Academic Journal of Polymer Science
ISSN: 2641-8282

Juniper Publishers
key to the Researchers

Short Communication
Volume 6 Issue 2 - October 2023
DOI: 10.19080/AJOP.2023.06.555682

Academ J Polym Sci

Influence of Humidity on the Mechanical Behavior of Fiber Composites. Effect of Reinforcement Type and Orientation

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Submission: September 07, 2023; **Published:** October 31, 2023

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Introduction

The FRP-type composites, formed by a polymeric matrix reinforced with glass fibres are widely used in different industrial environments. Considering its importance, the knowledge of the mechanical behaviour under different environmental conditions of temperature and humidity is extremely relevant to provide greater confidence in its application. In a study carried out by Naceri [1], the author concludes that the moisture absorption in fiberglass and epoxy resin laminates increases with the square root of time. Through these results, the author concluded that the water absorption behaviour obeys Fick's law. Chaichanawong [2] studied the effect of moisture absorption in glass fibre reinforced polyamide composites, concluding that the process can be divided into four stages: (I) the initial stage (1-7 days), (II) the second stage (8-24 days), (III) the third stage (25-35 days) and (IV) the saturated stage (36-60 days). This type of behaviour is characteristic, as mentioned by Kusmono [3], of a Fickian behaviour. Several studies report that water diffusion can occur according two different models - one that obeys Fick's law and another that does not obey this model, depending on the temperature. The Fickian model occurs at room temperature, as reported by Kusmono and Assarar [4].

The amount of moisture absorbed depends on the constituents of the composite material, type of matrix and type of reinforcement, and on the respective percentages. According to Lekatou et al. [5], the preferred mode of water absorption is by the matrix in case of low humidity and by the matrix-reinforcement interface when humidity is high. The study of the moisture absorption mechanism in composite materials has been the subject of interest by several authors. As referred by Lokavarapu et al. [6], moisture is absorbed by composite materials by three different mechanisms: by the reinforcement, by the matrix and by the interface.

The absorption of water by the reinforcement is related to the resistance that the fibres offer to the diffusion of water [2]. The literature suggests that natural fibres, due to their hydrophilic characteristics, have a superior capacity to absorb water compared to synthetic fibres [7]. References in the literature suggest that synthetic fibres absorb disposable amounts of moisture and, therefore, have a negligible impact on the degradation of the properties of the composite material [8,9]. These authors consider synthetic fibres as the most suitable for use as reinforcement in composite materials for applications involving contact with moisture.

According to Alam et al. [10], the nano-voids present in the epoxide resin promote pathways that allow water to enter the matrix, causing degradation of the epoxide resin. Moisture causes a decrease in the glass transition temperature of polymers, causing a softening effect that results in an increase in molecular mobility [11]. Furthermore, in polymers such as polyamides, moisture can increase its volume, resulting in a polymer with dimensions greater than those indicated (an effect known as swelling).

The adhesion of the interface can be altered by the presence of moisture and, consequently, the mechanical properties of the composite material are affected. According to Sujon et al. [12], due to the attack of water molecules at the interface by capillary effect, delamination occurs between the fibres and the matrix, that is, there is hydrolytic breakdown of the chemical adhesion between the fibre and the resin [13]. The presence of water molecules at the fibre-matrix interface reduces the frictional resistance and the matrix compression can only theoretically increase the fibrematrix friction if the percentage of water at the interface is low [10]. Deo et al. [14] reported that moisture trapping at the fibre-matrix interface leads to bond strength degradation, impairing the charge transfer mechanism from the matrix to the fibres.

Sandeep et al. [15], studied the moisture diffusion effect in unidirectional natural fibre reinforced polymer matrix composites. Considering Fick's law to model mass transport, several three dimensional models with different fibre orientations were used to analyse the diffusion mechanism along and through the fibres. From their work, Sandeep et al. concluded that there are several fibre orientations that can prevent moisture from entering. Sujon et al. [12] identified a minimum percentage of water absorption in unidirectional composite laminates. According to the same authors, the increase in the number of fibre and matrix interfaces in the composites with fibres disposed in different orientations, increases the water absorption when compared with the unidirectional and crossed hybrid sample. In a study carried out by Venkatesha et al. [7], the amount of moisture absorbed for different orientations was evaluated in hybrid composites of fiberglass and bamboo with epoxide resin. The laminates were placed in distilled water and saline water for 240 hours, leading the authors to the conclusion that laminates with an orientation of 60°, both in distilled water and in saline water, absorb a greater amount of water. On the contrary, when it comes to laminates with orientation at 45°, the absorption of distilled water is lower, which is no longer verified in the absorption in saline water. Vats et al. [16] used numerical analysis to conclude which is the preferred orientation, when in contact with water, based on Fick's Law. The authors concluded that laminates whose orientation is unidirectional (0°/0°/0°), present their saturation point earlier than any other configuration, concluding that the best configuration for the orientation of the fibres of a composite material is when they are perpendicular to the water flow, that is, with a 90°/90°/90° configuration.

The mechanical properties of composite materials are negatively affected by the presence of moisture. According to Bachchan [17], the moisture absorption decreases the fibre strength and may cause the initiation of micro cracks. Regarding the mechanical properties, the literature generally indicates a decrease. Chaichanawong [2] indicates a reduction in tensile (elastic limit and rupture) and flexural mechanical strength. He also refers a decrease in the elasticity modulus and a transition from brittle to ductile properties of glass fibre reinforced polyamide composites after moisture absorption. Alam et al. [10] showed that the absorption of water in the matrix of a CFRP-type composite can negatively affect the mechanical performance since it induces the swelling of the matrix, causing physicochemical changes in the interfaces and interactions with the surface of the fibre or with its coating. On the other hand, Collings and Stone [18], for example, suppose that moisture absorption in CFRP causes compression strain in the matrix and tensile strain in the fibres in unidirectional laminates.

Conclusion

The moisture absorption has a great influence on the behavior of polymer matrix composite materials contributing to the degradation of their mechanical properties. The absorption is dependent on several factors such as the matrix used, type and orientation of reinforcement. Preliminar studies conducted by the authors, indicate that reinforcements in the form of fabrics have less absorption than reinforcements in the form of chopped strand mats (CSM). The explanation is supported by literature as the CSM has a multiplicity of fiber-matrix interfaces that more easily allow water to enter the composite.

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How to cite this article: Gabriela P, AG Magalhães. Influence of Humidity on the Mechanical Behavior of Fiber Composites. Effect of Reinforcement Type and Orientation. Academ J Polym Sci. 2023; 6(2): 555682. DOI: 10.19080/AJOP.2023.06.555682

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