Water absorption behaviour of hybrid interwoven cellulosic fibre composites

To cite this article: A B Maslinda et al 2017 J. Phys.: Conf. Ser. 908 012015

View the article online for updates and enhancements.
Water absorption behaviour of hybrid interwoven cellulosic fibre composites

A B Maslinda, M S Abdul Majid, M J M Ridzuan and AR.A. Syayuthi

1 School of Mechatronic Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600, Arau, Perlis, Malaysia
2 Faculty of Engineering Technology, Universiti Malaysia Perlis, Uniciti Alam Campus, 02100, Padang Besar, Perlis, Malaysia

shukry@unimap.edu.my

Abstract. The present paper investigated the water absorption behaviour of hybrid interwoven cellulosic fibre composites. Hybrid composites consisting of interwoven kenaf/jute and kenaf/hemp yarns were prepared by an infusion manufacturing technique that used epoxy as the polymer matrix. Water absorption test was conducted as elucidated in ASTM D570 standard by immersing the composite samples in tap water at room temperature until reaching their water content saturation point. For each composite type, average from five samples was recorded and the percentage of water uptake against the square root of time was plotted. As the effect of hybridization, the water uptake, diffusion and permeability coefficient of the hybrid composites were lesser than the individual woven composites.

Keywords: Hybrid composites; natural fibres; water absorption; interwoven; cellulosic.

1. Introduction

Exploration on the natural resources fibres as a substitution to the petroleum-based fibres was rapid growth in the last few decades and nowadays, natural fibre reinforced polymer composites are widely used in the automotive industry, sports equipment and marine structure [1]. In comparison with the synthetic fibre, natural fibre possessed high specific strength, readily available at low cost, renewable and less abrasive to processing equipment and these features correspond well with the consumer demands and environmental sustainability. Cellulose based natural fibres that are widely studied and applied in composites engineering applications are flax, hemp, jute, ramie, kenaf and sisal [2].

The hybrid composite consists of at least two types of fibre in a single matrix system. Interest in hybridization started when there was increasing demand for a lighter material with improved toughness, especially for aircraft application. The early focus of hybridization is reducing the cost by combining carbon fibre with cheaper glass fibre. Through hybridization, the mechanical performance of the composites was improved which attributed by the changes in applied load distribution and failure development. Now, hybridization has been widely explored such as pseudo-ductility, ductile fibre and natural fibre hybrids composites [3].

Common types of reinforcement form in fibre reinforced composites are fibre, yarn and fabric. The arrangement of the reinforcement or layered affects the final performance of the composites and fabric structure, governs the properties rather than the others. Fabric can be classified as woven, knitted or non-woven. Woven fabric is interlacing between two sets of yarns along the longitudinal (warp) and transverse (weft) direction. Interloping between yarns at weft or warp direction defined the
knitted fabric, and for a non-woven fabric, it is termed as the bonding of raw material (fibre) using mechanical, chemical or solvent [4].

In particular, all polymer composites absorb moisture, and the water molecules can act as a plasticiser by influencing the fibres, the matrix and the interface simultaneously, thus creating regions of poor transfer efficiency, which results in a reduction of mechanical properties. It is now well established that composite materials are sensitive to humidity through absorption of water leading to differential swelling between the fibres and the matrix. This situation is even more complicated in the case of natural fibres, which are known to exhibit a poor resistance to water absorption, due to their hydrophilic nature that is related [5]. As an extension to the research involving hybrid and woven structure, this research’s primary focus is investigating the water absorption behaviour of hybrid composite made from interwoven kenaf/jute and kenaf/hemp yarns to observe their responses when subjected to moisture and at the same time predict their capability for outdoor applications.

2. Experimental procedure

2.1 Materials
As shown in figure 1, kenaf, jute and hemp fibre in a yarn form were used for the preparation of the woven fabric. All the fibre yarns were supplied by Innovative Pultrusion Sdn. Bhd. The EpoxAmite 100 series resin, provided by Castmech Technologies Sdn. Bhd was selected as the polymer matrix, mixed with a hardener in a ratio of 3:1 to form the binder for the composites preparation.

![Fibre yarns](image)

**Figure 1.** Fibre yarn; (a) jute, (b) kenaf and (c) hemp.

2.2 Woven fabric production
The woven fabric was fabricated using the manually constructed wooden frame. The wooden frame consists of nails at both of its side that served as the warp yarn guider. Following the plain weave pattern, the weft yarns were passed over and underneath the warp yarns that have been arranged earlier on the wooden frame to complete the woven fabric. The interlacing of kenaf yarns as the warp direction fibre with jute and hemp yarns as the weft direction fibre in the construction of interwoven kenaf/jute and kenaf/hemp hybrid composites is illustrated in figure 2.

![Woven fabric](image)

**Figure 2.** Warp and weft direction fibre of interwoven hybrid composites.
2.3 Composite fabrication

For comparison, five types of composites were prepared, and a symbol representing the composite types is as listed in Table 1. All the composites, with fibre weight content of 30% were prepared via vacuum infusion process using epoxy as the polymer matrix. Figure 3 shows the infused composites after moulding and curing for 24 hours at room temperature.

| Type of Composite         | Symbols |
|---------------------------|---------|
| Woven Kenaf               | KK      |
| Woven Jute                | JJ      |
| Woven Hemp                | HH      |
| Interwoven Kenaf/Jute     | KJ      |
| Interwoven Kenaf/Hemp     | KH      |

Table 1. Symbols used for representing the different types of composite prepared.

2.4 Water absorption test

Water absorption test was carried as per instructed in the ASTM D570 standard. Mass of the dried samples, $M_0$ were taken after oven dried at 100 °C for 10 minutes and left to cool at room temperature for 24 hours. Later, specimens were submerged in a container filled with tap water before being placed in the humidity chamber at 25 °C. To monitor the weight gain due to the water absorption, the specimens were withdrawn from the water, wiped dry to remove the surface moisture, and then weighted using a high accuracy 4-digit analytical balance. Samples are considered reached their equilibrium when the daily weight gain of the samples was less than 0.01%. For each type of the composites, five specimens were used, and the average result was recorded. Moisture content percentage, $\Delta M(t)$ was calculated using equation (1):

$$\Delta M(t) = \frac{M_t - M_0}{M_0} \times 100$$

where $M_0$ is the weight of the specimen before immersion and $M_t$ representing the weight of the specimen after immersion at a specific time. The percentage of moisture absorption was plotted against the square root of time ($\sqrt{t}$, hours).

Assuming the absorption process is linear at the early stage of immersion; times are taken at the beginning of absorption process so that the weight change is expected to vary linearly with the square...
The root of time. The kinetic parameter, diffusion coefficient, $D$ (m$^2$/s) is computed from the slope of moisture content versus the square root of time by equation (2):

$$D = \pi \left( \frac{kh}{4m_{\infty}} \right)^2$$  \hspace{1cm} (2)

Where $h$ is the thickness of the specimen, $m_{\infty}$ is the maximum water uptake, and $k$ is the initial slope of the linear portion of a plot of $M(t)$ versus $t^{1/2}$ curve.

The permeability of water molecules through the composite sample depends on the sorption of water by the fibre. Therefore, the sorption coefficients that are related to the equilibrium sorption of the principal penetrated is calculated by the equation (3):

$$S = \frac{M_{\infty}}{M_t}$$  \hspace{1cm} (3)

where $M_{\infty}$ and $M_t$ are molar percentages of water uptake at infinite time and at time $t$. The permeability coefficient, $P$ (m$^2$/s), which implies the net effect of sorption and diffusion, is given by equation (4):

$$P = D \times S$$  \hspace{1cm} (4)

where $D$ is the diffusion coefficient (m$^2$/s), and $S$ is the sorption coefficient.

When materials are known or suspected to contain any appreciable amount of water-soluble ingredients, the specimens, after immersion, shall be weighed, and then reconditioned for the same time and temperature as used in the original drying period. If the reconditioned weight is lower than the conditioned weight, the difference shall be considered as water-soluble matter lost during the immersion test. Percentage of soluble matter lost during immersion, calculated to the nearest 0.01% as equation (5):

$$\text{Soluble matter lost, } \% = \frac{\text{conditioned weight} - \text{reconditioned weight}}{\text{conditioned weight}} \times 100$$  \hspace{1cm} (5)

3. Result and discussion

Figure 4 shows the moisture absorption percentage as a function of the square root of time (hours) for various woven composites, which had been immersed in tap water at room temperature. From the water absorption curves, the absorbed water content increased with increasing immersion time. A similar finding was reported in a previous study where the water absorption effects of natural fibre reinforced polymer composites were investigated [6]. The water uptake process of the woven composites was linear at the beginning, especially for KK, JJ and HH composites, demonstrating the rapid water penetration into the composite materials. The water uptake then slowed down and approached saturation after a prolonged period.

From the graph, KK composites absorbed a higher amount of water, compared with JJ and HH composites. This was expected due to the higher cellulose and hemicellulose content in the kenaf fibre [2]. Cellulose and hemicellulose are the principal contributors to the moisture absorption, due to its open structure containing hydroxyl (OH) and acetyl (C$_2$H$_3$O) groups. When compared to the individually woven composites, a reduction of the water uptake was observed for KJ and KH hybrid composite. The KJ hybrid composite absorbed 46% less water than the KK and JJ composites. Meanwhile, the amount of water absorption of the KH hybrid composite was reduced by 64% and 58%, in comparison with the KK and HH composites, respectively. This reduction shows that the hybridization enhanced the water resistance properties of the kenaf, jute, and hemp fibres. A decrease in the water absorption properties of composites was also found when sisal fibre was added to a
banana/epoxy composite [7]. Lignin protects the fibres from hydrothermal degradation due to its hydrophobic features, and theoretically, composites with fibre containing higher lignin content as a filler should present lower values of water uptake [7,8].

![Figure 4. Water absorption curve for various woven composites.](image)

It is essential to measure their diffusion, $D$ (m$^2$/s) and solubility coefficient, $S$, when discussing the absorption behaviour of fibre or polymer as these two parameters determine the permeability coefficient of the polymer, $P$ (m$^2$/s); which implies the net effect of the sorption and diffusion [7]. The diffusion coefficient, $D$ is the velocity of water molecules transported into the composite structure, and also represent the ability of the water molecules to move among the polymer segments. The amount of water dissolved in a polymer is described by the sorption behaviour, $S$. Table 2 shows the diffusion and permeability study of the woven composite. The amounts of water uptake are corresponding well with the value of diffusion and permeability coefficient, where the individual woven composite have higher diffusion and permeability coefficient; compared with the interwoven hybrid composites.

| Specimens | Percentage of water uptake at infinite time $M_{\infty}$ (%) | Diffusion coefficients, $D \times 10^8$ (m$^2$/s) | Sorption coefficient, $S$ | Permeability coefficient, $P \times 10^7$ (m$^2$/s) | $k$ | $n$ |
|-----------|----------------------------------------------------------|-----------------------------------------------|--------------------------|-----------------------------------------------|-----|-----|
| KK        | 14                                                       | 6.32                                          | 3.7                      | 4.0                                           | 1.311 | 0.4823 |
| JJ        | 13.8                                                     | 6.29                                          | 4.9                      | 3.1                                           | 1.5086 | 0.5927 |
| HH        | 12                                                       | 4.36                                          | 5                        | 2.2                                           | 1.6957 | 0.6529 |
| KJ        | 7.5                                                      | 0.36                                          | 29                       | 1.0                                           | 1.7819 | 0.7437 |
| KH        | 5                                                        | 0.15                                          | 5                        | 0.075                                         | 1.7193 | 0.6039 |

Table 2 also presented the $k$ and $n$, which are constants. $k$ is a constant which indicates the interaction between the sample and water, while $n$ indicates the mode of diffusion. Both constants were determined from the slope ($n$) and intercept ($k$) of $M_t/M_{\infty}$ versus $t$ in a log plot; see figure 5, which can be drawn from the experimental data according to equation (6):
Where \( M_t \) is moisture content at time \( t \), and \( M_\infty \) is moisture content at saturation. In particular, the value of \( n \) shows different behaviour among the three cases; for Fickian diffusion (Case I) \( n = 0.5 \), while for Case II \( n = 1 \) (and for super Case II, \( n > 1 \)) and Case III (non-Fickian or anomalous diffusion) \( 0.5 < n < 1 \). Usually, the water absorption pattern of natural fibre composites at room temperature is found to follow Fickian behaviour, whereas at the elevated temperature the absorption behaviour can be non-Fickian [9].

\[
\log \left( \frac{M_t}{M_\infty} \right) = \log(k) + n \log(t)
\]  

(6)

\[ \frac{M_t}{M_\infty} = k_0 \left( \frac{t}{t_0} \right)^n \]

In contrast with the literature, the \( n \) values of the individual and interwoven hybrid composites, as presented in Table 2; are higher than 0.5, which indicates non-Fickian diffusion. The water uptake seems more sigmoidal in nature, could be due to the content of fibre, type of matrix, fibre/matrix bonding, and leaching out of resin particles [10, 11]. Calculated using equation (5), the non-Fickian diffusion mode of the woven composites also supported by the weight loss percentage of the water immersed samples, as presented in Table 3.

**Table 3.** Weight loss percentage of the water immersed samples after reconditioned.

| Composite | Conditioned weight (g) | Reconditioned weight (g) | Weight loss (%) |
|-----------|------------------------|--------------------------|-----------------|
| KK        | 10.453                 | 10.0966                  | 3.4             |
| JJ        | 11.1028                | 11.0503                  | 0.5             |
| HH        | 11.9097                | 11.3211                  | 5               |
| KJ        | 11.0924                | 11.0732                  | 0.2             |
| KH        | 11.1812                | 10.9275                  | 2.3             |
4. Conclusion
As a conclusion, longer exposure to the aqueous environment increased the water uptake of the composites, and the water content reaches saturation after 1400 h of exposure. Loss of resin particles was observed for the water-immersed samples, which confirmed that the absorption pattern of the composites followed the non-Fickian behaviour. Woven kenaf composite (KK) had the highest water uptake, diffusion and permeability coefficient, attributed by the higher cellulose and hemicellulose content in kenaf fibre compared with jute and hemp fibre. The diffusion coefficient and water uptake of the interwoven hybrid composites were less than their individual woven composites. As the lignin protect the fibres from hydrothermal degradation, hybridization of kenaf with high lignin content fibre such as jute and hemp fibre in the woven structure; enhanced their water resistance properties.

5. Acknowledgments
The author gratefully acknowledges the financial and technical support from Ministry of Higher Education Malaysia (MOHE) and School of Mechatronic Engineering, University Malaysia Perlis.

6. References
[1] Pickering KL, Efendy MGA and Le TM 2016 Composites Part A: Applied Science and Manufacturing 83 98
[2] Faruk O, Bledzki AK, Fink HP and Sain M 2012 Progress in Polymer Science 37 1552
[3] Swolfs Y, Gorbatikh L and Verpoest I 2014 Composites Part A 67 181
[4] Misnon MI, Islam MM, Epaarachchi JA and Lau K 2014 Materials and Design 59 359
[5] Sethi S and Ray BC 2015 Advances in Colloid and Interface Science 217 43
[6] Salleh Z, Taib YM, Hye KM, Mihat M, Berhan MN and Ghani MAA 2012 Procedia Engineering 41 1667
[7] Venkateshwaran N, Elayaperumal A, Alavudeen A and Thiruchitrambalam M 2011 Materials and Design 32 4017
[8] Akil HM, Omar MF, Mazuki AAM, Safiee S, Ishak ZAM and Bakar AA 2011 Material and Design 32 4107
[9] Chen H, Miao M and Ding X 2009 Composite Part A 40 2013
[10] Espert A, Vilaplana F and Karlsson S 2004 Composite Part A 35 1267
[11] Akil HM, Santulli C, Sarasini F, Tirillo J and Valente T 2014 Composites Science and Technology 94 62