Available online at www.sciencedirect.com

ScienceDirect

Procedia Chemistry 19 (2016) 577 – 585

Procedia Chemistry

5th International Conference on Recent Advances in Materials, Minerals and Environment (RAMM) & 2nd International Postgraduate Conference on Materials, Mineral and Polymer (MAMIP), 4-6 August 2015

Pultruded Kenaf Fibre Reinforced Composites: Effect of Different Kenaf Fibre Yarn Tex

Mohd Hafiz Zamri[a], HazizanMdAkil[a,b]*, ZainalAriffinMohdIshak[a,b],

[a]School of Materials and Mineral Resources Engineering, Engineering Campus, UniversitiSains Malaysia, 14300 NibongTebal, Penang, Malaysia
[b]Cluster of Polymer Composite (CPC), Science and Engineering Research Centre (SERC), Engineering Campus, UniversitiSains Malaysia, 14300 Nibongtebal, Penang, Malaysia

Abstract

Manufacturing high performance composites from natural fibres is one of an ambitious goal currently being pursued by researchers across the globe. The ecological benefits of this material among many others are environmentally friendly and do not cause health problems. In terms of sustainability, the natural fibre is an appropriate alternative candidate to replace the synthetic and other types of reinforcement since it is a renewable resource. In order for natural fibre reinforced composite to become competitive, it has to accommodate the processing avenues of which has long being associated with its synthetic counterpart. Among those proven technology in manufacturing advanced engineering component is pultrusion. In this paper, an attempt has been made to produce pultrudedkenaf fibre reinforced unsaturated polyester composites via pultrusion. The properties of the pultrudedkenaf fibre reinforced composites with different kenaf yarn sizes are reported and compared. Pultruded composites made with smaller tex number i.e. tex 1400 shows better compression properties of as compared to larger tex number. Smaller tex number help to produce better wetting on fibre during production of composites, consequently help to increase its properties. Pultruded composites made with smaller tex number i.e. tex 1400 shows better compression properties of as compared to larger tex number. Smaller tex number help to produce better wetting on fibre during production of composites, consequently help to increase its properties.

Peer-review under responsibility of School of Materials and Mineral Resources Engineering, Universiti Sains Malaysia
*Keywords:*Kenaf fibres; Pultrusion; Tex; Mechanical property; Fibre loading

* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000
E-mail address: hazizan@usm.my

Peer-review under responsibility of School of Materials and Mineral Resources Engineering, Universiti Sains Malaysia
doi:10.1016/j.proche.2016.03.056

1. Introduction

By the increasing of worldwide social awareness about environmental impact, sustainability, and renewable energy sources, the polymer natural fibre composites recently have attracted the attention of researchers due to the fact that they are recyclable and biodegradable. The increasing environmental awareness and new rules and regulations are asking the industries to seek more ecologically friendly materials for their products. Nowadays natural fibres composites are replacing the synthetic and conventional fibre composites because of their easy availability, high specific strength, and low cost. Many studies have been made on the potential of the natural fibres as reinforcements for composites and in several cases the results have shown that the natural fibre composites own good advantages compared to synthetic fibre such as availability in large amounts, renewable, biodegradable, low cost, low density, less equipment abrasion and less skin and respiratory irritation[1-6]. Recent studies have investigated the development of biodegradable composite materials using natural fibres such as kenaf[7-9], flax[10, 11], bamboo[12], pineapple[13], sisal[14] and jute[15] as a reinforcement for biodegradable polymer composites. Concerning the matrix, the choice of unsaturated polyester is only based on economic interest. It incorporates very cheap resin, is easily available, has good mechanical properties, and has been used in many applications, such as transport, maritime, and sport [16].

Natural fibre reinforced composites can be produced by almost all production techniques including hand lay-up, press molding, resin transfer molding and many more. Nevertheless, the most proven technology in manufacturing advanced engineering component is pultrusion process. The strongest growth of any composites industry sector is found in pultrusionprocess which involve the manufacturing of continuous lengths of reinforced composites material with constant cross sections. It offers high content of reinforcing fibre materials i.e. almost 70% of fibre and also orderly layout of the fibre. Therefore the pultruded product strength is very high, oriented and programmable. It also improves the composite properties by forcing the fibre materials to lie under tension as the resin cures and are therefore the matrix and the fibre will tightly bonded to each other[17]. Pultruded composites are usually manufactured using thermosetting resin systems. Unsaturated polyester resins (USP) are widely used as a matrix because of relatively low price than other resins, ease of handling and possess a good balance of mechanical, electrical and chemical properties[18].

The combination of unsaturated polyester resin and kenaf fibres as reinforcement in composites will cater the demand for environmentally friendly materials. Since there are new interests in the development of natural fibre using the pultrusion process, many studies were found in this particular area recently [19-21]. In this study, preparation of pultrudedkenaf fibre reinforced composite (PKFRC) has been described. In addition, the compression and flexural properties of pultrudedkenaf fibre reinforced composites were studied as a function of different tex number of kenaf yarn fibre and volume fraction (v/v %) of kenaf fibre in the PKFRC samples.

2. Material and Methods

Kenaffibre yarns were supplied by JUTEKO Bangladesh, Pvt. Ltd. Bangladesh, in three different tex (sizes) which were tex 1400, tex 2200 and tex 3300. The tex number of the yarn refers to different diameter size of yarn used for pultrusion process. Tex is defined as a unit of measurement for the linear mass density of fibres and as the mass in grams per 1000 metres. Unsaturated polyester resin (Crystic P9901) was purchased from the Revertex Company, Malaysia. Other mixtures for resin such as benzoyl peroxide (BPO) as initiator, calcium carbonate ($CaCO^3$) as filler and the release agent powder were supplied by Revertex Company as well.

2.1 Preparation of Pultruded Composites

PultrudedKenaf Fibre Reinforced Composites (PKRFC) samples were prepared using a thermoset pultrusion machine at the School of Materials and Mineral Resources Engineering, UniversitiSains Malaysia, Penang, Malaysia. Kenaf fibre yarn, in roving form, were placed on bookcase-type shelves and equipped with a roving guide to lead the strands into the resin bath. The exact number of kenaf yarn fibres needed for the process was determined using a fibre calculation formula. The roving guide was used to ensure that the strands did not scrape across one another, as this generates a considerable amount of static, causing ‘fuzz balls’ to build-up within the resin bath, thus raising its viscosity and stuck in the die cavity.

Pultrudedkenaf fibre reinforced composite (PKRFC) samples were prepared using a thermoset pultrusion machine at the School of Materials and Mineral Resources Engineering, UniversitiSains Malaysia, Penang, Malaysia. Kenaf fibre yarn which was in roving form were placed on bookcase-type shelves and equipped with a roving guide to lead the strands into the resin bath. The exact number of kenaf yarn fibres needed for the process was determined using a fibre calculation formula. The roving guide was used to ensure that the strands did not scrape across one another, as this will generates a considerable amount of static that caused the ‘fuzz balls’ to build-up within the resin bath, thus raising its viscosity and stuck in the die cavity.

The continuous kenaf fibres were first impregnated with unsaturated polyester resin in a resin impregnation tank. A pulling device, which was set at 12mm/m was used to pull the resin impregnated kenaf fibre through a steel die in order to obtain the desired shape. Curing was carried out using a curing die, which is a precision machine used to impart the final shape. Curing of PKFRC occurred at a temperature of 120 ℃. Finally, a cutting mechanism was used to cut the continuous pultruded composites into desired lengths [21, 22]. The average diameter of all composite rods was 12.7mm.

2.2 Fibre Bundle Tensile Test (ASTM D3822-01)

Fibre bundle tensile strength tests were performed using a computer controlled Instron machine with a gauge length of 30 mm and a crosshead speed of 5 mm/min according to ASTM D3822-01. The fibre specimens were prepared and glued between two pieces of cardboard with dimension of 70 mm length and 30 mm width. The hole with diameter of 20 mm was prepared at the center of cardboard and the illustration of the cardboard was shown in Figure 1. During the test, the cardboard was cut at the edge so that only fibre will be tested. For every set of kenaftex size, 5 specimens were tested to determine the average fibre bundle strength. The test was conducted at a standard laboratory atmosphere of 25 ℃ and the results were collected.

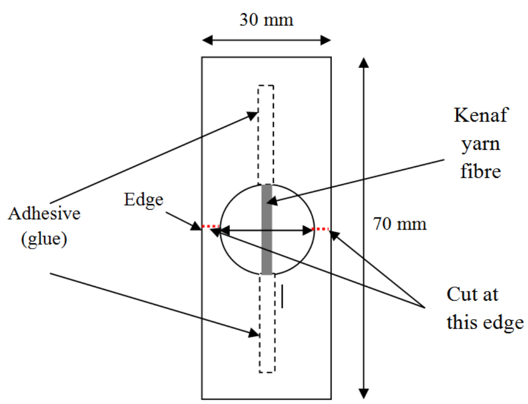


Fig. 1.Illustration of cardboard for fibre bundle tensile test

2.3 Flexural Test

A flexural test was performed using Instron 5982, in accordance with ASTM D4476–03. Specimens (pultruded rods with a diameter of 12.7mm) were cut into two parts, where the cross-section of each part is smaller than a half-round section. The total specimen length is 120mm with an overhang length of 10mm at both supports. The crosshead speed for the flexural test was set at 3mm/min. Three specimens for each condition were used to obtain a satisfactory result.

2.4 Compression Test

A compression test was performed using Instron 5982, in accordance with ASTM D 695-02a. The diameter and length of the specimen was 12.7mm and 25.4mm, respectively. The crosshead speed for the compression test was set at 1.3mm/min. Three specimens for each condition were used, in order to minimize errors.

3. Results and Discussion

3.1 Fibre Bundle Tensile Test

Table 1 shows the average diameter of kenaf yarn fibre with different tex. The diameter of kenaf yarn has been measured under stereo microscope using 5X magnification with 10 reading. It clearly shows that a bigger number of tex give a bigger diameter of kenaf yarn fibre. Basically the diameter of the yarn is related to the compaction of the yarn during twisting of the fibre into yarn form. Higher the number of fibre inside the kenaf yarn also caused more unruly fibrous of kenaf yarn which will be affected the properties of composites samples.

Table 1. Diameter of the different kenaf yarn fibre/tex

Tex	1400	2200	3300
Diameter (mm)	1.27	1.78	2.24

In practice, kenaffibres or others natural fibre are not used as single fibre, but it naturally come in group form such as in yarns or random form. Thus, tensile break of kenaf yarns bundles become the important part in the determination of kenaf yarn properties. Kenaf yarn fibre bundle tensile test with different tex of has been measured and the results are shown in Figure 2. From the Figure 2, it clearly shows that the larger size of the yarn give the higher tensile strength of the kenaf yarn. Basically, bigger the tex number and the diameter of the yarn, it will have higher number of individual kenaffibre in it. Higher the number of kenaffibre in the yarn, significantly will increase the tensile strength of the kenaf yarn. Figure 2 also shows that the tensile strength of kenaf yarn tex 3300 increased abruptly as compared to kenaf yarn tex 2200 and tex 1400. Kenaf yarn tex 3300 which have more fibrous fibre help to increase the kenaf yarn tensile strength as compared to the tex 1400 and 2200.

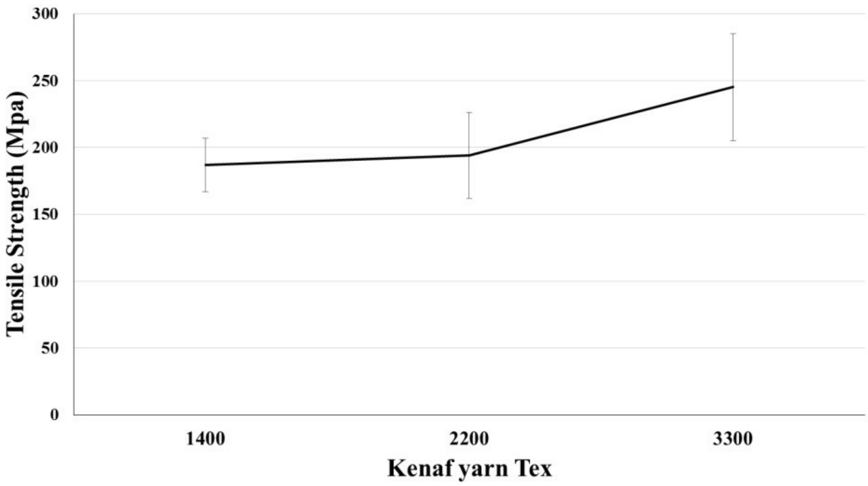


Fig. 2.Kenaf yarn fibre bundle tensile strength with different tex number

3.2 Mechanical Properties

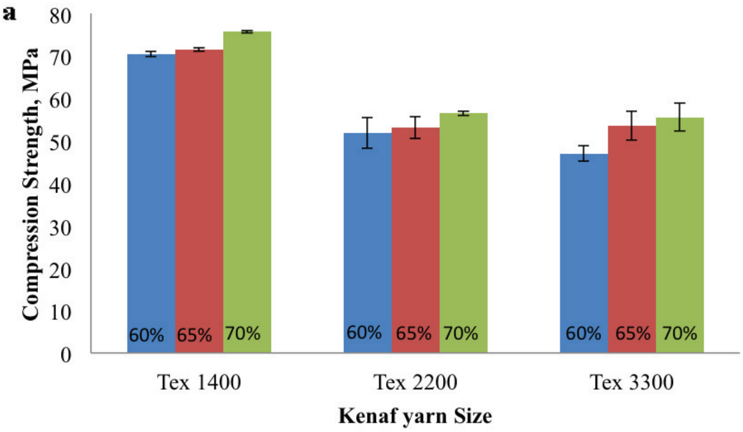
3.2.1 Compressive Properties

Compression strength, maximum compression strain and compression modulus for pultrudedkenaf fibre reinforced unsaturated polyester composite with different kenaf fibre tex are showed in Figure 3a–c, respectively. Each value represents an average data of three specimens. Figure 3a and 3c show that the compression strength and compression modulus of the PKFRC influenced by the fibre volume fraction and kenaf yarn tex number used. The highest compression strength recorded for sample made by 70% of fibre loading for all three different size of kenaf yarn. Compression modulus also increases remarkably with increasing the fibre content, showing a greater improvement than that seen in the strength. This proved that the increasing of fibre on the composites materials directly improve the mechanical properties of the composites [10, 15, 16].

Figure 3a and 3c also show a trend of decrease in compression strength and compression modulus with increasing size of yarn used to prepare the samples. Smaller the tex number of kenaf yarn i.e. tex 1400 will give maximum compression strength and modulus to the PKFRC samples followed by the sample tex 2200 and tex 3300 respectively. Different diameter of kenaf yarn for each tex number require different number of yarn during production of PKFRC samples. For example, to prepare the 70% v/v of kenaf fibre loading pultruded composite, it require 55 of kenaf yarn tex 1400 whereas for kenaf yarn tex 2200 and 3300, it require 43 and 35 of kenaf yarn respectively. In addition, better impregnation process between USP resins with kenaf yarn fibre easily archived to smaller diameter of kenaf yarn as compared to larger diameter of kenaf yarn. Better wetting of kenaf yarn with the USP resins give higher compression strength and compression modulus to PKFRC sample tex number 1400 as compare to tex 2200 and 3300.

Figure 3b shows the variation of the maximum compression strain of PKFRC for all samples with different fibre contents. The percent compression strain largely decreases with increasing of the fibre content. The maximum compression strains are directly related to the strength of the PKFRC samples. As the strength increases, it becomes more rigid and less flexible, thus the maximum strain compression will decrease. Base on the Figure 3b, the lowest compression strain are recorded for samples made of kenaf yarn tex 1400 followed by samples made of kenaf yarn tex 2200 and tex 3300.

a



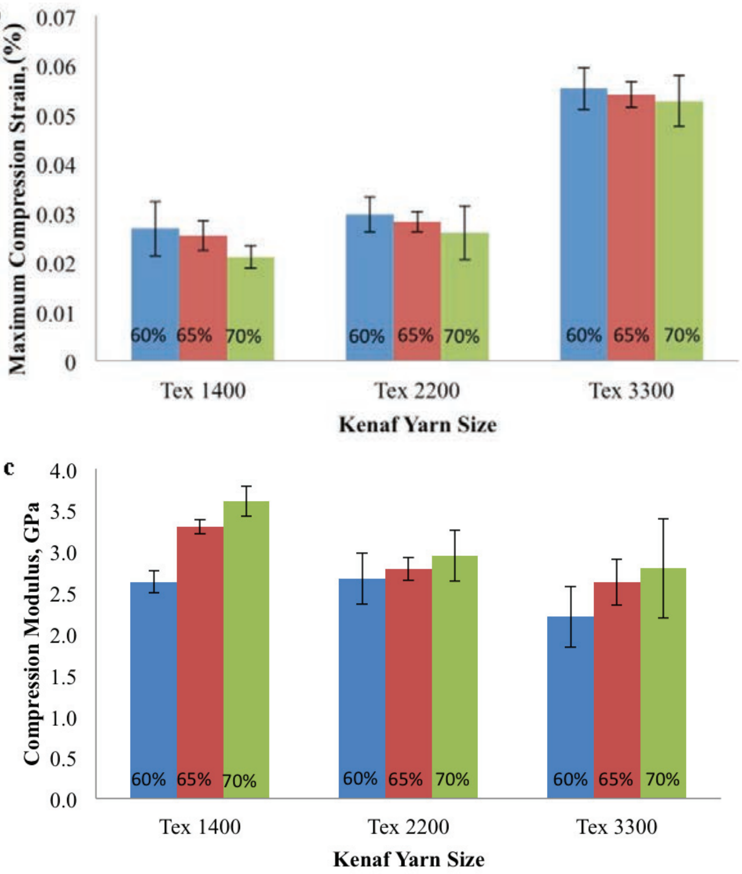


Fig. 3.Variations of (a) Compression strength, (b) maximum compression strain, and (c) compression modulus for pultrudedkenaffibre reinforced unsaturated polyester composite with different fibre loading and kenaf yarn size of tex 1400, 2200 and 3300

3.2.2 Flexural Properties

Figure 4a and 4c shows the flexural strength and flexural modulus for PKFRC, respectively. It clearly shows that the flexural properties of PKFRC increase with increasing fibre loading in the samples. For example, flexural strength for PKFRC made of kenaf yarn with tex 1400 are 253MPa, 278 MPa and 282 MPa for samples of 60%, 65% and 70% fibre loading, respectively. Similar trend are recorded for both composite samples made of kenaf yarn tex 2200 and tex 3300. The same finding was found by other researchers in which higher fibre loading will impart better flexural properties to composite materials [1, 8, 11].

Changing the tex number of kenaf yarn tex also significantly change the flexural properties of PKFRC samples. Figure 4a an 4b clearly show that the flexural properties decrease by increasing the kenaf yarn tex number. This trend actually follow the same trend obtained from the compression test discussed previously. The Figure 4a and 4c cleary show flexural strength and flexural modulus show higher maximum value for sample made from kenaf yarn tex 1400 followed by tex 2200 and 3300.

Figure 4b shows the result of the maximum flexural strain of PKFRC for all samples with different fibre contents. The percent compression strain largely decreases with increasing of the fibre content. The maximum flexural strains basically related to the strength of the PKFRC samples. Higher the samples' strength, it become less flexible, thus the maximum strain flexural will decrease. Base on the Figure 4b, the lowest flexural strain are recorded for samples made of kenaf yarn tex 1400 followed by samples made of kenaf yarn tex 2200 and tex 3300.

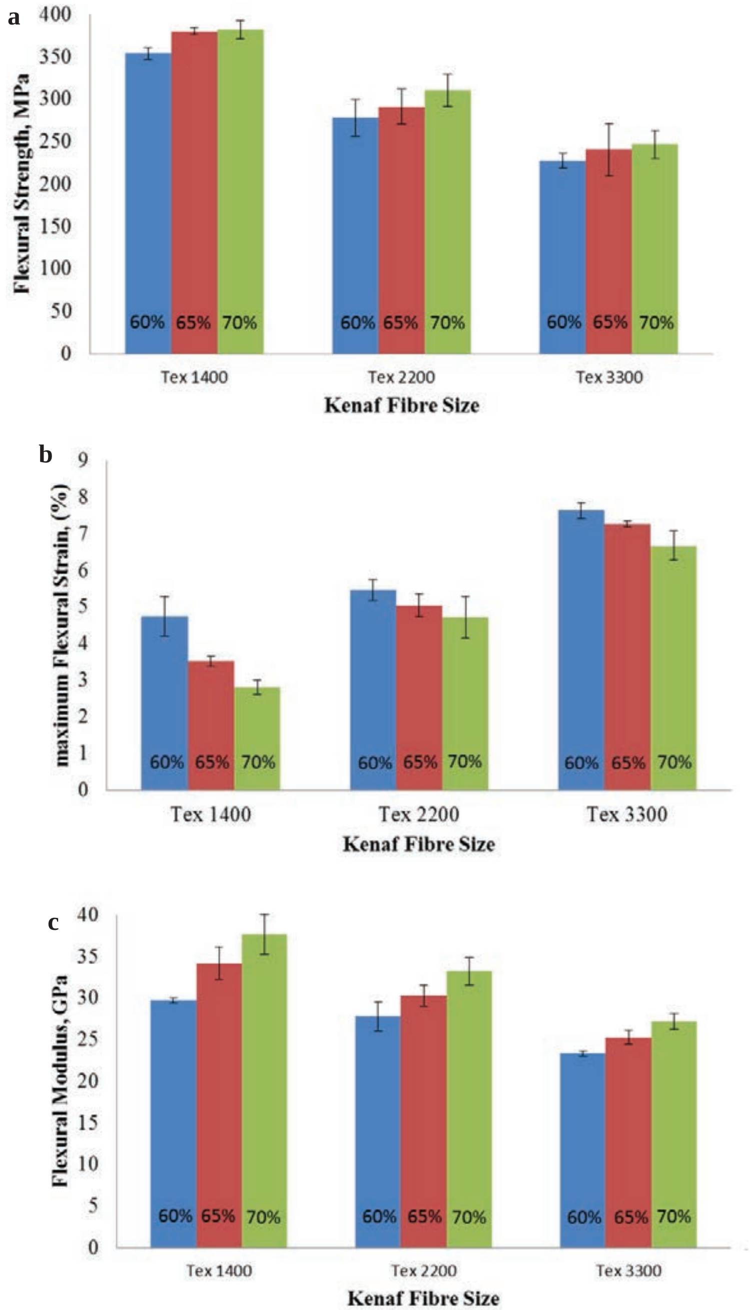


Fig. 4.Variations of (a) flexural strength, (b) maximum flexural strain, and (c) flexural modulus for pultrudedkenaffibre reinforced unsaturated polyester composite with different fibre loading and kenaf yarn size of tex 1400, 2200 and 3300

Both compression and flexural properties of PKFRC show that kenaf yarn with tex number 1400 show better performance as compared to kenaf yarn tex number 2200 ad 3300. Effectiveness of kenaf yarn wetting during impregnation process significantly become the important aspect of this issue. Figure 5 (a-c) show the cross sectional area of 70% v/v PKFRC sample made of (a) tex 1400, (b) tex 2200 and (c) tex 3300 with 30X magnification respectively. All figures clearly shows the present of kenaf yarn fibre (dark region) in round shape, the USP resin area (white region) and the micro crack. In the Figure 5a, tex 1400 give solid view of kenaf fibre inside the USP region with the present of crack between the kenaf fibre. This indicate that micro crack present in the resin region only. However, in the Figure 5b and 5c, the kenaf fibre region and resin region are hardly to identify. Moreover, there are micro crack present inside the kenaf yarn region. This indicate that there are poor wetting of kenaf fibre yarn to the USP resin. Poor wetting of reinforcement materials in the composite cased the lower properties of PKFRC sample of kenaf yarn tex 2200 and 3300 as compared to tex 1400.

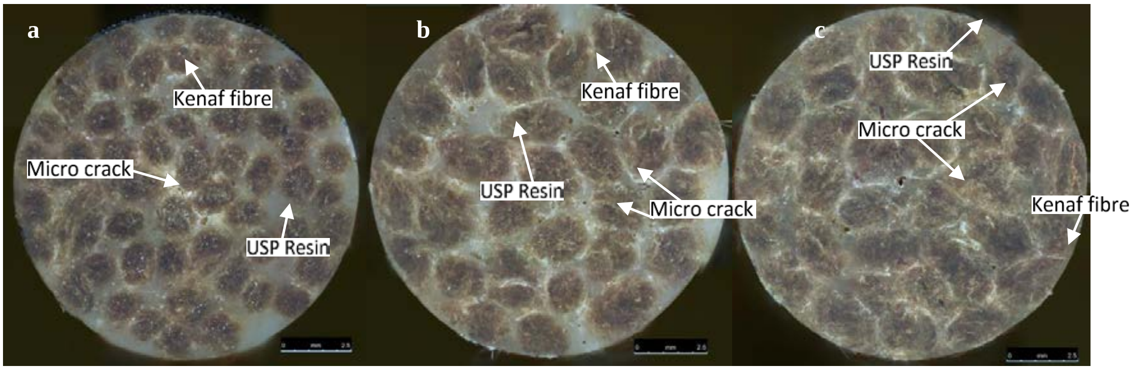


Fig.5: Cross sectional area of 70% v/v PKFRC sample made of (a) tex 1400, (b) tex 2200 and (c) tex 3300 with 30X magnification

The mechanical properties such as compression and flexural properties are strongly depending on several experimental factors like constitutive materials and processing parameters. Among them, the properties of the fibre reinforcement and matrix, fibre content, fibre length, fibre orientation, and processing method and condition are critically important. Indirect comparisons among the composite materials processed data with corresponding weight fraction of natural fibres with a similar type of reinforcement often provide useful information on understanding their performances and potentials [15]. However, the properties of natural fibre-based composites also rely on the sources of natural fibre which comes with different chemical composition and internal structure. In general, natural fibres exhibit considerable variation in fibre diameter along the length of individual filaments. Therefore, it is not simple and easy to compare their composite properties directly because the material, processing and analytical factors do not correspond to each other.

4. Conclusions

The development of high performance of composite structures using pultrusion process was successfully performed using kenaffibre as reinforcing materials at different fibre loading. Three different tex of kenaf yarn used in the production of PKFRC samples which were tex 1400, 2200 and 3300. Smaller the tex number require more number of yarn during production since it has smaller diameter. The observation and testing result showed that the increases of fibre loading in PKFRC increase the compression and the flexural properties. Maximum compression and flexural results recorded for sample made of 70 % of fibre loading (%v/v). The smaller the tex number of kenaf i.e. tex 1400 yarn give maximum compression and flexural properties to the PKFRC followed by the samples made of kenaf yarn tex 2200 and tex 3300. Effectiveness and better wetting of smaller tex number as compared to larger tex number help to improve the compression and flexural properties of PKFRC samples.

Acknowledgements

The authors wish to thank all contributors and their colleagues at the Institute of Postgraduate Studies and the UniversitiSains Malaysia (RU 814023).The authors gratefully acknowledge all technical and financial support.

References

1. Nosbi N, Akil H, Ishak Z, Bakar A. Degradation of compressive properties of pultrudedkenaffiber reinforced composites after immersion in various solutions. Materials & Design. 2010.
2. MunikencheGowda T, Naidu A, Chhaya R. Some mechanical properties of untreated jute fabric-reinforced polyester composites. Composites Part A: Applied Science and Manufacturing. 1999;30(3):277-84.
3. Li Y, Mai Y-W, Ye L. Sisal fibre and its composites: a review of recent developments. Composites Science and Technology. 2000;60(11):2037-55.
4. Joshi S, Drzal L, Mohanty A, Arora S. Are natural fiber composites environmentally superior to glass fiber reinforced composites? Composites Part A: Applied Science and Manufacturing. 2004;35(3):371-6.
5. Mazuki AAM, Akil HM, Safiee S, Ishak ZAM, Bakar AA. Degradation of dynamic mechanical properties of pultrudedkenaf fiber reinforced composites after immersion in various solutions. Composites Part B: Engineering. 2011;42(1):71-6.
6. Zamri MH, Akil HM, Bakar AA, Ishak ZAM, Cheng LW. Effect of water absorption on pultruded jute/glass fiber-reinforced unsaturated polyester hybrid composites. Journal of composite materials. 2012;46(1):51-61.
7. H. Akil, M. Omar, A. Mazuki, S. Safiee, Z. Ishak, A.A. Bakar, Kenaf fiber reinforced composites: a review, Materials & Design, 32 (2011) 4107-4121.
8. B. Yousif, A. Shalwan, C. Chin, K. Ming, Flexural properties of treated and untreated kenaf/epoxy composites, Materials & Design, 40 (2012) 378-385.
9. M.H. Zamri, M.R. Osman, H.M. Akil, Z.A.M. Ishak, H.A. Shahidan, Properties of Pultruded Natural Fiber Reinforced Composites: Effect of Different Kenaf Fiber Yarn Tex, Journal of Biobased Materials and Bioenergy, 9 (2015) 128-135.
10. C. Kong, H. Park, J. Lee, Study on structural design and analysis of flax natural fiber composite tank manufactured by vacuum assisted resin transfer molding, Materials Letters, 130 (2014) 21-25.
11. D. Scida, M. Assarar, C. Poilâne, R. Ayad, Influence of hygrothermal ageing on the damage mechanisms of flax-fibre reinforced epoxy composite, Composites Part B: Engineering, 48 (2013) 51-58.
12. C. Verma, V. Chariar, Development of layered laminate bamboo composite and their mechanical properties, Composites Part B: Engineering, 43 (2012) 1063-1069.
13. N. Kengkhetkit, T. Amornsakchai, Utilisation of pineapple leaf waste for plastic reinforcement: 1. A novel extraction method for short pineapple leaf fiber, Industrial Crops and Products, 40 (2012) 55-61.
14. Ramzy, D. Beermann, L. Steuernagel, D. Meiners, G. Ziegmann, Developing a new generation of sisal composite fibres for use in industrial applications, Composites Part B: Engineering, 66 (2014) 287-298.
15. H.M. Akil, C. Santulli, F. Sarasini, J. Tirillò, T. Valente, Environmental effects on the mechanical behaviour of pultruded jute/glass fibre-reinforced polyester hybrid composites, Composites Science and Technology, 94 (2014) 62-70.
16. Brahim SB, Cheikh RB. Influence of fibre orientation and volume fraction on the tensile properties of unidirectional Alfa-polyester composite. Composites Science and Technology. 2007;67(1):140-7.
17. Mishra S, Mohanty A, Drzal L, Misra M, Parija S, Nayak S, et al. Studies on mechanical performance of biofibre/glass reinforced polyester hybrid composites. Composites Science and Technology. 2003;63(10):1377-85.
18. Mazuki A, Akil H, Safiee S, Ishak Z, Bakar A. Degradation of dynamic mechanical properties of pultrudedkenaffibre reinforced composites after immersion in various solutions. Composites Part B: Engineering. 2010; 42,(1): 71–76.
19. Akil H, Cheng L, MohdIshak Z, Abu Bakar A, AbdRahman M. Water absorption study on pultruded jute fibre reinforced unsaturated polyester composites. Composites Science and Technology. 2009;69(11-12):1942-8.
20. Van de Velde K, Kiekens P. Thermoplastic pultrusion of natural fibre reinforced composites. Composite Structures. 2001;54(2-3):355-60.
21. Åström B. Manufacturing of polymer composites: CRC; 1997.
22. Starr T. Pultrusion for engineers: Woodhead Publishing; 2000.
23. Lee SM, Cho D, Park WH, Lee SG, Han SO, Drzal LT. Novel silk/poly(butylene succinate) biocomposites: the effect of short fibre content on their mechanical and thermal properties. Composites Science and Technology. 2005;65(3-4):647-57.
24. Nishino T, Hirao K, Kotera M, Nakamae K, Inagaki H. Kenaf reinforced biodegradable composite. Composites Science and Technology. 2003;63(9):1281-6.