Effects of Processing Method, Moisture Content, and Resin System on Physical and Mechanical Properties of Woven Kenaf Plant Fiber Composites

Mohaiman J. Sharba,[a,c,]* Suhad D. Salman,[a,e] Zulkiflle Leman,[a] M. T. H. Sultan,[b] Mohamad R. Ishak,[b,d] and Mohammad A. Azmah Hanim [a,d]

Effects of the processing method, moisture content, and polymer type were evaluated relative to the physical and mechanical properties of composites based on natural plants. When kenaf was heated above the glass transition temperature of lignin, there was a reduction in moisture content by more than 8% of the total weight of the raw material. To investigate polymer behavior, the raw material was reinforced with three types of polymers: epoxy, unsaturated polyester (UP), and vinyl ester fabricated using hand lay-up with cold press (HCP) and vacuum infusion (VI). The results of (HCP) showed a noticeable improvement in tensile and flexural strength and their moduli for all types of polymer used compared with (VI), in ascending order from UP and vinyl ester to epoxy. Using the HCP method, the tensile strength improved considerably, by 60% for epoxy, 59% for UP, and 250% for vinyl ester, while flexural strength was enhanced by 16% for epoxy, 126% for UP, and 117% for vinyl ester compared to VI. Impact results showed a slight or no improvement in absorbed energy.

Keywords: Plant fiber; Kenaf; Polymer; Mechanical properties; Morphological; Moisture content; Vacuum infusion; Cold press

Contact information: a: Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia; b: Aerospace Manufacturing Research Centre (AMRC), Level 7, Tower Block, Faculty of Engineering, 43400 UPM Serdang, Selangor, Malaysia; c: Mechanical Engineering Department, AL-Suwayrah Technical Institute, Middle Technical University, Baghdad, Iraq; d: Laboratory of Bio-Composites Technology, Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia; e: Materials Engineering Department, Faculty of Engineering, The University of Mustansiriyah, Baghdad, Iraq;
** Corresponding author: mohaimaneng@gmail.com*

INTRODUCTION

Kenaf (*Hibiscus cannabinus*) fiber is a plant fiber offering numerous advantages such as biodegradability, considerable strength, low cost, and low density. The kenaf fiber is attracting high interest in the composite materials field, especially for polymer composites. There are a number of thermoset resins that show an excellent compatibility with synthetic and natural fibers. The applicability of composites made of natural and synthetic fibers have been highlighted in many studies, including those on plant fiber composites (Jawaid and Abdul Khalil 2011; Faruk *et al.* 2012; Salman *et al.* 2015a; Sharba *et al.* 2016). Some examples of such polymer resins include polyester, epoxy, and vinyl-ester. Natural fibers based composite usage has extended dramatically during the past few decades, and they are involved in many engineering applications because of their high specific strength and modulus, low density, bio-degradability, and considerable stiffness.

The processing of plant fiber composites and the final product properties are influenced significantly by factors such as moisture content of fiber, fiber loading, and orientation. Therefore, selection of the appropriate fabrication process for natural fiber composites is very important.

In recent years, manufacturing designers have focused on a number of criteria, such as size and shape of composites, favorable properties, speed of production, processing characteristics, and cost (Faruk *et al.* 2014).The fabrication method of a composite material influences the mechanical properties and is strongly related to parameters such as the direction and length of fiber and the resin system used (Thakur and Thakur 2014).The fabrication of composites based on thermosets is a multifaceted process that includes steps such as preparation, distribution on fibers, and curing (Salit *et al.* 2015)

One of the extensive studies (Rassmann *et al.* 2011) investigated the effects of water absorption and fiber loading on the mechanical properties of non-woven kenaf mat. The composites were fabricated using a resin transfer molding. The results showed that the composite properties were influenced greatly after immersion in water. Salleh *et al.* (2014) found that high-temperature processing led to an improvement in the tensile modulus of composites; in contrast, properties were reduced when processed at low processing temperatures, especially for high fiber contents. Furthermore, with increased fiber contents, the tensile strength and strain of the composite decreased at both low and high processing temperatures. Alkbir *et al.* (2014) investigated the effect of load-carrying capacity and geometry on energy absorption capability of hexagonal tube kenaf fiber reinforced composites. A kenaf fiber mat form was used to fabricate composites using a hand lay-up method. Fiore *et al.* (2015) combined two processing methods to fabricate unidirectional kenaf treated with 6% NaOH, first preparing the composites with a hand lay-up method, and then curing them in a vacuum bag. The composites were then immersed in water for two or four days. The mechanical properties were evaluated using scanning electron microscopy to examine morphological changes. All the composites offered higher moduli compared to neat epoxy resin after treatment. Yuhazri *et al.* (2010) compared the mechanical properties of kenaf fiber reinforced polyester composites fabricated with vacuum infusion and simple hand lay-up methods. The kenaf fiber was treated with two concentrations of NaOH. Based on the results, the vacuum infusion process appears to produce a slight improvement in the tensile properties compared with composites manufactured by the hand lay-up method. Ibrahim and Hafeez (2014) investigated experimentally the crashworthiness characteristics of kenaf fabric (mat) reinforced polyester (KFRP) circular tubes from the point of view of energy absorption, with different geometry. It was found that geometry was an important factor to determine the ability of a material to absorb energy.

Although kenaf fibers have the potential to supplement synthetic fibers in polymer composites, limitations arise with respect to mechanical performance and moisture absorption (Al-Oqla and Sapuan 2014; Hojo *et al.* 2014). The literature highlights the fact that there are many important design parameters yet to be investigated, such as cost, process suitability with natural fibers, expensive chemical treatments, and production time. Consequently, in this study, a comparison was made between methods involving vacuum infusion and hand lay-up with a cold press.

EXPERIMENTAL

Materials

Woven kenaf fiber was used as reinforcement material in this study. The fiber was thermally treated to remove the moisture before fabricating the composites. Three types of resins were used to fabricate the composites: epoxy, unsaturated polyester, and vinyl ester. The company ZKK Sdn Bhd, Malaysia, supplied all the materials used in this study. Table 1 shows the mechanical properties of each resin and catalyst percentage used.

Table1. Physical and Mechanical Properties of Thermosets Resin

Polymer	Density (g/cm^3)	Tensile strength (MPa)	Elastic modulus (MPa)	Elongation at Break (%)	Catalyst %
Epoxy LY556	1.14	73.3	3470	4.5	1:2 [HY951]
Unsaturated polyester	1.14	69	3800	2.3	0.2 [MEKP]
Vinyl ester	1.14	86	3200	5 - 6	0.2

Fabrication of Composites

Vacuum infusion (VI)

The fabrication of laminates was performed on a flat and smooth polished surface with releasing agent (glass was used in this work) to achieve a good surface finishing and ensure easy de-molding for the composite. The resin distributor, resin, vacuum pipes, and silicone tape were fixed in a suitable position at the edge of the fiber. One layer 30*30 cm^2 of kenaf fiber used to fabricate the composite laminates under a vacuum pressure of 100 bars and cold press methods. The kenaf fabric was dried in a ventilated oven at 105 °C for 24 h to remove moisture.

The resin first was mixed with the catalyst; after mixing, the matrix was loaded by feeding pipes until the whole fiber saturated with resin. The composites were cured at room temperature for 24 h before cutting to standard dimensions in preparation for mechanical tests. The fabrication procedure described by (Salman et al. 2015b) was used in this study.

Hand lay-up and cold press (HCP)

A combination of hand lay-up and hydraulic cold press methods was conducted to fabricate a single kenaf layer composite laminates. Kenaf fabric was dried in a ventilated oven at 105 °C for 24 h to remove moisture. The moisture content was measured for five samples, and the average value (8.3% of the total weight of the sample) was used. The resin was mixed with catalyst and then poured on each layer of fabric; a roller was used to separate the resin along the layers and expel the air bubbles from the surface, same procedure was repeated with epoxy and vinyl ester resins. After laying-up the reinforcements, the mold was closed and placed under a cold press at 50-bar pressure for 1 h. In addition, the composites were post-cured in an oven for 2 h at 80 °C, which was the curing temperature of unsaturated polyester, and finally left to cure at room temperature for 48 h before composites were cut to the required dimensions for testing.

In addition, the experimental density of composites was measured using Archimedes' approach following ASTM D-792 (1997b) method with distilled water and a sensitive digital balance with three significant figures. Five samples were measured, and the average value was recorded. The void contents of composites were determined using Eq. 1. In addition, the fiber volume fractions of composites were calculated using Eq. 2.

$$Void\ content\ (\%) = 1 - \rho_c \left[\frac{w_f}{\rho_f} + \frac{w_m}{\rho_m}\right] * 100\ \% \quad (1)$$

where W_f and W_m are the weight fractions of fibers and matrix. The ρ_c, ρ_f, and ρ_m are the densities of composite, fiber, and matrix, respectively.

$$v_f\% = \left[\frac{\left({w_k}/{\rho_k}\right)}{\left({w_k}/{\rho_k}\right)+\left({w_m}/{\rho_m}\right)}\right] * 100\% \quad (2)$$

where W_k, and W_m are the weight fractions of kenaf (fiber weight/composite weight) , and matrix (resin weight/composite weight) or (1- kenaf weight fraction). In addition, ρ_k and ρ_m are the densities of kenaf and matrix.

Characterization

Tensile testing

The tensile samples were cut according to the recommended dimensions of ASTM D-3039 (1995) with length of 250 mm, width of 25 mm, and gauge length of 170 mm. At least eight samples were prepared and tested. Results were averaged for tensile strength and other parameters. The testing was conducted using a universal testing machine (model 3366 with Bluehill software, Instron, USA) with a 100-kN load capacity and crosshead speed of 2 mm/min. Emery cloth tabs were used because of the low thickness of the samples and to prevent slipping of specimens during testing.

Impact (Izod) strength testing

The impact notched specimens were prepared according to ASTM D-256 (2006) with lengths of 63.5 mm, widths of 12.7 mm, and notch depths of 2.5 mm. The specimens were tested with energy of 0.5 J and speed of 6 m/s. Eight samples from each group were tested and averaged to obtain the impact strength and absorbed energy.

Flexural testing

The flexural strength and modulus of 127 x 12.7 mm samples were calculated according to ASTM D-790 (1997a). Three-point bending tests were conducted using universal testing machine (model 3365 with Bluehill software, Instron, USA) with a load capacity of 10 kN and cross head speed of 1 mm/min. The span length was determined using length to depth ratio of 16:1.

Morphological (SEM) examination

The Morphological observations were conducted using a model S-3400N PC-based variable pressure SEM (Hitachi, Japan). The fracture surfaces of specimens after tensile testing were observed. One sample from each group was observed to compare the results with different polymers. All fractured specimens were coated with a thin layer of gold using a model K575X Sputter Coater (Emitech, UK), to avoid electron charge accumulation, and subjected to a voltage of approximately 5 to 10 kV.

RESULTS AND DISCUSSION

Moisture content, processing procedure, and resin are important parameters that should be considered when choosing natural fibers as reinforcement in polymer composites (Rassmann *et al.* 2011). The moisture content could be used to determine electrical resistivity, dimensional stability, tensile strength, and porosity of natural fiber reinforced composites (Sukumaran *et al.* 2001). The average value of the moisture content of woven kenaf was 8.35% for five specimens, and the average water uptake was 148.86% for five specimens, after 24 h. It should be noted that results are within the range of other natural fiber results reported previously (Akil *et al.* 2011).

VI *vs*. HCP

It was found that vacuum infusion method (VI) ensures a uniform resin distribution over the fibers; however, this leads to a lower fiber volume fraction compared to hand lay-up with a cold press (HCP), in which the fiber volume fraction can be higher and controllable.

In terms of surface finishing, it was observed that the final composite had a rough surface, which can be attributed to the poor adhesion of natural fibers with resins. The composite formed by HCP was extremely smooth because of the static force applied. The thickness of the laminate was non-uniform with VI and showed no control of composite thickness because of the low pressure, and the thickness range was 2.5 to 3.3 mm, which is much higher than HCP, which gives composites with thicknesses of 1.9 to 2.1 mm. A comparison between VI and HCP is given in Table 2.

Table 2. Comparison of Kenaf Reinforced Composites using Vacuum Infusion (VI) and Hand Lay-up with Cold Press (HCP)

Property	(VI)	(HCP)
Volume fraction (%)	32 to 35	43 to 45
Void contents (%)	2.3 to 3.5	1.1 to 1.4
Thickness (mm)	2.5 to 3.2	1.7 to 2.1
Density (g/cm^3)	1.17	1.17
Cost	High	Very low
Fabrication time (h)	3 to 5	1 to 2

Mechanical Properties

Figure 1 shows a comparison of kenaf reinforced polymer composites. The highest tensile strength was obtained with epoxy resin; unsaturated polyester possessed lower strength, and vinyl ester had the lowest for both VI and HCP methods. Nevertheless, in terms of values, with the HCP method, the tensile strength improved considerably, by 60% for epoxy, 59% for UP, and 250% for vinyl ester. The tensile modulus increased for all composites in the same manner.

This notable improvement in tensile strength can be attributed to low moisture content, thickness reduction, and fewer voids, which leads to a better set of properties. These factors are well identified in the literature as parameters that affect the mechanical properties of natural fiber composites (Faruk *et al.* 2012). Good adhesion can result in additional matrix-fiber load transfer and produce more resistance from the composite.

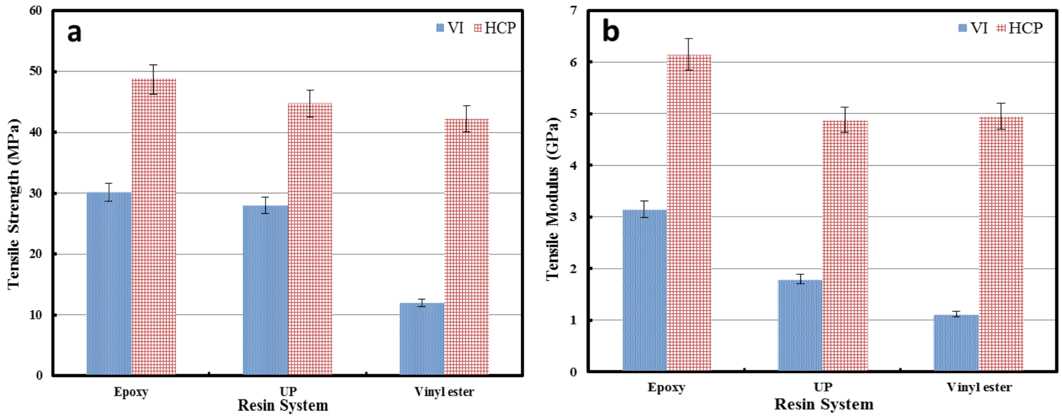

Fig. 1. Comparison of (a) Tensile strength, (b) Tensile moduli for composites using VI and HCP methods

Figure 2 shows the stress–strain curves for all composites tested. The HCP composite showed less strain, which can be attributed to high bonding between fiber and matrix, as the resin has low elongation at break (Ratna Prasad and Mohana Rao 2011).

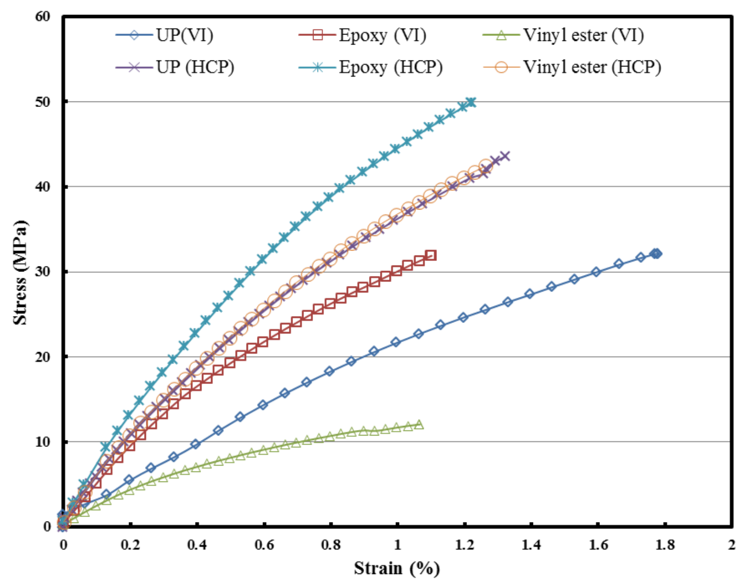

Fig. 2. Stress–strain curves of polymer reinforced kenaf fiber composites using HCP and VI methods.

The three-point bending test results were compared with previous work concerning VI composites. Figure 3 shows the improvement in flexural strength of HCP composites as a result of the absence of moisture and reduced void content. The results reveal an improvement in flexural strength of composites using the HCP method for the three types of resins, but with different percentages of improvement. The flexural strength of epoxy, which showed the highest value, was enhanced by 16%, that of UP increased by 126%, and that of vinyl ester increased by 117%. The low improvement with epoxy resin was due to the good specific properties of this type of thermoset and the high resistance to moisture compared with other kinds of polymers (Rassmann *et al*. 2011).

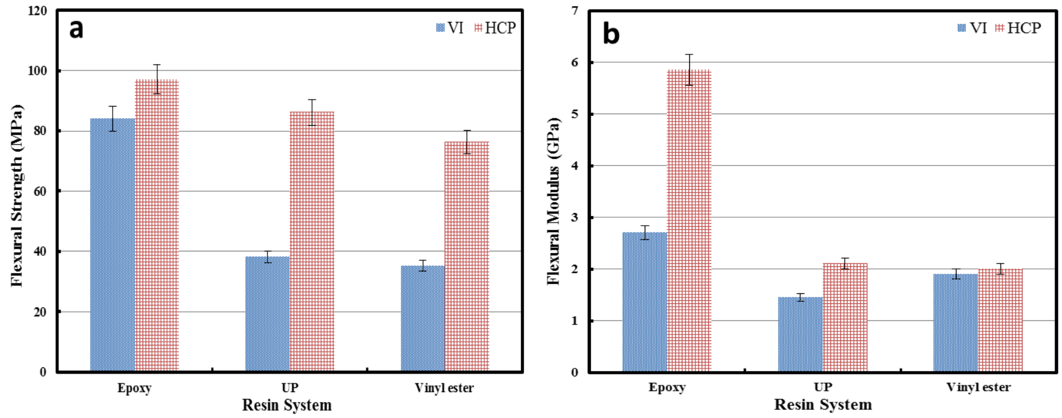

Fig. 3. Comparison of (a) Flexural strength, (b) Flexural moduli for composites using VI and HCP methods

Similar trends can be observed in the literature. The enhancement may be due to migration of lignin and the opening up of the fiber bundles. This leads to better fiber-matrix adhesion and results in low defects in the final composite (Prasad and Sain 2003; Bismarck *et al*. 2005; Dhakal *et al*. 2007).

Figure 4 depicts the flexural load-extension relationships for VI and HCP composites; the HCP showed better resistance for the composite to the applied load.

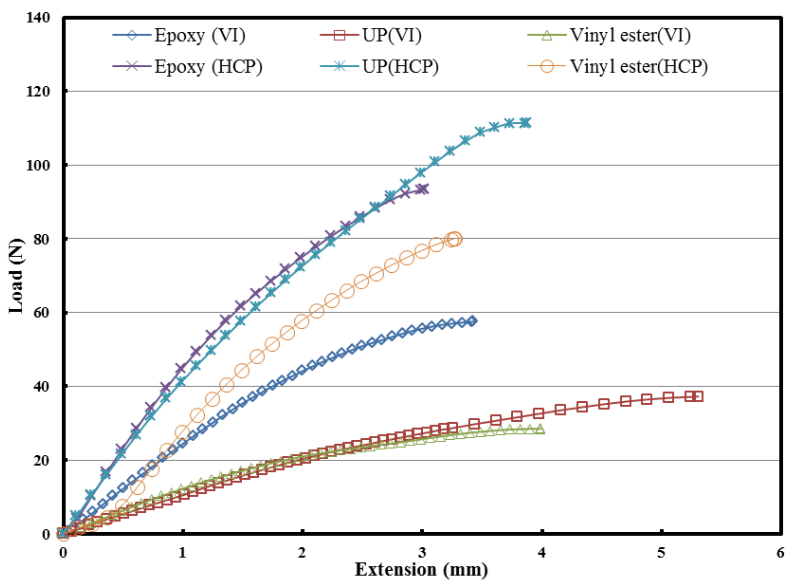

Fig. 4. Flexural load–extension relationship of kenaf fiber composites using different polymers types and methods

Generally, the impact results trend of composites in the three types of resins showed no improvement, while tensile and flexural results trend displayed a major enhancement in their strength and moduli relative to (VI) composites in current study as well as in previous study reported by (Salman *et al.* 2015b) with moisture. Although there was an improvement in both tensile and flexural strength, the energy absorbed showed a slight increase with epoxy and decreased with polyester and vinyl ester resins. Figure 5 shows the results of impacted specimens of VI and HCP composites. The results present the epoxy as the best polymer that can be used with kenaf, in terms of impact applications, because of its high strength and modulus with all types of loads. Moreover, the impact energy in polyester and vinyl ester showed no improvement compared to (VI) composites result and offered almost similar value because of the difference in failure mechanism and the load direction (Bismarck *et al.* 2005; Rassmann *et al.* 2011; Wong *et al.* 2010). A slight improvement was noticed with epoxy, this trend of result is confirmed by (Athijayamani *et al.* 2009) as they reported an equal impact strength of wet and dry roeselle/sisal/polyester composites, and concluded that moisture has no effect on impact strength of natural based composites.

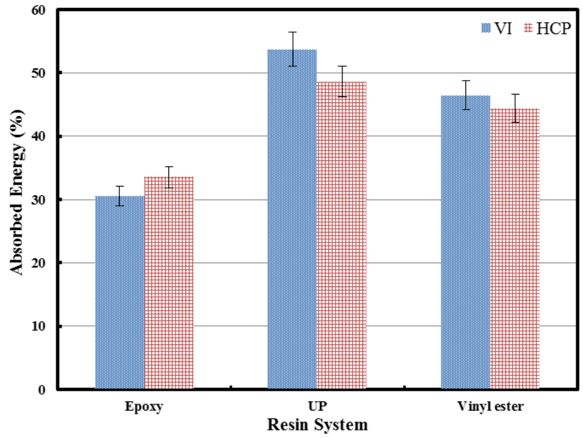

Fig. 5. Impact strength of kenaf reinforced polymer composites using VI and HCP methods

Morphology

Figure 6 (a-d) shows examples of typical SEM images for tensile test fiber fracture of kenaf unsaturated polyester composites.

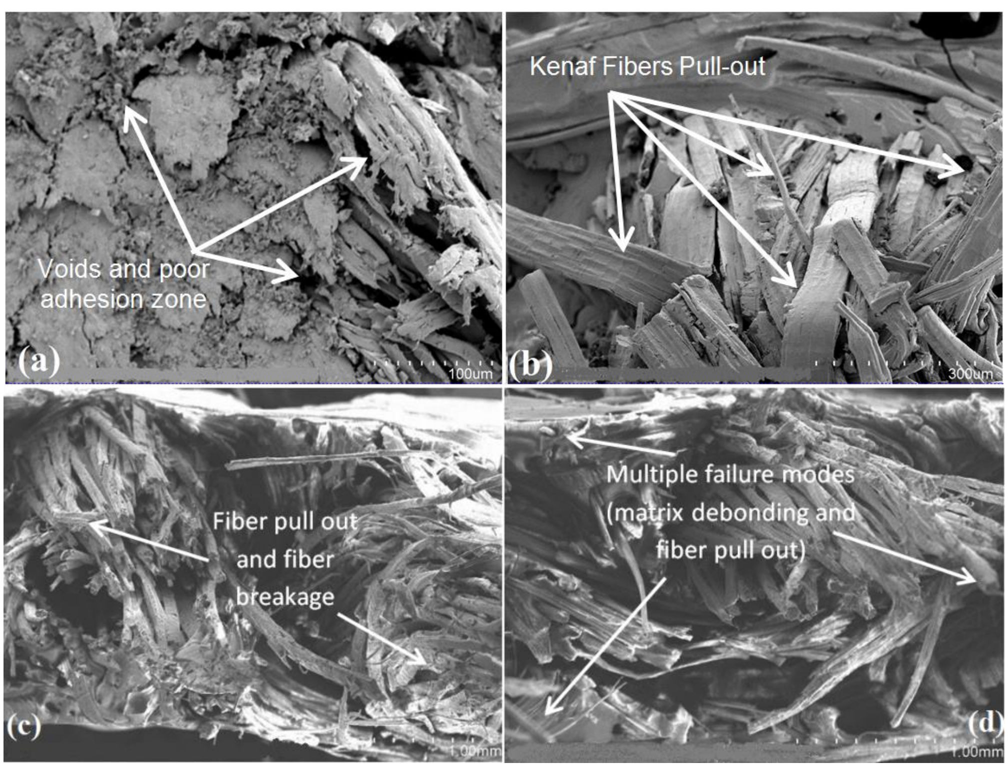

Fig. 6. SEM images of tensile section failure of kenaf reinforced UP composites (a) and (b) using VI method (c) and (d) using HCP method

Figures 6 (a) and (b) represent the composites fabricated using VI. In these images, many voids and pores can be observed and a high frequency of bundles having been pulled out, which is related to poor fiber-matrix adhesion. Therefore, these are regarded as the main reasons behind low tensile strength and modulus. On other hand, Figs.6 (c) and (d) shows a lower extent of fiber pull-out with more fiber breakage, which confirmed better fiber-matrix adhesion, also indicates fibers were carrying higher load share than matrix (Ku *et al.* 2011). It observed that the composites displayed an internal failure surface than VI composites. This perhaps explains the relatively poor impact strength of composites, which was an indication of fiber pull out, good fiber-matrix adhesion and impact strength reduction (Chow *et al.* 2000; Chen *et al.* 2009).

CONCLUSIONS

1. The hand lay-up with cold press (HCP) processing method resulted in better mechanical properties of woven kenaf fiber composites. Higher tensile and flexural strength and respective moduli of composites observed for all composites compared with vacuum infusion (VI).
2. The impact properties showed no noticeable change between composites fabricated by (HCP) and (VI) methods, as there was no observed improvement when compared to previous work reported (VI) with moisture, implying that impact strength is not dependent on these parameters.
3. Morphological observations indicated that HCP method offered better fiber-matrix bonding with low void contents, which resulted in an improvement to mechanical properties.

ACKNOWLEDGMENTS

This work supported by UPM under GP-IPS 9438714 and FRGS/5524499 grant. The authors would like to express their gratitude and sincere appreciation to the Ministry of Higher Education and Scientific Research of Iraq for its financial support.

REFERENCES CITED

Akil, H., Omar, M., Mazuki, A., Safiee, S., Ishak, Z., and Abu Bakar, A. (2011). "Kenaf fiber reinforced composites: A review," *Materials & Design* 32(8), 4107-4121. DOI: 10.1016/j.matdes.2011.04.008

Al-Oqla, F. M., and Sapuan, S. (2014). "Natural fiber reinforced polymer composites in industrial applications: Feasibility of date palm fibers for sustainable automotive industry," *Journal of Cleaner Production* 66, 347-354. DOI: 10.1016/j.jclepro.2013.10.050

Alkbir, M., Sapuan, S., Nuraini, A., and Ishak, M. (2014). "Effect of geometry on crashworthiness parameters of natural kenaf fibre reinforced composite hexagonal tubes," *Materials & Design* 60, 85-93. DOI: 10.1016/j.matdes.2014.02.031

Athijayamani, A., Thiruchitrambalam, M., Natarajan, U., and Pazhanivel, B. (2009). "Effect of moisture absorption on the mechanical properties of randomly oriented natural fibers/polyester hybrid composite," *Materials Science and Engineering: A*, 517(1), 344-353. DOI:10.1016/j.msea.2009.04.027

ASTM D-256. (2006). "Standard test methods for determining the izod pendulum impact resistance of plastics," ASTM International, West Conshohocken, PA.

ASTM D-790. (1997a). "Standard test methods for flexural properties of unreinforced and reinforced plastics and electrical insulating materials," ASTM International, West Conshohocken, PA.

ASTM D-792 (1997b). "Standard test methods for density and specific gravity (relative density) of plastics by displacement," ASTM International, West Conshohocken, PA.

ASTM D-3039. (1995). "Standard test method for tensile properties of polymer matrix composite materials," ASTM International, West Conshohocken, PA.

Bismarck, A., Mishra, S., and Lampke, T. (2005). "Plant fibers as reinforcement for green composites," *Natural Fibers, Biopolymers and Biocomposites* 37-108. DOI: 10.1201/9780203508206.ch2

Chen, H., Miao, M., and Ding, X. (2009). "Influence of moisture absorption on the interfacial strength of bamboo/vinyl ester composites," *Composites Part A: Applied Science and Manufacturing* 40(12), 2013-2019. DOI:10.1016/j.compositesa.2009.09.003

Chow, P., Lambert, R. J., Bowers, C., and McKenzie, N. (2000). "Physical and mechanical properties of composite panels made from kenaf plant fibers and plastics," *Proceedings of the 2000 International Kenaf Symposium, Yasuura, Hiroshima, Japan*, 139-143.

Dhakal, H., Zhang, Z., and Richardson, M. (2007). "Effect of water absorption on the mechanical properties of hemp fibre reinforced unsaturated polyester composites," *Composites Science and Technology* 67(7), 1674-1683. DOI: 10.1016/j.compscitech.2006.06.019

Faruk, O., Bledzki, A. K., Fink, H.-P., and Sain, M. (2012). "Biocomposites reinforced with natural fibers: 2000–2010," *Progress in Polymer Science* 37(11), 1552-1596. DOI: 10.1016/j.progpolymsci.2012.04.003

Faruk, O., Bledzki, A. K., Fink, H. P., and Sain, M. (2014). "Progress report on natural fiber reinforced composites," *Macromolecular Materials and Engineering* 299(1), 9-26. DOI: 10.1002/mame.201300008

Fiore, V., Di Bella, G., and Valenza, A. (2015). "The effect of alkaline treatment on mechanical properties of kenaf fibers and their epoxy composites," *Composites Part B: Engineering* 68, 14-21. DOI: 10.1016/j.compositesb.2014.08.025

Hojo, T., Xu, Z., Yang, Y., and Hamada, H. (2014). "Tensile properties of bamboo, jute and kenaf mat-reinforced composite," *Energy Procedia* 56, 72-79. DOI: 10.1016/j.egypro.2014.07.133

Ibrahim, T., and Hafeez, T. M. (2014). "A study of crashworthiness characteristic of woven kenaf fabric reinforced composites tube," Universiti Tun Hussein Onn Malaysia.

Jawaid, M., and Abdul Khalil, H. (2011). "Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review," *Carbohydrate Polymers* 86(1), 1-18. DOI: 10.1016/j.carbpol.2011.04.043

Ku, H., Wang, H., Pattarachaiyakoop, N., and Trada, M. (2011). "A review on the tensile properties of natural fiber reinforced polymer composites," *Composites Part B: Engineering* 42(4), 856-873. DOI: 10.1016/j.compositesb.2011.01.010

Prasad, B. M., and Sain, M. M. (2003). "Mechanical properties of thermally treated hemp fibers in inert atmosphere for potential composite reinforcement," *Materials Research Innovations* 7(4), 231-238. DOI: 10.1007/s10019-003-0258-y

Rassmann, S., Paskaramoorthy, R., and Reid, R. (2011). "Effect of resin system on the mechanical properties and water absorption of kenaf fibre reinforced laminates," *Materials & Design* 32(3), 1399-1406. DOI: 10.1016/j.matdes.2010.09.006

Ratna Prasad, A., and Mohana Rao, K. (2011). "Mechanical properties of natural fibre reinforced polyester composites: Jowar, sisal and bamboo," *Materials & Design* 32(8), 4658-4663. DOI: 10.1016/j.matdes.2011.03.015

Salit, M. S., Jawaid, M., Yusoff, N. B., and Hoque, M. E. (2015). *Manufacturing of Natural Fibre Reinforced Polymer Composites*, Springer. DOI: 10.1007/978-3-319-07944-8

Salleh, F. M., Hassan, A., Yahya, R., and Azzahari, A. D. (2014). "Effects of extrusion temperature on the rheological, dynamic mechanical and tensile properties of kenaf fiber/HDPE composites," *Composites Part B: Engineering* 58, 259-266. DOI: 10.1016/j.compositesb.2013.10.068

Salman, S. D., Leman, Z., Sultan, M. T. H., Ishak, M. R., and Cardona, F. (2015a). *Kenaf/Synthetic and Kevlar®/Cellulosic Fiber-Reinforced Hybrid Composites: A Review*. DOI: 10.15376/biores.10.4.Salman

Salman, S. D., Sharba, M. J., Leman, Z., Sultan, M., Ishak, M., and Cardona, F. (2015b). "Physical, mechanical, and morphological properties of woven kenaf/polymer composites produced using a vacuum infusion technique," *International Journal of Polymer Science*, 2015. DOI: 10.1155/2015/894565

Sharba, M. J., Leman, Z., Sultan, M. T. H., Ishak, M. R., and Azmah Hanim, M. A. (2016). "Effects of kenaf fiber orientation on mechanical properties and fatigue life of glass/kenaf hybrid composites," *BioResources* 11(1), 1448-1465.

Sukumaran, K., Satyanarayana, K., Pillai, S., and Ravikumar, K. (2001). "Structure, physical and mechanical properties of plant fibers of Kerala," *Metals Materials and Processes* 13(2/4), 121-136.

Thakur, V. K., and Thakur, M. K. (2014). "Processing and characterization of natural cellulose fibers/thermoset polymer composites," *Carbohydrate Polymers* 109, 102-117. DOI: 10.1016/j.carbpol.2014.03.039

Wong, K. J., Nirmal, U., and Lim, B. (2010). "Impact behavior of short and continuous fiber-reinforced polyester composites," *Journal of Reinforced Plastics and Composites* 29(23), 3463-3474. DOI: 10.1177/0731684410375639

Yuhazri, Y. M., Phongsakorn, P. T, and Sihombing, H. (2010). "A comparison process between vacuum infusion and hand lay-up method toward kenaf/polyester composite," *International Journal of Basic & Applied Sciences. Vol: 10 Issue*. DOI:10.1.1.365.7751

Article submitted: October 11, 2015; Peer review completed: December 2, 2015; Revised version received and accepted: December 6, 2015; Published: December 17, 2015.
DOI: 10.15376/biores.11.1.1466-1476