EFFECT OF WATER ABSORPTION ON THE MECHANICAL PROPERTIES OF PULTRUDED KENAF FIBRE REINFORCED POLYESTER COMPOSITES

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ABSTRACT

Kenaf fibre reinforced polyester composites (KFRPC) were prepared using pultrusion method with 30:70 matrix to fibre ratio. The effect of water absorption 260 days in distilled water at room temperature on the mechanical properties was evaluated. Test results indicated KFRPC strengths had decreased with increase in percentage of water uptake. The moisture absorption leads the degradation and creating poor stress transfer efficiencies resulting in a reduction of mechanical properties.

Key words: kenaf fibre, fibre reinforced polymers (FRPs), water absorption, pultrusion.

1. INTRODUCTION

Fibre reinforced polymer (FRP's) has been successfully used in various applications especially in construction and building industries. These composites offer alternative materials to steel and aluminum for similar applications. There are various aspects that had encouraged the used of these composites such as easy handling, damage tolerance and low cost of fabrication [1-2]. The fibre reinforced polymer (FRP's) composite materials are the combinations of polymeric matrix resin with additives and the reinforcement fibres which are usually in the form of yarn. The commonly used polymeric matrix resins include vinylester, unsaturated polyester resin and epoxy with occasionally glass microsphere and clay particles as the additives [3].

To date, most FRPs' are produced using synthetic fibres typically glass fibre, carbon fibre and etc. FRP's using synthetic fibres are less competitive in terms of price as compared to steel and galvanized steel. In order for FRP's to advance as one of competitive materials in construction, the price has to be more competitive. One way of making FRP's more competitive is reducing the cost of fibre. The use of natural fibre (NF) as the material composite in place of synthetic fibre will tremendously reduce the cost of FRP due to the low prices of natural fibre (NF) [4]. There are varieties of natural plant fibres used as reinforcement fibre for FRP's such as hemp, sisal, jute and recently kenaf fibre. Presently, the use of kenaf fibre as reinforcement for FRP's is increasing rapidly due to its availability in the form of yarn which can suit various processing techniques of manufacturing FRP's especially pultrusion, filament winding and hand lay-up technique. In comparison, FRP's using natural fibres is better due to its high strength, greater moisture and flame retardant than pure wood. In terms of properties and esthetic values, NF is environmentally friendly, high specific stiffness, sustainable and renewable as compared to synthetic fibres [5]. Other than that, natural fibre (NF) has good specific strengths and modulus, economical viability, low density and good biodegradability [6-7]. However, the main problem associated with NF is that the properties of the fibre is strongly influenced by the geographical factors where it is grown such as the climate and the nature of soil [8]. Also, the moisture absorption in FRP's using NF has been reported to significantly affect its properties and performance [7, 9-10].

Another way of reducing cost of FRP is by choosing an appropriate processing technique. Commercial FRP's are normally produced using various techniques such as hand lay-up, spray-up, closed-mold infusion, extrusion and compression molding. One of the most promising processing techniques of manufacturing FRP with unlimited length is pultrusion. The continuous process of pultrusion technique consists of pulling rovings through a resin bath, then into preforming plate and finally into a die where the product is heated and cured to its final dimensions [11-12]. To date, limited numbers of works are re-

ported on producing fibre reinforced polymer (FRP) with natural fibre (NF) using pultrusion technique. Pultrusion process is capable of producing structural components that are commonly used in building and construction industries such as I-beam, and T-beam. The pultrusion process can produce product with high fibre content up to 70% by volume. Furthermore, the method allows production of constant cross-section with unlimited length.

In this study, kenaf fibre reinforced composite was produced using pultrusion machine. The matrix to fibre ratio was kept at 30:70 by volume. All composites were immersed in distilled water for a period of 260 days. The weight gain was closely monitored and the properties of composites were determined after the immersion period.

2. EXPERIMENTAL

2.1 Materials

Kenaf fibres used in this study were supplied by Malaysian Kenaf and Tobacco Board, Malaysia in the form of twisted yarn with diameter ranging from 3 mm to 3.5 mm. Table 1 shows the properties of the kenaf fibre supplied by the company. The Reversol P-9941 is an orthophtalic unsaturated polyester resin which was purchased from Revertex (M) Company, Malaysia containing filler (15.4%), Catalyst (1.6%) and mould releasing agent (3.8%).

Table 1: Properties of kenaf fibre

Properties	Unit	Value
TEX	g/km	1400
Density	g/cm^3	1.44
Tensile strength	MPa	393-773
Specific strength	UTS/density	302 - 595
E-modulus	GPa	26.5
Elongation	%	1.5 – 1.8

2.2 Preparation of kenaf fibre reinforced polyester composite (KFRPC)

KFRPC (in rod shape) with diameter of 12.7 mm was produced using pultrusion method with unsaturated polyester resins as matrix. Details of kenaf fibre and unsaturated polyester used are given in Table 2. Firstly the fibres were soaked in the resin bath and pull at a speed of 195 mm/min through a heated die at temperature of 135 °C. Finally, the cured KFRPC (in rod form) was cut into required length using a bench-saw.

Table 2: Details used of kenaf fibre and unsaturated polyester resins.

Properties	Unit	Value
Percentage of matrix	%	70
Percentage of fibre	%	30
Number of kenaf fibre roving	nos	60
Density of composite	g/cm^3	1.19

Table 3: Moisture absorption of KFRPC immersed in distilled water at room temperature.

Samples	Maximum of moisture content, M_m (%)		Initial slope of plot (k) M(t) versus t $^{1/2}$		Diffusion coefficient, D (mm^2/s)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Flexural	24.7	1.13	38.73×10^{-3}	0.83	1.93×10^{-5}	1.46×10^{-4}
Compression	25.1	0.56	38.34×10^{-3}	0.50	7.36×10^{-5}	1.08×10^{-4}

2.3 Material characterization

2.3.1 Water absorption tests

Specimens were immersed into distilled water at room temperature. For the water absorption measurements, the specimens were withdrawn from the waters, wiped dry to remove the surface moisture, and then weighted using an electronic balance with an accuracy of 0.1 mg to monitor the mass change during the aging process. The moisture content, *Mt (%)* of each specimen is calculated as follows:

$$Mt\,(\%) = \frac{w_t - w_o}{w_o}\, x\, 100 \quad (1)$$

where w_o is the dry weight and wt is wet weight after absorption.

2.3.2 Three point bending test

The flexural properties before and after water immersion were determined by performing three point bending experiments at room temperature. The test was carried out on an Instron 8802 testing machine. The sample was in semicircular cross section of the pultruded rod following ASTM D4476-03. Specimens (pultruded rod with diameter of 12.7 mm) were cut into two parts with the cross section of each part is smaller than a half round section. The total specimen length is 120 mm with overhang length of 12 mm at both supports. The crosshead speed was set at 6 mm/min. Five specimens were used to obtain a satisfactory result.

2.3.4 Compression test

Compression tests were carried out using Instron 8802 in accordance to the standard ASTM D695 test method. The diameter and length of the specimen were 12.7mm and 25.4mm respectively. The crosshead speed was set at 5 mm/min. Five specimens were used to minimize error.

2.3.5 Microstructure analysis

In order to investigate the effect of water absorption on the microstructure and mechanical properties of KFRPC, SEM micrograph was used to examine the kenaf fibre and composites before and after immersion.

3. RESULTS AND DISCUSSIONS

3.1 Sorption behaviour of KFRPC

The analysis of the diffusion mechanism was per-

formed once the water absorption characteristic was obtained for the entire composites. Two types of KFRPC samples were evaluated namely compression and flexural specimens. The sorption behaviour was characterized using Fick's law [13] which is derived from Fick's first and second laws of a homogeneous model where water molecules are assumed to penetrate in the surface layers of the polymer matrix and diffuse with the concentration gradient acting as a driving force.

It is expected that in the case of Fickian, the diffusion coefficient D is concentration-independent of the absorbed water through out the specimen and has the dimensional length^2 time^{-1} (mm^{2}s^{-1}) which can be determined from the slope of moisture content versus square root of time as depicted in Equation 2. The slope was taken at an early stage of the plot.

$$D = \pi \left(\frac{kh}{4M_m}\right)^2 \quad k = \left(\frac{M_2 - M_1}{\sqrt{t_2} - \sqrt{t_1}}\right)^2$$
$$D = \pi \left(\frac{h}{4M_m}\right)^2 \left(\frac{M_2 - M_1}{\sqrt{t_2} - \sqrt{t_1}}\right)^2 \quad (2)$$

Where k is the initial slope of a plot of Mt (%) versus √ t (√ h), Mm (%) is the maximum weight gain (%) and h (mm) is the thickness of the composites [9].

Fig. 1 shows percentages of weight gain as a function of square root of time for flexural and compression samples immersed in distilled water at room temperature for 260 days. The moisture content shows Fickian behaviour for both flexural and compression specimens where the moisture gain increases at the early stage of 36 hour (A) for then after 144 hour (B) slows and approaches saturation after prolonged immersion. The slightly higher percentage of water uptake for flexural specimens could be attributed to the specimen's shape where in this case, flexural specimen has an area of 1335.99 mm^2 as compared to compression 1266.76 mm^2. At the early stage, the presence of crack, void, defect due to processing results in the transporting of water molecules via crack, voids and defects became active along the fibre-matrix interface. At this stage, sharp increased in weight gain can be observed before moisture content reach saturation.

Diffusion coefficients (D) and maximum moisture content (Mm) for both flexural and compression specimens calculated using Equation 2 is summarized in Table 2. In comparison, the recorded values of D and Mm are somewhat comparable with

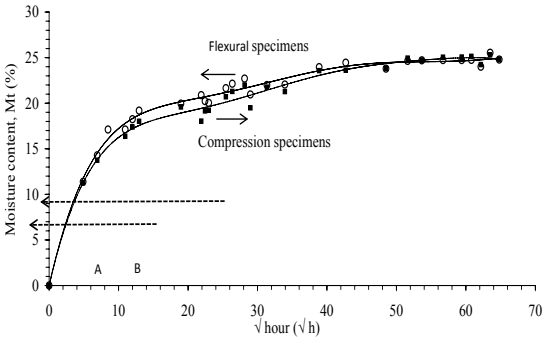

Fig. 1: Water absorption curves in distilled water for flexural and compression specimens

previously reported work [14] where the values D and Mm of immersed specimens are higher than pultruded jute fibre reinforced polyester composites. From Table 2, it can be seen that the maximum moisture content (Mm) and the diffusion coefficient (D) values of compression specimens are higher than that of flexural specimens. The difference can be attributed to the surface area that was in-contact with water molecules. Since the exposed compression area was higher, the amount of area was greater and therefore, the tendency of absorbing water was high. Greater amount of area also indicated that per volume of composite was higher. This could be due to the moisture, micro cracks developed on the surface and inside the materials [9, 15-16]. The moisture diffusion depends upon the molecular and microstructures aspects such as polarity, the extent of crystallinity of polymers and the presence of residual hardeners or other water attractive species [17-18].

3.2 Mechanical properties

3.2.1 Flexural properties

A series of flexural stress-strain curves corresponding to the samples immersed in distilled water at different exposure time are depicted in Fig. 2. Variations of flexural properties such as flexural strength,

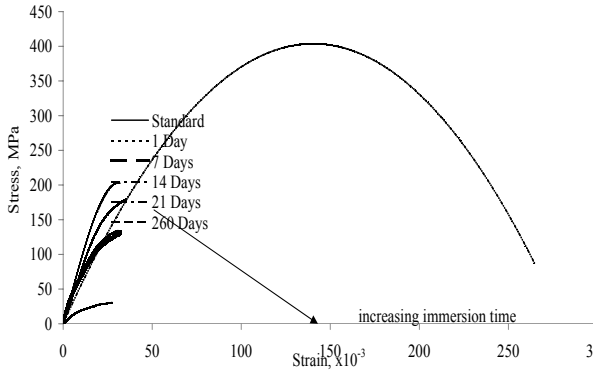

Fig. 2: Stress-strain curve of flexural test in distilled water immersion

maximum flexural strain and flexural modulus for kenaf fibre reinforced unsaturated polyester composite after being exposed to environmental condition are summarized in Fig. 3a-c. As shown in Fig. 3, the flexural strength and flexural modulus decreased with the increase time of immersion. It is assumed that the fibre-sensitive properties in composites are affected by moisture absorption where the stress transfer between fibre and matrix interface is less effective due to the presence of moisture. Moisture causes the formation of hydrogen bonding between the cellulose fibre and water molecules [9]. On the other hand, the maximum flexural strain at failure increased as the immersion time increased. The strain is higher compared to standard specimen, where the water molecules mostly act as plasticizers alter the failure modes of KFRPC under flexural loading.

3.2.2 Compression Test

Fig. 4 presents a summary of compressive stress-strain curves before and after immersion over a range time. On the other hand, Fig. 5a-c shows

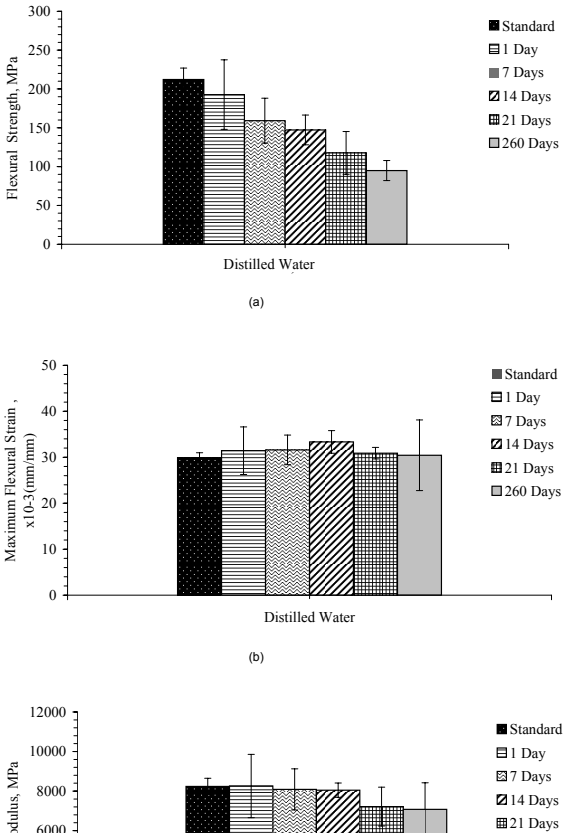

Fig. 3: Variations of (a) flexural Strength, (b) maximum flexural Strain at break/failure, and (c) flexural modulus for pultruded kenaf fibre reinforced unsaturated polyester composite after exposed to distilled water.

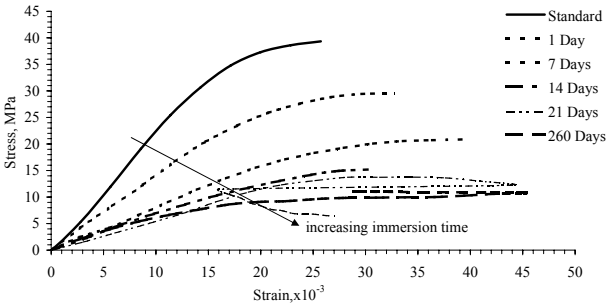

Fig. 4: A curve of compressive stress-strain for KFRPC immersed in distilled water.

the variations of compression strength, maximum compression strain and compression modulus for KFRPC. The compression strength and compression modulus decreased with increasing immersion time, whereas the compression strain increased with increasing immersion time. These results are similar

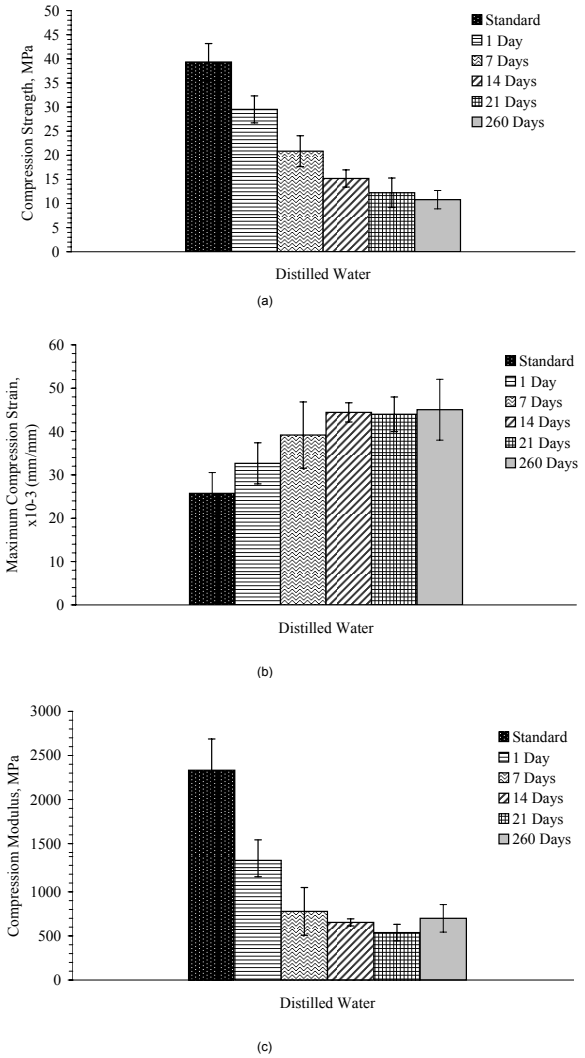

Fig. 5: Variations of (a) compression strength (b) compression strain at yeild (c) compression modulus for KFRPC with respect to immersion period in distilled water.

with the flexural properties as discussed earlier in previous section. The compression strength in Fig. 5 shows a reduction from 39 MPa to 10 MPa for standard and samples 260 days immersion. Similar observations have been reported for the flexural strength where it decreased 260 days of soaking in water. The high hydrophilic nature of the kenaf fibre attracts more water molecules which significantly weakens the interface KFRPC and thereby reducing the strength. Other than that, the reason of the water molecules absorbed, flow along cellulose fibre-matrix interfaces by the capillarity action and contributed towards the formation of hydrogen bonding. The cellulose structure was weakening which could have led to plasticization in KFRPC and increased the failure strain causing reduction in stiffness when the samples were exposed to distilled water [9]. The observations made earlier for the effect of water absorption on mechanical stress-strain properties indicated that the increase of moisture content will decrease the mechanical properties. It is due to the hydrogen bonding between water molecules and cellulose fibre that the natural fibres are hydrophilic. The fibre structure of hydroxyl groups (-OH) forming a large number of hydrogen bonds between the macromolecules of the cellulose and polymer [9, 19-20]. If there is a high –OH group it shows a low moisture resistance.

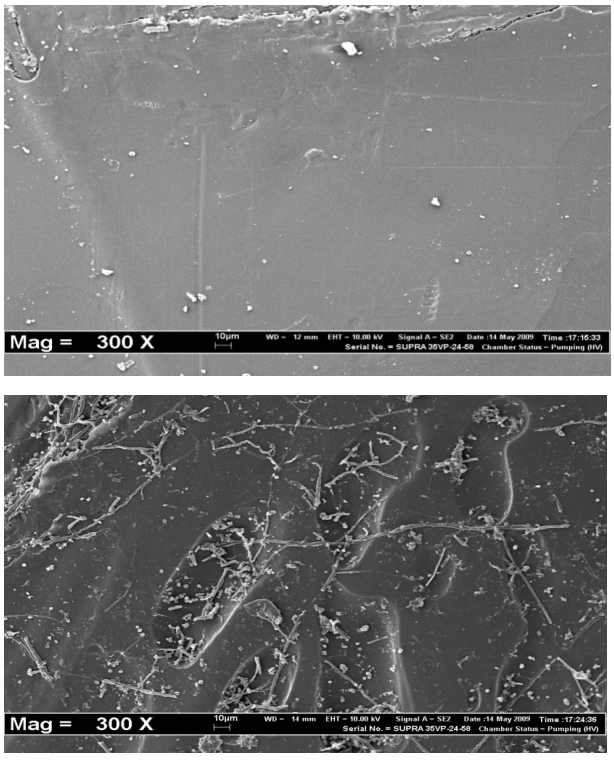

Fig. 6: SEM micrographs of pultruded kenaf fibre reinforced polyester composites (a) standard specimen (b) immersed in distilled water.

3.2.3 SEM micrograph

Fig. 6a-b shows micrographs of standard specimen in comparison with immersed specimen. The shear fracture leading to the lack of fibre-matrix debonding and the layers of polyester and fibre are evident in the SEM figures that indicate strong interfacial bonding. Voids and surface dissolution of the KFRPC are also evident after a long time immersion in distilled water. It can be clearly seen that the KFRPC response to the overall moisture absorption process, cracks, and surface peeling/ dissolution. The specimen weights increase as the surface peeling crack, resin dissolution and voids between fibres trap water molecules. The overall weight change profile encompasses the combined competing effects of water diffusion, physio adsorption of water molecules at crack tips which promote weight gain in the KFRPC, and surface mass loss mechanisms which contribute to gross weight reduction. The long term water uptake induces swelling and cracking to appear while stresses develop along the bond strength of kenaf fibre and matrix interface give result to the difference in elasticity.

4. CONCLUSIONS

The effect of water absorption on the mechanical properties of kenaf fibre reinforced polyester composites has been studied following immersion in distilled water at room temperature. From water absorption study for a period of 260 days, it was found that the water absorption behaviour of KFRPC is following a Fickian behaviour and can be accurately modelled using Fick's Law. Exposure to moisture induced degradation to the KFRPC and significantly descends the flexural and compression properties due to interference of the fibre and matrix interface. Moisture absorbed into the composites formed tiny cracks and swells up the fibres.

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References:

1. **Rowell, R.M. and Stout, H.P.** "Handbook of fibre chemistry 3rd Edition", CRC Taylor & Francis Group, United State of America, (2007), 406-450.
2. **Moore D.R. and Cervenka A.** "Future requirements in the characterization of continuous fibre-reinforced polymeric composites", (IUPAC technical report), *ICI Technology, Pure Appl. Chem.* **74**/4 (2002), 601-628.

3. **Takashi Nishino,Koichi Hirao, Masaru Kotera, Katsuhiko Nakame and Hiroshi Inagaki.** "Kenaf reinforced biodegradable composite", *Composite Science and Technology,* **63** (2003), 1281-1286.
4. **Bolton J.** "The potential of plant fibres as crops for industrial use", *Outlook Agric*, **24** (1995), 85-9.
5. **Gassan J. and Cutowski V.S.** "Effect of corona discharge and UV treatment on the properties of jute-fibre epoxy composites", *Compos. Sci. Technol.* **60** (2000), 2857-2863.
6. **Krishan K. C.** "Fibrous materials", Cambridge University, Press, (1998), 1-270.
7. **Joseph P.V., Marcelo S.R., Mattoso L.H.C., Kuruvilla J. and Sabu T.** "Environmental effects on the degradation behaviour of sisal fibre reinforced polypropylene composites", *Composites Science and Technology,* **62** (2003), 1357-1372.
8. **Stamboulis A., Baillie C.A, Peijs T.** "Effects of environmental conditions on mechanical and physical properties of flax fibres", *Composite Part A,* **23** (2001), 1105-1115.
9. **Dhakal H.N., Zhang Z.Y., and Richardson M.O.W.** "Effect of water absorption on the mechanical properties of hemp fibre reinforced unsaturated polyester composites", *Composites Science and Technology*, **67** (2007), 1674-1683.
10. **Ana E.** "Natural fibres/polypropylene composites from residual and recycled materials", KTH, Fibre and polymer technology, Fibre-och polymerteknologi, Stolckholm, (2003), 1-38 .
11. **Meyer R.W.** "Handbook of pultrusion technology", Chapman and Hall, (1985), 1-160.
12. **Moshiar S.M., Reboredo M.M., Vazquez A.,** edited by Cheremisinoff N.P. "Advance polymer processing operations", Noyes Publications, Westwood, New Jersey, USA, (1998), 126-154.
13. **Daly H.B., Brahim H.B., Hfaied N. and, Boukhili R.** "Investigation of water absorption in pultruded composites containing fillers and low profile additives", *Polymer composite,* **28**/3 (2007), 355-364.
14. **Hazizan M. A., Cheng L.W., Mohd Ishak Z.A., Bakar A.A. and Abd Rahman M.A.** "Water absorption study on pultruded jute fibre reinforced unsaturated polyester composites", *Composites Science and Technology,* **69** (2009), 1942-1948.
15. **Zhou J. and Lucas J.P.** "The effects of water environment on anomalous absorption behaviour in graphite epoxy composites", *Composite Science Technology,* **53** (1995), 57-64.
16. **Nosbi N., Md Akil H., Mohd Ishak Z.A. and Abu Bakar A.** "Degradation of compressive properties of pultruded kenaf fibre reinforced composites after immersion in various solutions", *Materials & Design*, **31**/10 (2010), 4960-4964.
17. **Joseph P.V., Rabello M.S., Maattoso L.H.C., Joseph K. and Thomas S.** "Environmental effects on the degradation behaviour of sisal fibre reinforced polypropylene composites", *Composite Science and Technology,* **62** (2002), 1357-72.
18. **Jones F.R.** "Moisture absorption-anomalous effects. In:Handbook of polymer fibre composites", UK Longman scientific and technical., (1994), p.371-5.
19. **Sharifah H.A. and Martin P. A.** "The effect of alkalization and fibre alignment on the mechanical and thermal properties of kenaf and hemp bast fibre composites: Part 1-polyester resin matrix", *Composite Science and Technology*, **64** (2004), 1219-1230.
20. **Sombastsompop N. and Chaochanchaikul K.** "Effect of moisture content on mechanical properties, thermal and structural stability and extruded texture of poly (vinyl chloride)/wood sawdust composites", *Polym. Int.,* **53** (2004), 1210-8.