a composite. In this study, the addition of compatibilizer had aided in improving the surface interaction inside the composite.

CONCLUSIONS

As a conclusion, kenaf fibre reinforced with propylene (K/PP) composite had been successfully produced. The impact strength of samples was studied and found to be comparable with other research findings. Therefore, the application of composite for industries, especially automotive field, is convincing. From the results of Izod impact test, several factors, such as fibre length, fibre ratio, and impact angle, played significant roles in determining the impact strength of K/PP composite. In fact, the best sample was obtained by using design of experiment (DOE) analysis; which was I/1/30 with fibre length 1cm and fibre ratio 30 wt.%, and it projected impact strength values of 347.54 kJ/m²,174.21 kJ/m², and 35.17 kJ/m² for impact angles 120°, 135°, and 150° respectively. Other than that, the density test showed almost constant water absorption for all samples that ranged between 8 g/m³ and 9g/m³. Meanwhile, hardness properties of samples were affected by two factors; compact arrangement of fibre and matrix. This was proven with sample I/1/30, which had a hardness value of 64. The microstructure observation was completed by using Dino Lite digital microscope. The addition of a coupling agent, maleic anhydride-grafted-polypropylene (MAPP), greatly improved the surface interaction between fibre and matrix, as reported by previous researchers. From the study, impact strength of composite can be predicted based on empirical model generated through design of experiment (DOE) analysis. This formula covers fibre length in the range between 1 cm and 3 cm, fibre ratio from 0 wt.% until 40 wt.%, and subjected under impact angle 120° to 150°.Moreover, hybrid composite material is indeed gaining its fame in the market trend. For example, it can be produced by mixing polymer with two different types of natural fibres to generate a more advance material. Besides, expanding the natural fibre selection into industries is a good choice of developing new market demand on more cost effective material or more competitive product.

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