Research on Hygrothermal Property of Jute Woven Fabric Reinforced Composites

Changtai Luo\textsuperscript{1, 2}

1 Nanchang Institute of Technology, Nanchang 330099, Jiangxi, China
2 East China University of Technology, Nanchang 330013, Jiangxi, China
Email: lct@nit.edu.cn

Abstract. Jute woven fabric reinforced composites are manufactured by means of VARI technology, hygroscopic property changes in the composites is analyzed, and the influence of hygrothermal aging on their tensile performance is investigated. The results show that moisture uptake of the composites at stage one conforms well to Fickian diffusion. Based on experimental data, the correlation between diffusion coefficient and temperature in Fickian equation is corrected. Meanwhile, the mild deviation between experiment-based moisture uptake curve and the one predicted by the modified equation validates the effectiveness of the correction. In addition, as temperature increases, the tensile strength of the composites decreases, due to the intensification of the resin dissolution.

Keywords. Jute fabric, composites, hygroscopic, tensile strength.

1. Introduction
Relying on characteristics of flexible design, corrosion resistance and high strength-to-weight ratio, fiber-reinforced composite (FRP) has evolved into an essential research direction in new materials, on the other hand, as petrochemical products, the limitations of traditional fibers are clearly visible, like high production cost, complex recycling process and environmental pollution. As a result, natural plant fibers are gaining popularity in view of their affordable price, rich resources and biodegradability. In recent articles, Wambua [1] adopted pressure molding in producing natural fiber/polypropylene composites and the findings led to the conclusion that natural fiber can be an alternative to glass fiber in most circumstances, according to Guedes et al.[2], the palm fiber/low-viscosity polyethylene composites with vegetable fibers appeared better mechanical property than those with pure resin. Overall, these studies highlight the need for more researches on natural plant fabric reinforced composites.

Among various natural plant fibers (bamboo, coconut shell, wood plastic and diverse hemp.), extensive studies have been conducted on jute fiber due to its soundproofing, bacteriostasis [3] and outstanding mechanical property [4]. Zhang et al. [5] and Li et al. [6] made jute fiber/unsaturated polyester composites by pressure molding and investigated the influence of preparation process on their mechanical property. Ma et al. [7] produced jute/polypropylene composite using extrusion molding technology and contrasted quasi-static, dynamic tensile and compressive property of composites with different filling materials. In practical application, the property of composites considerably depends on environmental conditions, and the most common are moist air and high temperature. Shang et al. [8] focused on hygroscopic behaviors in different types of glass fiber mat/ polypropylene composites, and discovered the behavior varies a lot. Liu et al. [9] manufactured hemp fiber /butanediol polybutyrate composites, discussing hygroscopic behaviors...
with regards to different proportions and types of hemp fiber. Furthermore, Liu Liyan et al. [10] developed jute braid/polypropylene composites and researched the influence of sanding thread orientation and preparation process. However, much uncertainty still exists in mechanical property of jute woven fabric reinforced composites especially after hygrothermal aging process. Hence the purpose of this paper is to investigate the hygroscopic property of jute woven fabric reinforced composites prepared by VARI technology and analyse the impact of hygrothermal aging on their tensile property.

2. Experimental Procedure

2.1. Composites Preparation
The jute fabric reinforced composites in this study consist of woven fibers with two dimension, vinylester resin and methyl ethyl ketone peroxide (MEKP) which serve as reinforcement, substrate and hardener respectively. Figure 1 displays the technology process, firstly, lay out tailored materials as illustrated in figure 2, then cover the vacuum bag on top of them and seal the surrounding gaps with tapes to create an airtight space. Next step is to draw the air out of the space using pump machine, after repairing the detectable air leakages, the mixture of vinylester resin and MEKP will flow into the composites pushed by pressure differential. Finally, maintain the level of the pressue differential until the impregnation occurs, then leave these materials to cure at room temperature. By following these steps, jute fabric reinforced composites with six-layer fibers on each side were prepared.

![Figure 1. Technology flow chart](image1)

2.2. Hygrothermal Property Experiment
According to ASTM D5229/D5229M, a specification for water absorption and equilibrium in polymer matrix composites, the jute fabric reinforced composites with standard size were divided into three groups and soaked in thermostatically demineralized water at 25°C, 50°C and 75°C respectively (the fluctuation is within ±1°C). During such aging process, the weight of test samples was measured on daily basis for one month, and the moisture absorption rate at day t is determined by

\[ M(t) = \frac{W_w - W_d}{W_d} \times 100\% \]  

(1)

where \( W_d \) and \( W_w \) are dry weight, wet weight respectively. Followed by the aging experiment aforementioned, tensile tests on these composites were carried out with 5 mm/min loading speed on machine css-44100, and the size of the samples is stipulates as 250 mm×25 mm in ASTM D3039/D3039M-17.
3. Hygrothermal Property of the Composites

Composites in hygrothermal environment generally experience two hygroscopic stages [11]: in stage one, with negligible change in the mass of fibers, the resin part absorbs moisture continuously, which results in the gradual increase in the weight of the composites, after reaching the saturation, moisture absorption rate will maintain at this level. In stage two, accompanied by dissolution of resin, jute fibers are exposed and begin to participate in absorbing moisture, while the mass increment out of the moisture absorption is smaller than the decrement due to the dissolution, so the weight of the composites decreases eventually. For stage one, the hygroscopic law is usually consist with Fickian equation:

\[
\frac{M(t)}{M_m} = 1 - \exp \left[ -7.3 \times \frac{D \cdot t}{h^2} \right]^{0.75}
\]  

(2)

where \( M_m \), \( D \), \( h \) and \( t \) refers to saturated moisture absorption rate, (water molecule) diffusion coefficient, thickness of the composites and aging days respectively. In accordance with equation (3), diffusion coefficients at the above three temperatures can be evaluated (as listed in table 1).

\[
D = \pi \left( \frac{h}{4M_m} \right)^2 \left[ \frac{(M(t_2) - M(t_1))^2}{t_2 - t_1} \right]^{0.5}
\]  

(3)

According to equation (2) and table 1, Fickian equation-based curves can be obtained, which are presented together with experimental data-based curves in figure 3. Hygroscopic behaviors of the composites in stage one at different temperatures exhibit similar features: initial moisture absorption rate increases linearly with days (based on the slope of the curves), then it slows down and reach the saturation.

| T(℃) | \( M_m \) (%) | \( D \) \( 10^6 \text{ mm}^2/\text{s} \) |
|-------|----------------|-------------------------------|
| 25    | 6.66           | 3.24                          |
| 50    | 5.98           | 17.6                          |
| 75    | 5.33           | 78.0                          |

**Table 1. Hygroscopic parameters.**

![Figure 3. Experimental and Fickian curves.](image)

Based on the assumptions of stable material property, simple diffusion of water molecules in Fickian equation, the saturated moisture absorption rate should be a constant value. Nevertheless, as shown in table 1, the rate decreases with the increase of temperature and it suggests that some unexpected changes occurred in the composites during aging process, which can also explain for the detectable deviation between experiment curves and Fickian curves in stage two especially at 75℃. Therefore, for better describing the hygroscopic behaviors of composites, it is necessary to modify the Fickian equation [12]. Arrhenius law [13] indicates that
The diffusion coefficient is only dependent on temperature, so after plotting the temperature-diffusion coefficient curve with the data in Table 1, the fitting equation can be obtained from Figure 4:

\[ D = 7 \times 10^{-7} \times e^{0.0636T} \]  \hspace{1cm} (4)

where, \( T \) is temperature (°C). Then combining equation (5) with (2), the Fickian equation for the composites can be modified as the equation (6), to evaluate the reliability of the modification, hygrothermal aging test at 40°C was carried out and the experimental data-based curves are compared with the curves plotted by the modified equation. In Figure 5, the mild deviation between two curves shows that the modified equation has a good applicability in describing the practical hygroscopic process, which can demonstrate the efficiency of the modification as well as the feasibility of predicting the hygroscopic curves for jute fabric composites at other temperatures.

\[ \frac{M(t, T)}{M_{\text{in}}} = 1 - \exp \left\{ -7.3 \times \left( 7 \times 10^{-7} \times e^{0.0636T \times t} \right)^{0.75} \right\} \]  \hspace{1cm} (5)

**Figure 4.** Diffusion-temperature curve.

**Figure 5.** Curves at 40°C.

### 4. Tensile Property of the Composites after Hygrothermal Aging

The tensile stress-strain curves of jute fabric composites are shown in Figure 6. It can be detected that the overall trend of these curves is similar: with the increase of displacement, the load changes non-linearly, at the early stage, the load increases with a comparatively high growth speed, after that, the growth slows down, and then panel suddenly breaks when the curve reaches the peak, which is a typically brittle failure. Moreover, the critical tensile loads of the composites at 25°C, 40°C, 55°C, 70°C are 56.42 MPa, 52.17 MPa, 33.51 MPa, 16.60 MPa, respectively, that is, tensile strength is negatively related to the temperature. Consistently, during the experiment (Figure 7), at the beginning of loading, there was no obvious change on the surface of the composites, but as the load continued to increase, the specimen broke instantaneously. Looking more closely at the breaking cross-section (Figure 8), pores and different level of extension in fibers can be observed, which suggests that uneven force is the main reason for premature failure. Furthermore, for investigating the causes of this uneven force, high-resolution images (Figure 9) of the composites were produced by scanning electron microscopy (SEM). It can be seen that the resin part has dissolved largely after aging process. On the one hand, it is the dissolution that causes the increase in the number of pores, undermining the bond strength between the fibers. On the other hand, due to the lack of protection from resin, part of fibers are exposed in hot and humid environment, and the tensile bearing capacity of this part is weakened when compared with other protected fibers. These findings suggest that as temperature increases, the resin begin to dissolve resulting in deterioration of tensile property in the composites.
5. Conclusions

(1) The hygroscopic behaviors of jute fabric reinforced composites at stage one in this study are aligned well with Fickian diffusion.

(2) The mild deviation in the course of hygroscopic curve given by modified equation and experimental data-based curve at 40\(^\circ\)C can validate the efficiency of the correction as well as the feasibility of predicting the hygroscopic curves of jute fabric composites at other temperatures.

(3) The critical tensile loads of the composites at 25\(^\circ\)C, 40\(^\circ\)C, 55\(^\circ\)C, 70\(^\circ\)C are 56.42 MPa, 52.17 MPa, 33.51 MPa and 16.60 MPa, respectively, which suggests that as temperature increases, the resin begin to dissolve resulting in tensile property deterioration of the composites.
Acknowledgments

This work is financially supported by the Foundation of Jiangxi Educational Committee (GJJ201926, GJJ180956, GJJ190948, GJJ200947).

References

[1] Wambua P, Ivens J and Verpoest I 2003 Natural fibres: Can they replace glass in fibre reinforced plastics? Composites Science and Technology 63(9) 1259-1264.
[2] Guedes J R, Florentino W M, Rodrigues L M, et al. 2016 Mechanical property of natural Fibers reinforced polymer composites: palm/low density polyethylene Materials Science Forum.
[3] Wei C and Guo R H 2019 Property and application of jute fiber Journal of Textile Science and Engineering 36(4) 79-84, 96.
[4] Farhan A, Sultan M T H, Hamdan A, et al. 2017 Science direct hybrid composites based on kenaf, jute, fiberglass woven fabrics: Tensile and impact property International Conference on Materials Manufacturing and Modelling.
[5] Zhang Y C, Meng X J, Qiu C P, et al. 2015 Preparation of unsaturated polyester composite reinforced with jute fiber Polymer Materials Science & Engineering 31(10) 160-164.
[6] Li R, Bai T, Tatou D T, et al. 2019 Fabrication and performances of jute fiber reinforced polyester composites Journals of Northeast Forestry University 47(6) 57-60.
[7] Ma D F, Ma B H and Zhang X Q 2019 Mechanical property of Natural Fiber Reinforced Polymer Composites under Impact Loading Chinese Journal of High Pressure Physics 33(2) 117-124.
[8] Shang Q D, Hou R G and Yao N 2017 Hydrothermal ageing of different fiber fabrics/vinylester composites Journal of Materials Science and Engineering (5) 80-85.
[9] Liu X J, Xie Z C, Cheng J G, et al. 2017 Preparation and property of the environmental friendly fibrilia reinforced composite New Chemical Materials 45(8) 134-137.
[10] Liu L Y, Song X F, Fan J H, et al. 2013 Influence of manufacturing process on properties of knitted jute / PP composites Journal of Textile Research 34(1) 46-49.
[11] Zhen L, Chang X L, Zhao F, et al. 2007 Research on moisture absorption of composites in the hydrothermal environment Fiber Composites (2) 37-39.
[12] Hu L, Xu Y Y and Wu J 2005 Research status and prospect on application of Fick's second law Journal of Hebei University of Engineering (Natural Science Edition) (3) 1-9.
[13] Bond D A 2005 Moisture diffusion in a fiber-reinforced composite: Part I, Non-fickian transport and the effect of fiber spatial distribution Journal of Composite Materials 39(23) 2113-2141.