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The Effect of the Kenaf Natural Fiber on Enhancing the Mechanical Properties of Bio-Composites Materials Used in Civil Engineering

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In this work, we have investigated the effect of the natural Kenaf reinforcement on the improvement of the interfacile bond between two types of epoxy and Polypropylene (PP) matrix. Our genetic model is based on Weibull's probabilistic models and on Cox's interface model. The moisture content for each material is determined by Fick's law. Our simulation results show that the most resistant interface is that of Kenaf-Polypropylene compared to the other interfaces. This result coincides perfectly with the experimental data found by Paul Wambua et al. Which have shown that Kenaf is a promoter fiber for the improvement of the mechanical properties of biocomposite used in the field of civil engineering.

Keywords: Kenaf, bio-composite, fiber, epoxy, polypropylene, genetic algorithm.

1. Introduction

The Kenaf is related to jute. These thorny stems 1 to 2 cm in diameter are often, but not always branched. The leaves of 10 to 15 cm in length are of variable shape, those of the base are lobed and those of the top lanceolate. Flowers 8 to 15 cm in diameter are white, yellow or purple. The fruit is a capsule containing several seeds [1–8].
The Kenaf insulation products meet all the requirements for proper use in the construction sector. (Perfect thermal and acoustic insulation, Eco-sustainable and recyclable product, Does not rot and emits no polluting substances, Insensitive to humidity, is not contaminating) [2, 8–13] (see Fig. 1).

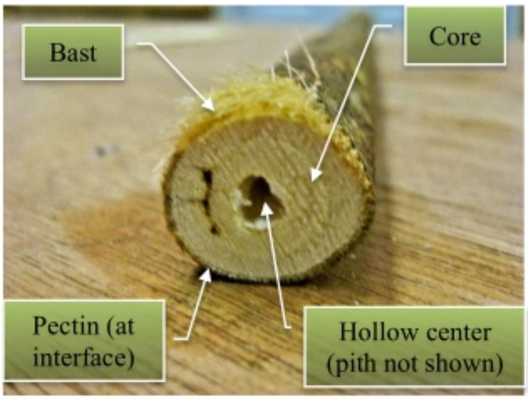

Figure 1 Cross-section of the kenaf fiber [13]

The Kenaf wool is used in new construction as well as in rehabilitation for thermo-acoustic insulation of vertical walls, dividing and distributing partitions, soils, crawling, ceilings and attics built and lost [1-5].
In the building sector, we seek to use materials, both in the renovation and in the new construction, that they are increasingly efficient and environmentally friendly. Kenaf wool is used in new construction as well as in rehabilitation for thermo-acoustic insulation of vertical walls, dividing and distributing partitions, soils, crawling, ceilings and attics built and lost [3-8].
Our objective in this paper is to study by a genetic model, the resistance of the Kenaf-epoxy, Kenaf-Peek and Glass-epoxy interface to the different mechanical constraints and in particular to the humid environment.

2. Method of calculation

2.1. *Materials used*

2.1.1. *The fibers*

We present in Table 1 the mechanical properties of the two fibers used in our simulation model.

Table 1 Kenaf fibers and E-glass fibers properties [14]

Fibers	Density g/cm^3	Tensile strength MPa	E modulus GPa	Specific E/density	Elongation at failure %	Cellulose /Lignin %
E-Glass	2.6	2000	76	29	2.6	-
Fiber	1.5	350-600	40	27	0.33-0.88	75-90

2.1.2. *The polypropylene matrix*

Polypropylene (PP) has a density between 0.895 and 0.92 g/cm^3 [15-23]. The PP has a Young's modulus between 1300 and 1800 N/mm^2 [20-24], so it is resistant, especially when it is copolymerized with ethylene. This allows polypropylene to be used as a technical plastic, competing with materials such as acrylonitrile butadiene styrene (ABS). Polypropylene is reasonably economical.
The PP is becoming basic plastic with the lowest density. With a lower density, molded parts with a lower weight and more parts of a certain mass of plastic can be produced. Unlike polyethylene, crystalline and amorphous regions differ only slightly in density [15-23].

2.2. *Mathematical modeling of interface shear*

One of the first solutions that of Cox [24], gives the shape of the shear stress along the length of the fiber in the form:

$$\tau = \frac{E_f a\varepsilon}{2}\left(\frac{2G_m}{E_f r_f^2 \ln(\frac{R}{r_f})}\right) th\left(\frac{2G_m}{E_f r_f^2 \ln(\frac{R}{r_f}}l/2\right) \tag{1}$$

with:
G_m – shear modulus of the matrix,
E_f – Young's modulus of the fiber,
ε – deformation,
a – radius of the fiber,
R – distance between fibers,
τ – shear stress of the interface.

2.3. *The moisture model*

The distribution of water depends on the quantity of cavities and their size. During the diffusion, the water molecules move from one site to another with an activation energy (Fig. 2). Water is then considered as liquid or free water [25-29].
To simplify dissemination analyzes, the following assumptions have been made:
- The diffusion coefficient D is independent of the water concentration C
- The diffusion profile is considered plane and in the direction x. [25-29]

The following equation is then determined:

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} \tag{2}$$

2.4. *Statistical approach*

Damage to the matrix, when the stress is uniform, is given by formula (1) Weibull [30]:

$$D_m = 1 - \exp\left\{-V_m\left[\frac{\sigma + \sigma_m^T}{\sigma_{0m}}\right]^{m_m}\right\} \tag{3}$$

with:
σ – applied stress,
σ_m^T – heat stress,
V_m – the volume of the matrix,
m_m and σ_{0m} – Weibull parameters.
The rupture of the fiber can be described by a law similar to that of the matrix [30]:

$$D_f = 1 - \exp\left\{-A_f L_{equi}\left[\frac{\sigma_{\max}^f}{\sigma_{0f}}\right]^{m_f}\right\} \tag{4}$$

2.5. *Development of the genetic algorithm*

Our genetic algorithm consists in showing the influence of humidity and the tensile mechanical stress on the interface damage of the three types of biocomposite materials based on Kenaf fiber. For this, this requires a set of mathematical and analytical tools defined by the Cox model, the Weibull probabilistic model and the linear laws of diffusion of water in a polymer. The principle begins by randomly generating an initial population and selecting D (diffusion coefficient), then changing this population (the number 240 with a maximum of 120 equal to the generation as stopping criterion) by a set of genetic operators (selection, crossing and mutation ($P = 0.27$)) and calculating in each case the diffusion coefficient of the water in the matrix. The population is composed of chromosomal genes representing the following variables: the mechanical stress which is 125 N/m^2, the Young's moduli of the three materials, the shear modulus of the matrix, the diameter of the fiber and the distance R. For exploit the maximum tensile stresses see the progress of our genetic algorithm, we chose a selection of roulette and the mutation selected value equal to 0.27. The calculation by iteration values C and D was carried out according to the principle of Fick's law [29] (see Fig. 2).

3. Results and discussions

Our numerical approach was carried out on two biocomposite materials (Kenaf-epoxy and Kenaf- Polypropylene) and a composite material (E-Glass-epoxy). We examined the variation of the damage for different moisture values and the tensile stress of 125 N/m^2, and see the influence of the Kenaf fiber on the interface damage. Figures 3, 5 and 7 show the level of damage of the interface as a function of the length of each fiber of the three studied materials; Figures 4,6 and 8 show the level of damage as a function of the moisture content.

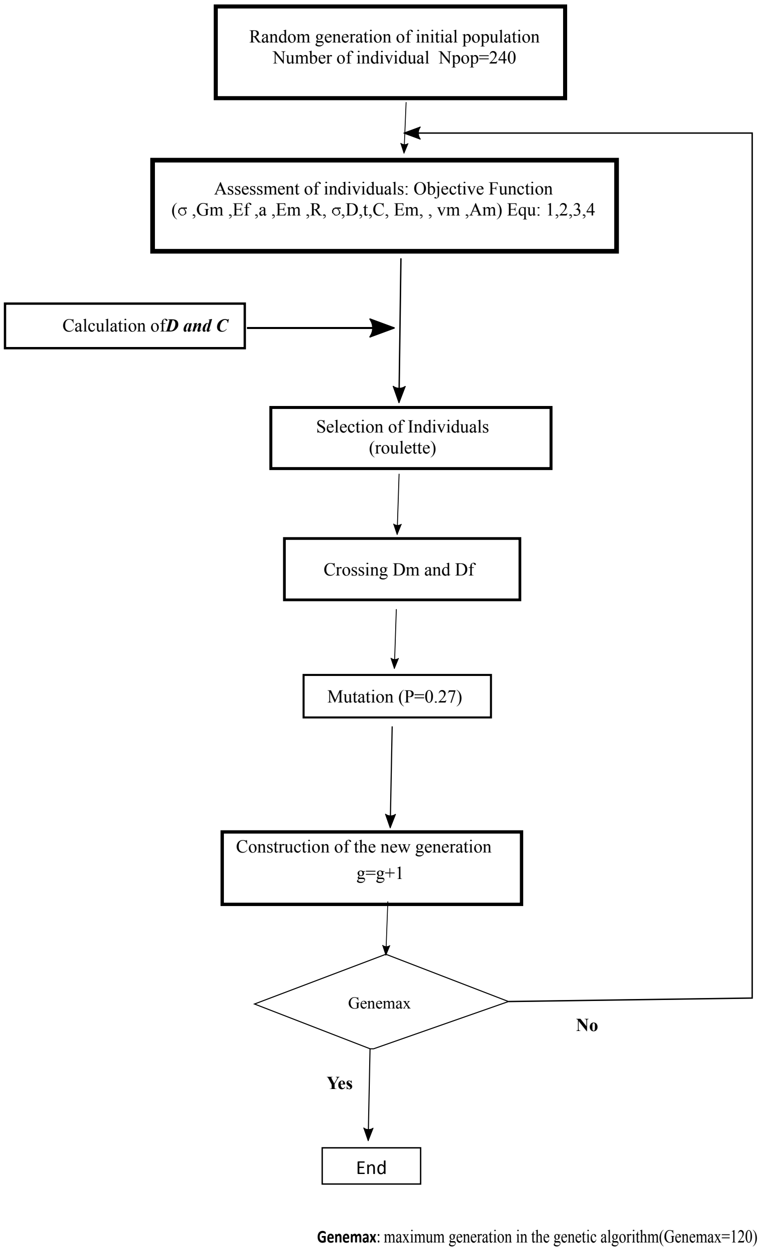

Figure 2 The flowchart of genetic algorithm

3.1. *E-Glass/Epoxy*

Figure 3 shows that for an applied tensile stress of 125 N/m^2, the damage "D" of the interface is equal to 0.295. We also note the presence of symmetry of the damage. In a humid environment of 60% (Fig. 4), we found that the damage increased to a value of 0.6 for the first E-Glass-Epoxy composite material.

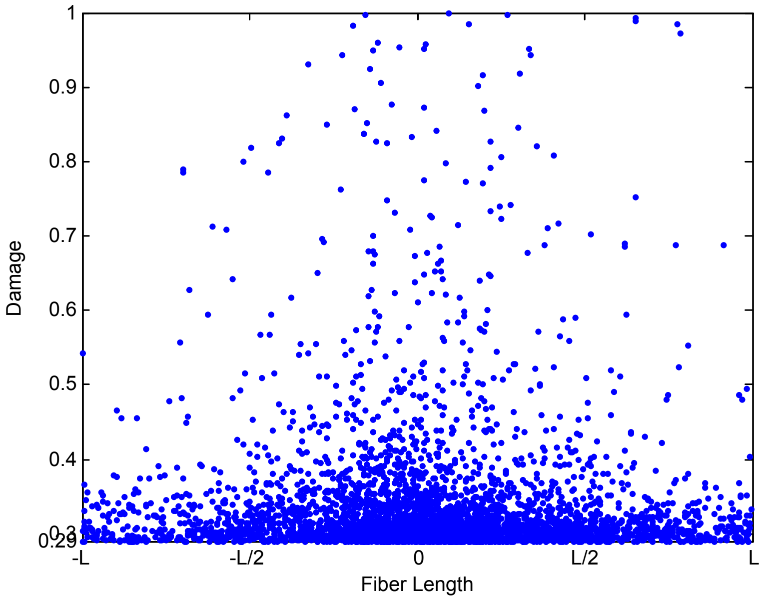

Figure 3 Damage to the fiber-matrix interface of E-Glass-Epoxy

3.2. *Kenaf/Epoxy*

Figure 5 shows that for an applied tensile stress of 125 N/m^2 , the damage "D" of the interface is equal to 0.2. We also note the presence of symmetry of the damage. In a humid environment of 60% (Fig. 6), we found that the damage increased to a value of 0.35 for the Kenaf-Epoxy Biocomposite material.

3.3. *Kenaf/Polypropylene*

Figure 7 shows that for an applied tensile stress of 125 N/m^2, the damage "D" of the interface is equal to 0.15. We also note the presence of symmetry of the damage. In a humid environment of 60% (Fig. 8), we found that the damage increased to a value of 0.19 for the Kenaf- Polypropylene Biocomposite material.

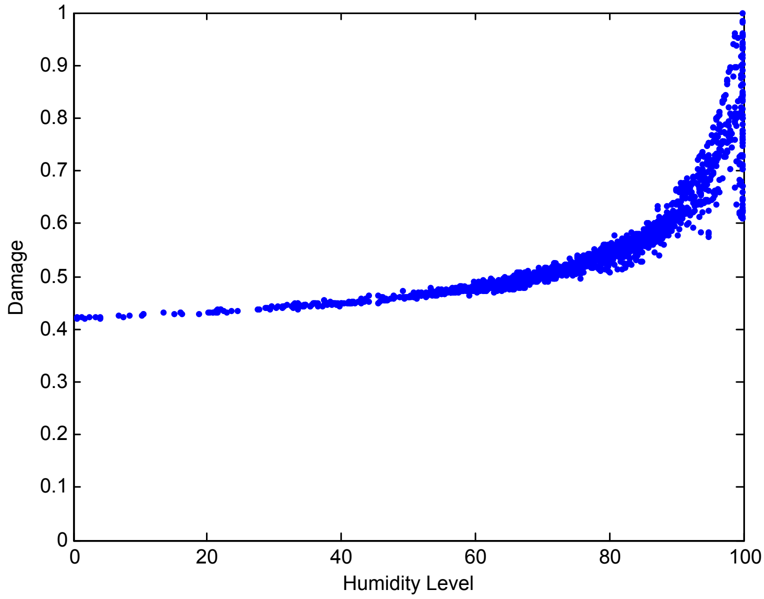

Figure 4 Influence of moisture on the damage of the fiber-matrix interface of the Glass-epoxy

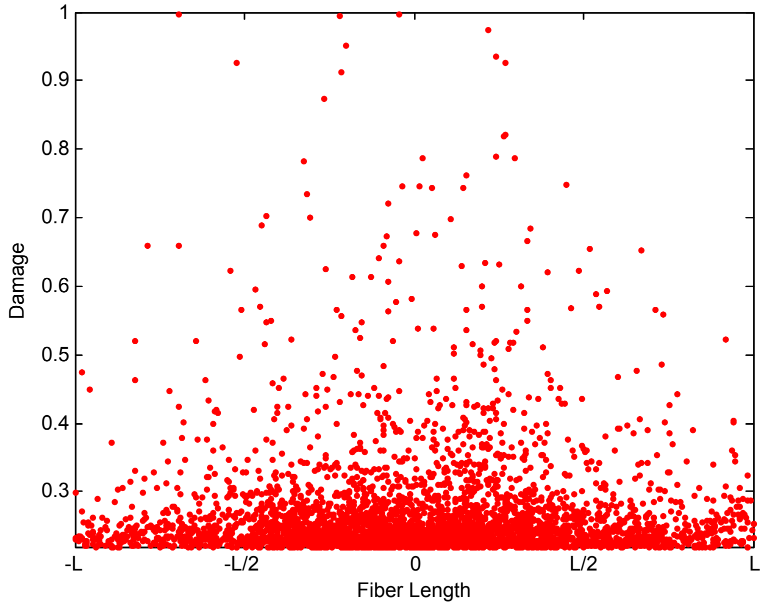

Figure 5 Damage to the fiber-matrix interface of Kenaf-Epoxy

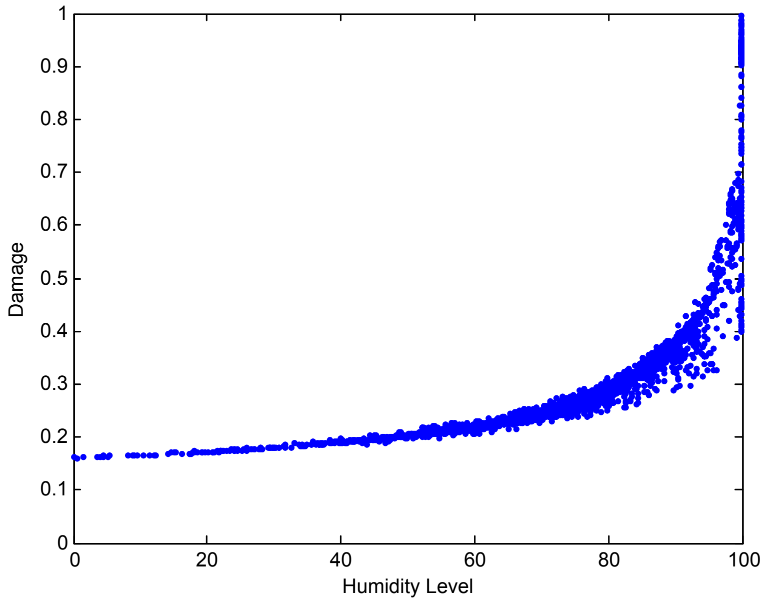

Figure 6 Influence of moisture on the damage of the fiber-matrix interface of the Kenaf-Epoxy

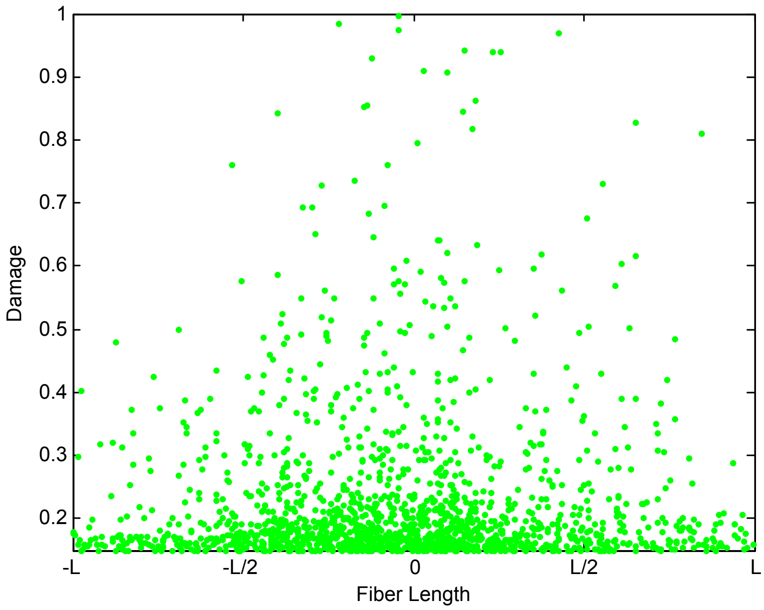

Figure 7 Damage to the fiber-matrix interface of Kenaf-Polypropylene

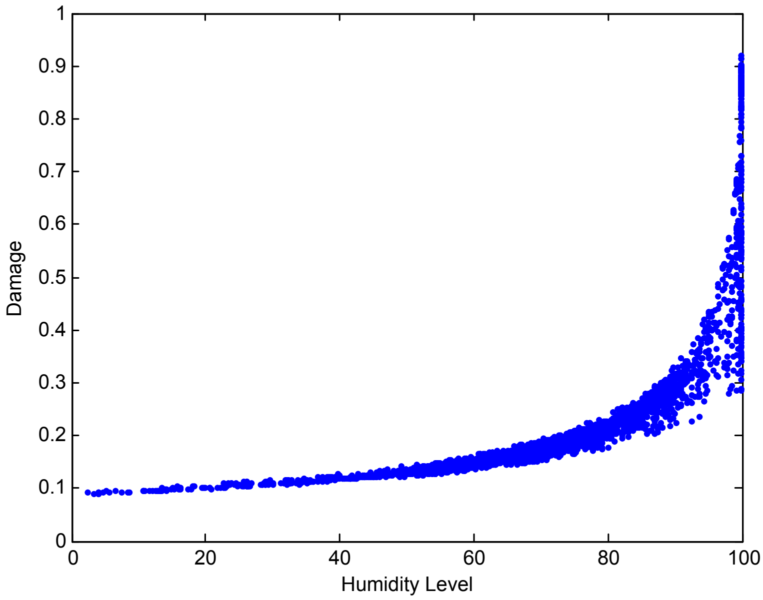

Figure 8 Influence of moisture on the damage of the fiber-matrix interface of the Kenaf-Polypropylene

4. Conclusion

The results found by calculation of genetic algorithm, show that the humidity has a significant influence on the progressive degradation of the interface. Our results show that the 60% moisture content does not affect the fiber-matrix interface the two Kenaf-PP and kenaf-epoxy biocomposites compared to the E-Glass-epoxy composite material whose interface damage increases to 0.28, we can understand that the stress concentration along the length of the fiber and humidity create a strong degradation of the interface, values are lower compared to those found for the Kenaf/PP. This result coincides perfectly with the experimental data found by Paul Wambua et al [11], which have shown that Kenaf is a promoter fiber for the improvement of the mechanical properties of biocomposite used in the field of civil engineering.

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