

The influence of kenaf fiber as reinforcement on recycled polypropylene/recycled polyamide-6 composites

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Abstract The objective of this study is to develop a green composites based on recycled polypropylene (rPP)/recycled polyamide 6 (rPA6) reinforced with kenaf. The investigations were carried out by collecting rPP from the nearest landfill and rPA6 was prepared by re-extrusion and composites preparations were obtained using a twin screw extruder and injection moulding. The rPP/rPA6 composition was selected in a ratio of 70/30 with compositions of kenaf from 10–30 wt.%. Tensile, flexural and impact tests were conducted to investigate the mechanical properties. The composites thermal properties, processing behaviour and morphological study were also investigated. Beside the decrement in impact properties other mechanical properties of the composites were improved upon as the compositions of kenaf were increased. A difficulty resulted in processing the composites using injection moulding machine as the melt flow index values increased. Scanning Electron Microscopy (SEM) micrographs showed an improvement in the dispersion of kenaf in the matrix when kenaf compositions were increased. The overall results showed the best composition of kenaf was at 30 wt. %.

Keywords Recycled composites · Green composites · Kenaf · Recycled polypropylene · Recycled polyamide 6

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Introduction

Presently, the use of natural fibres reinforced polymeric materials to produce the green composites is becoming favourable by the manufacturers and researchers. The green composites significantly provide advantages to the environment. The significant improvement of the mechanical and thermal properties of green composites was shown by the use of natural fibres.

Every year, the amount of plastics consumed is increasing progressively, this shows that the use of plastics is becoming compulsory and also an integral part of our life [1]. At present, plastics are being used in automotive, packaging, medical, electronic and construction. A report indicates that nearly 260 million matrices tons of plastics were produced globally in 2010 [2]. Hence, it caused the generations of 24.6 million tons of post-consumer plastics waste in Europe, especially in the packaging, constructions, automotive, and electronic equipment industries. Approximately, 50 % of this waste was disposed of in landfills and only 20 % was recycled whereas 30 % was recovered as energy [2]. The research on recycling of plastic materials is carried out due to high cost of virgin materials, high volume of plastics waste in domestics waste, and environmentally they are non-degradable. Hence, the tendency of using the recycled polymeric materials to replace the virgin polymeric materials is gaining interest day by day [3–5].

The use of recycled polymeric materials is more economical and environmentally friendly and is also being promoted in reducing the amount of solid waste disposed of in landfills. There are four types of recycling method; they are primary recycling, mechanical recycling, chemical recycling, and energy recovery [6]. The polyolefin's polymers such as polypropylene (PP) are being used widely in many applications. Blending of PP with engineering plastics has become one of the focuses of polymer engineering for many years. Blending PP and PA6 were provided materials with additional balanced properties, including low moisture absorption, reasonable mechanical and thermal properties, and good processability with acceptable price [7]. Therefore, the aim of this study is to produce green composites from plastic waste based on PP and PA6.

A few natural fibres are suitable for reinforcement and one of the most commonly used is kenaf due to good mechanical strength, low density, low cost, recyclability and biodegradability [8, 9]. However, low interfacial properties between kenaf and polymer matrix often reduces their potential as reinforcing agent, chemical modifications are considered to optimize the interface of the fibres [10]. In this study, kenaf surface was modified chemically to activate the hydroxyl group (OH) in the fibres and to improve the effective interaction and adhesion between kenaf and polymer matrix [11]. In general, chemical coupling agents acted in two ways, the first reacted with the hydroxyl group in cellulose and second reacted with the functional group of polymer matrix [8]. Previous researchers indicated that alkaline treatment was more preferred for chemical modifications since it was very effective in increasing the surface roughness and is a possible reaction sites for blends [9, 10, 12–14]. The study of kenaf reinforced rPP/rPA6 compatibilized by the maleic anhydride-graph-polypropylene (MAPP) was carried out to investigate the effects of kenaf compositions in mechanical, processing properties and morphology.

Experimental

Materials

The recycled polypropylene (rPP) was collected from industrial waste located in Johor Bahru, Malaysia with MFI of 23.7 g/10 min. The virgin PA6 (Amilan CM1017) from Toray Nylon Resin, Malaysia was re-extruded to produce PA6 with recycled properties. The MFI of rPA6 recorded was 42.9 g/10 min. Both MFI were carried out for both polymers at 230 °C with standard plunger weight of 2.16 kg (kg). The kenaf was supplied by the Kenaf and Tobaccos Board Malaysia, Kelantan, Malaysia. After the alkaline treatment, the bulk density of kenaf recorded was 0.1986 g/cm³. The MAPP as a compatibilizer was supplied from Shanghai Jiangqiao Plastics Ltd., China with MFI of 120 g/10 min. The sodium hydroxide (NaOH) used for the alkaline treatment was purchased from the Quality Reagent Chemical, Malaysia with a molecular weight of 40.0 g/mol.

Chemical modification of kenaf fibres

Kenaf fibre was soaked in 5 % of NaOH at room temperature for 4 h before washing it with distilled water three times. The kenaf was washed once again with dilute acetic acid in order to neutralize and remove the remaining NaOH at the surface of the kenaf before finally washing with distilled water. The final washing with distilled water was to remove any excess acetic acid on the kenaf surface. The washed kenaf was then dried in an open air for 24 h before drying it finally in an oven for another 24–48 h at 110°C. The treated kenaf was then grinded to powder form. The grinded kenaf was sieved for 10 min using a sieve with 75 µm mesh size. This method of treatment was adopted from the method of Mishra *et al.* [12] and Ray *et al.* [13].

Preparation of kenaf reinforced rPP/rPA6 composites

Blending of treated kenaf and recycled polymers was conducted with four different formulations of 0, 10, 20 and 30 wt.% of kenaf in the composites. The blend ratio of rPP to rPA6 was 70:30. MAPP was introduced into the blends at a composition of 3 wt.%, the rPP composition was fixed at 67 wt.% in order to maintain exactly 30 wt.% of rPA6 in the blends as mentioned by Rosch and Mulhaupt [15]. The composites were prepared using single screw extruder with a speed of 50 rpm at 230°C.

Characterization and analysis

The samples for the tests were prepared using JSW N100 BII Injection Moulding machine. Each formulation was prepared with 10 specimens for 3 point bending flexural test and tensile test. Tensile test was conducted as stated in ASTM D638, with a speed of 5 mm/min and flexural test using standard ASTM D790 with a speed of 3 mm/min. Both tests were performed using Instron Model 20K computer controlled testing machine. Every formulation was repeated five times and the average values were determined. The izod impact test was performed using a pendulum with the

impact energy of 5.54 J at room temperature according to ASTM D256. The notched test specimens were used. The tests were repeated five times for each formulation and the mean impact strength with the standard deviation were calculated. The mechanical tests were conducted at Polymer Engineering laboratory, Faculty of Chemical Engineering, UTM, Malaysia.

Thermal characterization was conducted using differential scanning calorimetry (DSC) TA instruments DSC 2920 under nitrogen gas environment at Polymer Engineering Laboratory, UTM Johor Bahru, Malaysia. The specimens (10–20 mg) was placed in a sealed aluminium pan, and then cyclically heated from 25 to 250 °C at a heating rate of 10°C/min [4]. Equilibrium was attained at 250 °C for 1 min, and cooled back to 25 °C. Crystallinity levels were determined using ΔH_m for PP 209 J/g and ΔH_m for PA6 230 J/g for hypothetically fully crystalline (100 %) [9].

The MFI test was conducted to study the melt flow of the composites, which provided basic properties in the processing process. The MFI test was conducted at 230 °C, with a plunger weight of 2.16 kg (kg) for all formulations. The method was described in similar standards D1238. Even though there is no specific method for recycled materials, these conditions were chosen based on the nearest properties with the recycled materials. The MFI test was conducted at Polymer Engineering laboratory, UTM Johor Bahru, Malaysia.

The rheological flow was also conducted by using a capillary rheometer (Rheograph 2003, Gottfert®, Germany) at 190 °C at Malaysian Rubber Board (LGM), Sungai Buloh Selangor, Malaysia. The apparent shear rate was varied from 10^0 s^{-1} to 10^3 s^{-1} to measure the melt flow curves (relationship between shear stress and shear rate). All data were Bagley corrected.

The morphology of composites was then studied using scanning electron microscopy (SEM) at Material Laboratory, Faculty of Mechanical Engineering, UTM Johor Bahru, Malaysia. The samples were frozen in liquid nitrogen for 30 min and then impact-fractured for SEM analysis. The fractured surface was gold-sputtered before SEM observation. These tests were conducted at magnification of 200x.

Results and discussion

Tensile test analysis

Figure 1 shows the tensile strength versus kenaf composition by wt. % in the rPP/rPA6 composites. The tensile strength of the composites without kenaf has a tensile strength of about 31 MPa. It seems that MAPP was miscible with PP matrix, which promoted good adhesion between rPP and rPA6 polymer matrix [10]. It also shows that, the addition of 10 wt.% kenaf into the composites has resulted in a decrease of tensile strength drastically to 27 MPa. This may be due to the poor dispersion of kenaf in the matrix, and may also be attributed to the presence of impurities in the recycled polymer. The effects of poor dispersion of kenaf in the polymer matrixes which resulted in low tensile strength have been studied by previous researchers [5, 16]. The addition of MAPP obviously improved the interfacial adhesion between recycled paper fibre and polymer matrix [5] and enhanced the adhesion of kenaf fibre with poly (lactic) acid and when kenaf was treated chemically it also improved the mechanical properties [16]. A

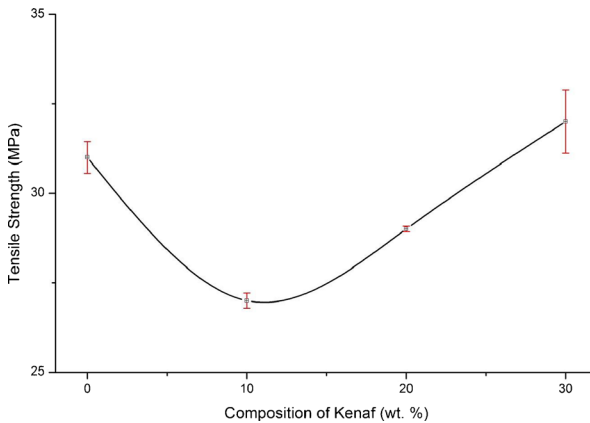


Fig. 1 The tensile strength of kenaf reinforced rPP/rPA6 composites as a function of composition wt. % of the kenaf

despite of poor dispersion of kenaf and the presence of impurities, it was observed that kenaf successfully enhanced other mechanical properties of the composites due to the improvement of interfacial interaction caused by kenaf surface treatment. Generally, pretreatment of fibres in kenaf-reinforced composites usually shows improvement in tensile properties compared with untreated fibres which is increased fibre-matrix adhesion and dispersion of the fibre in the polymer matrix [17–19]. Kenaf was treated by alkaline treatment in order to reduce the hydrophilic properties which will provide better adhesion with polymer matrix as a reported by Mishra and Naik [11]. The efficiency of MAPP as compatibilizing agent improved the dispersion of rPA6 in rPP matrix which resulted in the formation of rPP/rPA6 copolymer [15, 20, 21].

Increasing the kenaf content in the composites by 20 wt.% has slightly increased the tensile strength (29 MPa) as compared to 10 wt.%. However, this value is still lower than the composites without kenaf. The reason for a reduction in tensile strength with the addition of kenaf was attributed to the properties of PA6 itself easily absorbs water. Kenaf also has high ability to absorb moisture from the environment and that influences the reduction of tensile strength. High contents of moisture in the composites caused the kenaf to slip easily when stress is applied. Previous researchers stated that rPA6 exhibited solid-like property with long relaxation time as compared to the rPP, thereby reinforcing the moisture influences [3]. The rPA6 had better resistance to applied force than rPP because rPA6 has a higher ability to absorb moisture better than rPP. Consequently, the moisture content in the rPA6 increased the efficiency of stress transfer.

Furthermore, the addition of 30 % kenaf into the composites has significantly increased the tensile strength to 32 MPa, and higher than as compared to the composites without kenaf. Better tensile strength was achieved because of better dispersion and adhesion of the kenaf reinforced polymer matrix. This result is in agreement with the previous findings [16]. The void areas in the composites are now fully occupied by kenaf. Hence, the closer arrangement of the fibres in the matrix the more the applied stress is easily absorbed by the composites, which then resulted in higher tensile strength. Generally, incorporation of kenaf in the composites has increased the tensile strength and achieved good mechanical properties [22].

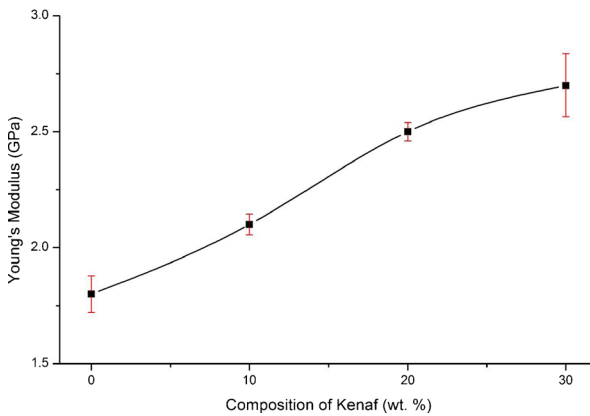


Fig. 2 The Young's modulus of kenaf reinforced rPP/rPA6 composites as a function of composition wt. % of the kenaf

Figure 2 shows the Young's modulus of composites versus kenaf compositions. From the figure, the Young's modulus increases proportionally to the increase in percentage of the kenaf in the composites. This is due to the void area occupied by the fibres in the blending polymers, increased the stiffness hence increased the Young's modulus of the composites. This result is in agreement with the previous study [23]. When the composition of kenaf in the composites increased, the Young's modulus of composites improved, resulting in a better resistance to the force applied to the composites.

Flexural test analysis

Figure 3 shows the flexural strength of the composites versus kenaf compositions. Referring to Fig. 3, without kenaf, the flexural strength recorded was 43 MPa, which then decreased to 37 MPa with the addition of 10 wt.% of the kenaf. The reduction might be due to the poor dispersion of the kenaf in the composites and poor adhesion

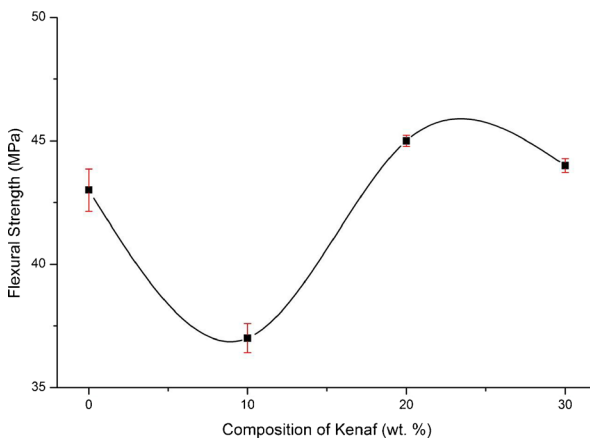


Fig. 3 The flexural strength of kenaf reinforced rPP/rPA6 composites as a function of composition wt. % of the kenaf

between kenaf and polymer matrix even when MAPP was incorporated into the system. Moreover, when kenaf was increased to 20 wt.%, the flexural strength drastically increased to 45 MPa which was slightly higher than the flexural strength of the composites without kenaf. This was due to the better adhesion of kenaf and polymer matrix, which shows that the unoccupied area in the composites has been occupied by kenaf. Further increase of kenaf into the system to 30 wt.% had a slightly decrease in the flexural strength of the composites but still higher than without kenaf. It was therefore concluded that the best flexural strength was at 20 wt.% of kenaf.

Similar to the results of Young's modulus, the flexural modulus increased proportionally with the kenaf compositions in the composites. Figure 4 shows the flexural modulus versus kenaf compositions in the composites. The flexural modulus recorded without kenaf was 1.6 GPa, which was slightly lower than the composites with kenaf at any compositions. When, 10 wt.% of kenaf was added to the composites, significant increase of flexural modulus was recorded which was 23 % higher than the composites without kenaf with a flexural modulus of 2.0 GPa. Then, further increase of kenaf to 20 and 30 wt. % also increased the flexural modulus. The flexural moduli achieved were 2.6 GPa and 3.1 GPa respectively. The reasons of the proportional increase of the flexural modulus were due to the void areas in the blends were occupied by the kenaf; thereby causing the composites to become stiffer than the composites without kenaf. A similar observation was also stated by others, higher improvement of mechanical properties was attributed to the efficient stress transfer from the polymer matrix to the kenaf which increased the composite stiffness [23]. Overall results of the flexural strength and modulus are in agreement with a previous study done by Sukri *et al.* [9].

Impact strength analysis

Figure 5 shows the impact strength of 70/30 rPP/rPA6 against kenaf compositions. It can be seen that an increased in kenaf compositions in the composites, resulted in a reduction of the impact strength. The introduction of 10, 20, and 30 wt.% of the kenaf,

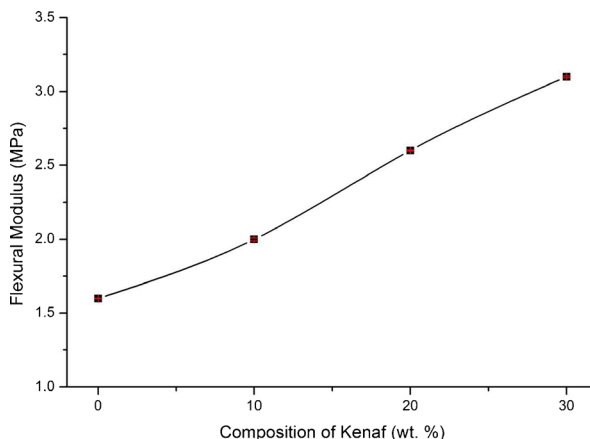


Fig. 4 The flexural modulus of kenaf reinforced rPP/rPA6 composites as a function of composition wt. % of the kenaf

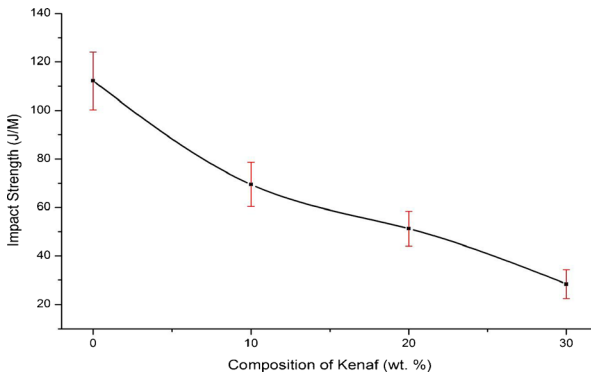


Fig. 5 The impact strength of kenaf reinforced rPP/rPA6 composites as a function of composition (wt. %) of the kenaf

gave the impact strength of 69.3, 51.22, and 28.40 J/M, and decreased by 38.0, 54.3, and 74.7 % than without kenaf, respectively. The decreased of the impact strength was due to the presence of kenaf in the composites, which reduced the energy absorbed by the composites. In other words, the addition of kenaf created the regions of stress concentrations which were required less energy to initiate a crack. It attributed to the changed in the fracture behaviour from ductile to brittle which increase the risk of kenaf to form an agglomeration at higher kenaf contents. The similar observation was reported on the study of short kenaf fiber-filled polypropylene composites treated with maleated polypropylene by Law *et al.*, [24].

Thermal analysis

The DSC results with different composition by weight of kenaf are shown in Table 1. It was observed that the kenaf reinforced rPP/rPA6 composites exhibited two separate fusion peaks from heating and cooling process. Cooling curves show two peaks, which is clearly independent of rPP and rPA6 crystallization. Moreover, when the composition of kenaf was increased in the composites, the crystallization of the rPP decreased whereas the crystallization of rPA6 was increased. This was typical of immiscible blends behaviour even though the composites were content with compatibilizer. The crystalline temperature for rPP/rPA6 composites was around 122 °C for all kenaf

Table 1 Crystallization and melting temperature of rPP/rPA6 blends with addition of MAPP as function of composition of kenaf (wt. %)

Compositions of kenaf	T_m (°C) (rPP)	T_m (°C) (rPA6)	ΔH_m (J/g) (rPP)	ΔH_m (J/g) (rPA6)	T_c (°C) (rPP)	T_c (°C) (rPA6)	ΔH_c (J/g) (rPP)	ΔH_c (J/g) (rPA6)	X_c (%) (rPP)	X_c (%) (rPA6)
0 wt.%	162.67	221.33	50.9789	15.0830	122.47	187.97	71.341	3.7047	83.61	29.95
10 wt.%	162.50	220.89	47.1105	12.9673	121.47	188.13	63.6421	6.398	83.27	30.87
20 wt.%	162.17	220.17	45.4054	9.0612	122.97	188.3	55.5607	8.9465	82.82	31.32
30 wt.%	163.00	221.17	38.4586	7.6799	122.3	189.63	53.9966	9.2461	82.15	31.89

compositions compared to PP alone was 112.6°C. The reason for the increase was due to the solidification of rPA6 phase improved the nucleation in the rPP phase [4]. The addition of MAPP as compatibilizer has caused the crystalline temperature of rPP to be higher than uncompatibilized composites. The crystallization temperature and the melting behaviour of blend rPA6/rPP with MAPP as compatibilizer gave a better melting and crystallization temperature than SEBS-g-MA and POE-g-MA compatibilizer as stated by previous researchers [10]. The MAPP was well mixed with PP matrix and it also reacted with the amide group of PA6. Good interaction between polymer matrix and compatibilizer resulted in high melting and crystallization temperature of the composites.

For the melting temperature of the blends, T_m for rPP and rPA6 decreased with an increase in kenaf compositions up to 20 wt.% kenaf. This is due to the thermal conductivity of kenaf was smaller than rPP, which delayed the release of melting heat to the rPP during DSC testing conditions [11]. When maleic anhydride from MAPP reacted with kenaf, the crystallization of rPP was hindered and thereby resulted in lower crystalline temperature. Different observation was made for rPA6 which was the crystalline temperature was higher as compared to without kenaf. However, at 30 wt.% of kenaf, the melting temperature was slightly higher. This was due to the increase in kenaf compositions in the composites that occupied the voids space in the composites; hence it improved the melting temperature of the composites. It can therefore be concluded that the minimum kenaf compositions to ensure it can act as reinforcement for the rPP/rPA6 blends was at 30 % kenaf.

Rheological analysis

Melt flow index analysis

Figure 6 shows the MFI versus kenaf compositions. From the figure, the MFI of the composites were inversely proportional to the increases of kenaf compositions. The composite without kenaf gave higher MFI, which was 12.0 g/10 min. The high value of MFI indicates that the composite are suitable to be processed by using injection moulding and extrusion. However, this value is still lower than the rPP and rPA6 with

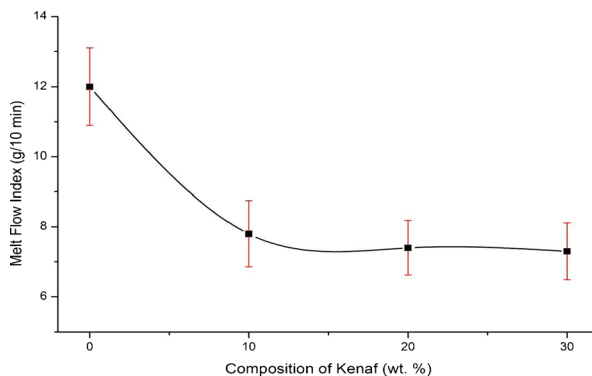


Fig. 6 The melt flow index (MFI) of kenaf reinforced rPP/rPA6 composites as a function of composition wt. % of the kenaf

MFI 23.7 g/10 min and 42.9 g/10 min, respectively. The reason for the difference in MFI between rPP, rPA6 and rPP/rPA6 composites was due to the void spaces in the rPP matrix were occupied by the dispersed rPA6 polymers. A similar observation was reported by the previous researcher, increasing rPA6 contents increased the crystallinity and sizes, hence improved their mechanical properties [4]. The presence of MAPP ensured the effectiveness blend in polymer matrix bind tightly between each other, which reduces the flow of the composites. Another reason is that the presence of MAPP allows the copolymer to interfere with PA6 polymer, binds both PP and PA6 effectively.

When 10 wt.% of kenaf was added to the composites, MFI drastically dropped to 7.8 g/10 min. However further increase of kenaf compositions to 20 and 30 wt.% led to a slight decreased in MFI of the composites, to 7.4 and 7.3 g/10 min, respectively. However, the addition of the kenaf into the composites did not affect the MFI values much. The reasons were when kenaf was added, the composites became packed, void spaces were occupied by the kenaf, then it led to an increase in the temperature to break the bond between polymer matrix and kenaf, thereby reducing MFI values, hence the composites became more difficult to processed using injection moulding. These results are in agreement with the previous study [4], where high crystallinity of composites with fibres reduced the melt flow of the composites during processing.

Shear viscosity

Figure 7 shows the actual shear viscosity against the actual shear rate with different kenaf compositions. It can be seen that, the actual shear viscosity decreased with an increased in actual shear rate for all blends. The highest actual shear viscosity was shown by the rPP/rPA6 blends with 10 wt.% of kenaf and followed by the blends of 20 wt.%, 30 wt.%, and 0 wt.% of kenaf respectively. The actual shear viscosity decreased with an increased in the kenaf composition in the blends was due to the rising temperature inside the barrel and die of capillary rheometer that burned the kenaf. The rising temperature burned the kenaf partially and formed a carbon layer at the surface of the kenaf. Thereby, allowing the carbon layer to act as a lubricant rather than as reinforcement to the composites that helped to improve the flow ability of the composites. This was indicated by decrement of the viscosity of the composites.

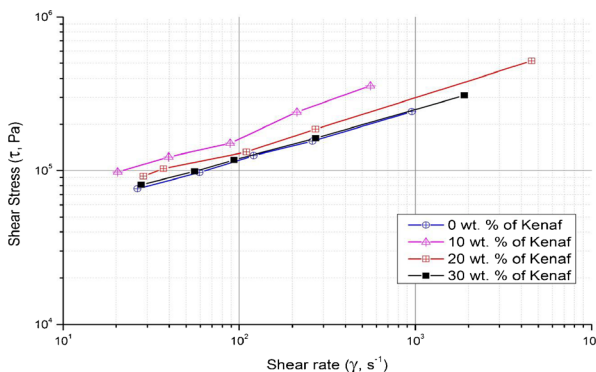


Fig. 7 Plots of shear stress as a function of shear rate for rPP/rPA6 composites at different loading of kenaf

Previously, a significant reduction in the shear viscosity and viscoelastic behaviour was shown by incorporation of filler in the molten polymers [25].

Shear stress

Figure 8 shows the actual shear stress against the actual shear rate with different kenaf compositions. It can be seen that, the actual shear stress increased with an increased in actual shear rate of the composites. The highest actual shear stress was shown by the rPP/rPA6 blends with 10 wt.% of the kenaf. It was followed by 20 wt.%, 30 wt.%, and 0 wt.% of the kenaf, respectively. In terms of the composite interphase point of view when kenaf was burned, the size of the kenaf reduced and a carbon layer was formed at the surface of the kenaf. The polymeric materials and kenaf became incompatible as a result of the carbon layer and consequently it weakens the adhesion and bonding between polymers matrix and the kenaf. Hence, less shear stress was recorded due to less energy requirement to break-up the interaction.

Figure 9 shows the illustration of kenaf before and after burning. It is assumed that, the size of the kenaf particles decreased during flow in the capillary. The burned kenaf formed small particles that agglomerated when it flow through the capillary rheometer. The agglomeration contributed to the poor compatibility between fillers and the polymeric matrixes [25]. The agglomerated kenaf weakens and caused de-bonding between the matrix and kenaf. Therefore, an increased in kenaf composition in the blends reduced the shear viscosity of composites. Another reason is that, the kenaf flow aligned with the flow direction of the composites and improved the flow ability of the composites. This is also attributed to the reduction of viscosity.

The hydrophilic properties of kenaf also led to the reduction in viscosity of the composites due to its high ability to absorb moisture. There was a time delay before the composites was tested in the capillary rheometer, hence it was assumed that the composites absorbed some moisture from the surrounding and enough to influence the rheological properties. The increased in the kenaf compositions in the composites increased the amount of moisture absorbed by the composites. The presence of high amount of moisture in the composites helped to increase the flow of the composites, hence reducing the shear viscosity and shear stress of the composites [25].

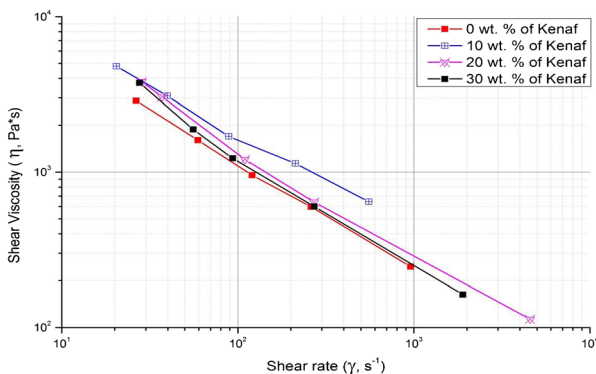


Fig. 8 Plots of shear viscosity as a function of shear rate for rPP/rPA6 composites at different loading of kenaf

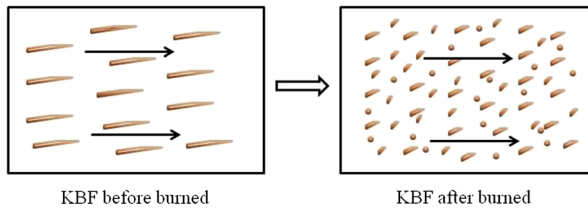


Fig. 9 An illustration of kenaf particles before and after capillary rheometer test of kenaf reinforced rPP/rPA6 composites

Morphological analysis

Figure 10 shows the rPP/rPA6 SEM micrographs of fracture surface of tensile test with different kenaf compositions. Figure 10a shows micrograph without kenaf, fine dispersion has been observed and facilitates good adhesion between rPP/rPA6 by the presence of MAPP in the composites. Huda *et al.* [16] reported that the compatibilizer causes a significant better wetting of the kenaf through the polymer matrix and good compatibility of rPP and rPA6 phase [4]. Good dispersion avoids unoccupied area of the blending; hence it gave a desired mechanical strength when stress or strain is applied to it, better mechanical strength compared to composites without compatibilizer. This was proven by the mechanical test applied to the composites, from Figs. 1, 2, 3 and 4, the mechanical properties shows that without kenaf, the composites have significant higher strength.

Moreover, when 10 wt.% kenaf was added; Fig. 10b shows that there are some void areas in the composite fracture, meaning that with 10 wt.% of kenaf, it's not enough to

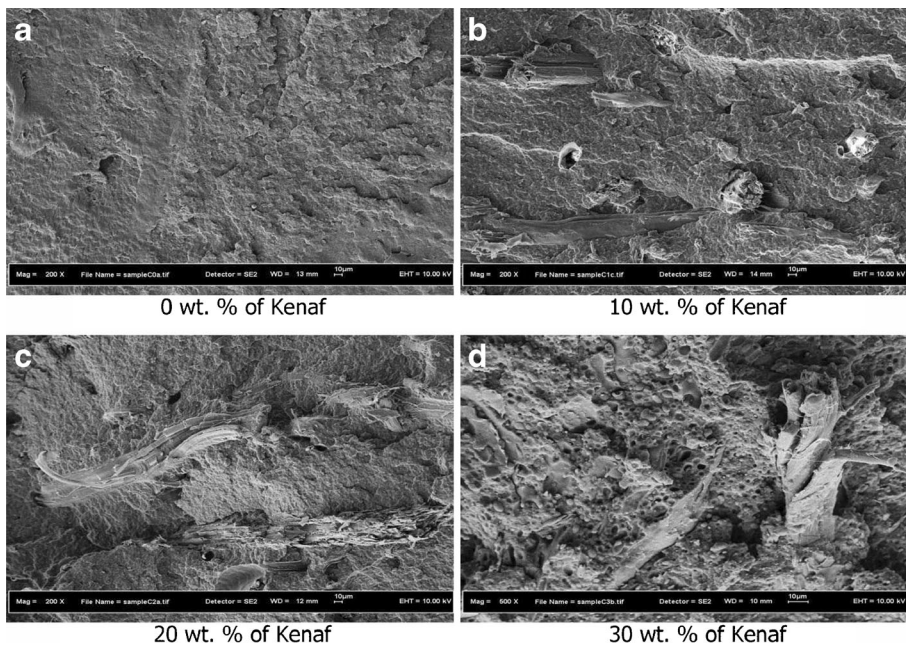


Fig. 10 The rPP/rPA6 morphology with compositions of kenaf, a) 0 wt.%; b) 10 wt.%; c) 20 wt.%; d) 30 wt.%

occupy all empty areas of the polymer blending. It is believed that these voids were occupied by moisture. The amount of kenaf was not enough to fully occupy the recycled polymer matrix and resulted in moisture being released by kenaf and trapped in molten polymers during processing. Also, there are still some empty spaces in the composites, which reduced the efficiency of transferring stress to the composites, and also lowering the mechanical properties. However, the occupied space of polymer matrix shows a good adhesion and dispersions of kenaf, which shows that the use of kenaf is compatible with these polymers. Other researchers stated that good adhesion between the polymer matrix and kenaf is shown with alkali treated kenaf [23].

Further increase of kenaf to 20 wt.% is shown in Fig. 10c. It showed that the unoccupied space reduced with an increased in kenaf contents. The kenaf occupied more empty space in the polymer matrix thus better mechanical strength was recorded due to better dispersion and distribution. It was also due to less moisture uptake in the polymer matrix that increased the stiffness of the composites. According to Figs. 1 and 4, there was an increase in mechanical properties compared to 10 wt.% kenaf. It shows that better dispersion in SEM micrograph is proportional to the mechanical properties of the composites.

Finally, the micrograph with 30 wt.% of kenaf added is shown in Fig. 10d. Better dispersion in the polymer matrix for kenaf was found in (Fig. 10d). Lesser unoccupied space can be seen which means that most of the void areas were occupied by the kenaf. The best kenaf dispersion is shown with 30 wt.% of kenaf. In conclusion, Fig. 10a-d shows the increase in kenaf composition to the composites resulted in better dispersion and adhesion.

Conclusion

The best Young's and flexural modulus are shown with the addition of 30 wt.% of kenaf fibres added into the rPP/rPA6 composites. However, the best flexural strength was recorded with the addition of 20 wt.% kenaf fibres in the blends. The MFI of the blends decreased with an increase of kenaf fibres compositions added into the blends. The decrease in MFI values led to difficulty in processing the composites using injection moulding. From the morphological study, the kenaf fibres were well dispersed in the blends with the addition of 30 wt.% kenaf fibres. It can be concluded that the best kenaf fibres composition for the rPP/rPA6 composites was with the addition of 30 wt.% kenaf fibres which produced green composite materials which is a potential for replacing the use of virgin materials and it will also reduce the number of plastic waste end in the landfills.

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