N. Ziani[1], A. Boudali[2], *A. Mokaddem[3], B. Doumi[4], N. Beldjoudi[5], A. Boutaous[1]

Study by Genetic Algorithm of the Role of Alfa Natural Fibre in Enhancing the Mechanical Properties of Composite Materials Based on Epoxy Matrix

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[1]**Faculty of Physics,
Department of Materials Technology
U.S.T.O BP**
1505 Oran, Algeria

[2]**Laboratoire des Etudes Physico-Chimiques,
Université de Saïda,**
Saïda 20000, Algérie

[3]**Faculty of Physics,
Department of Materials and Components,
U.S.T.H.B,**
Algiers, Algeria,

[4]**Faculty of Sciences,
Department of Physics,
Dr. Tahar Moulay University of Saïda,**
20000 Saïda, Algeria

[5]**Faculty of Physics,
Theoretical Physics Laboratory,
U.S.T.H.B,**
Algiers, Algeria

*E-mail: mokaddem.allel@gmail.com

Abstract
Natural fibres have a very important role in improving the mechanical properties of composite materials. Our objective in this study was to use alfa natural fibre in a composite material based essentially on epoxy matrix and calculate the interface fibre-matrix damage of carbon-epoxy, glass-epoxy and alfa-epoxy. Each sample was reinforced with the same volume fraction before being subjected to various mechanical tests. The results found by genetic simulation showed that the level of damage to the alfa-epoxy material was lower compared to other composite materials studied. We can say that alfa natural fibre has a high resistance to the mechanical stress applied; but the question remains whether the new material has the same resistance to thermal stress.

Key words: *damage, interface, alfa, fibre, matrix, genetic algorithm.*

Introduction

Technological development coupled with consumer expectations continue to rise at the expense of land resources, leading to significant problems related to hardware availability and environmental sustainability [1 - 3]. Recently general consensus regarding the important contribution of man in global warming has been reached. This awareness has also led to express interest in materials from sustainable resources that require only low energy for their production, as well as recyclable materials, including those whose energy can be recovered, as found for example in composite reinforcements of natural fibres. Wood was the first natural composite material used. Later, the mud has been used in building for its insulating properties and low cost. Among the first composites made by Man, there is also the Mongol bows (2 000 years before J-C), these more recent measures have encouraged the extension of their use [1 - 6]. An important area under development for the past decade is the use of thermoplastic panels, obtained by compression moulding and reinforced natural fibres, which have been widely adopted in the European automotive industry for parts such as door panels , car interiors, dashboards and car trunk coverings [1, 5 - 7]. Indeed considerable effort has focused on improving the mechanical performance of thermoplastic composites reinforced with natural fibres to permit extension of their application. Much of this attention has been aimed at improving the interfacial resistance, for which a range of treatments of fibres and coupling agents has been evaluated. Indeed the choice of a preferred orientation, increasing the fibre length or the use of other matrix, which are, inter alia, the current areas of research, can affect mechanical properties of the composite [1]. A new application that presents an alternative polymer matrix is the use of biodegradable polymers which exhibit a better mechanical strength where biodegradability and high performance are already among the priorities of study [1, 2].

Another major area of investigation that could extend the application of composite materials with natural fibres is improving the long-term performance, including improved resistance to moisture, ultraviolet radiation and creep. As mentioned above, thermoplastic matrix composites and natural fibre reinforcements are developed for the automotive as well as traditional wood industries, commonly used as reinforcing thermosetting matrices in furniture [1 - 4]. Generally composites reinforced by natural fibres are

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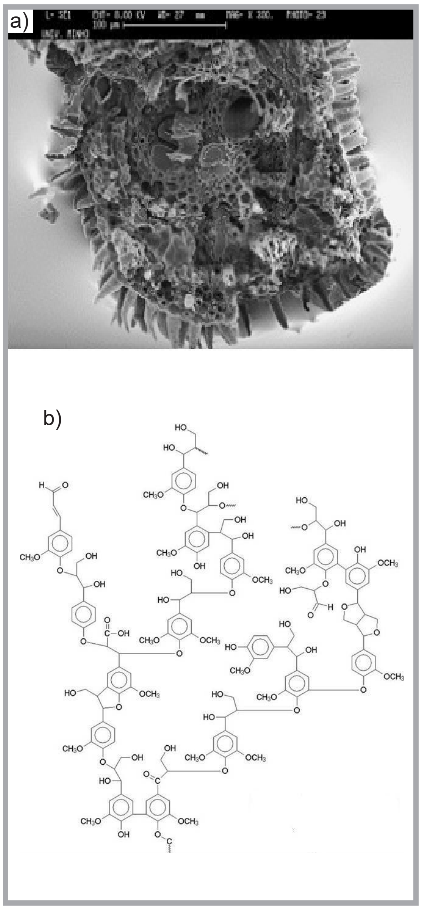

Figure 1. Representation of alfa plant; a) MEB image of cross section of alfa rod, b) molecular structure of lignin.

considered to be potential materials for many engineering applications [5 - 7]. However, there are still important issues that limit their future use, including long-term performance and the ability to be able to predict the performance during service. Fracture mechanics can give many ideas about the physical effects that occur in these materials; which will help in the production of natural fibre composites with improved properties.

The Alfa plant grows in the wild in the Mediterranean region. Alfa rods are composed of cellulosic filaments bound by lignin, hemicellulose and pectins. Short fibres are obtained by aggressive extraction methods that eliminate binders. They are used for the production of paper and composite reinforcements (see ***Figure 1***).

Our objective in this study was to use alfa natural fibre in a composite material based essentially on epoxy matrix, calculate the interface fibre-matrix damage of carbon-epoxy, glass-epoxy and alfa-epoxy, and then see the influence of the alfa fibre on optimisation of the shear damage of all composite materials studied.

Mechanical properties of the reinforcement and resin used

Composite material is usually understood as the combination of two or more materials on a macroscopic scale used to form a useful third material. In this section we present the mechanical properties of the two basic constituent fibres and matrix of composite materials of alfa/epoxy, glass/epoxy and carbon/epoxy that will be used later in our numerical simulation.

Reinforcement

Table 1 shows mechanical properties of the reinforcement (alfa fibre, carbon and glass)[8].

Epoxy resin

The resin used was a high-performance organic resin of the epoxy type, the characteristics of which is presented in ***Table 2*** [9]:

Reminder of analytical models

Modelling of the interface

The fibre matrix interface is formed at the time of preparation of the material; its behaviour is not reducible to that of the constituent phases, ensuring physical continuity of the component to another throughout the material. The composite fibres work together, and a matrix is used to distribute and transmit the force between fibres; but these efforts must go through the interface. From the damage to the fibre-matrix interface it is difficult to characterise the overall composite since the answer is diluted (masked by that of the two main constituents). In fact, different damage affecting the various components (fibre, matrix and interface) can be distinguished:

- damage to the matrix by transverse micro cracking,
- damage to the fibre-matrix debonding interface [10].

Table 1. Mechanical properties of the reinforcement.

Fibre	Density, kg/dm³	Strain at break, %	Specific stress at break, MPa	Specific Young modulus, GPa
Alfa	1.4	1.5 - 2.4	134 - 220	13.0 - 17.8
E Glass	2.6	2.5	770 - 1345	27
S Glass	2.6	2.8	1750	33
Carbon	1.7	1.4 - 1.8	2350	140

Table 2. Mechanical properties of the epoxy resin.

Density, kg/dm³	Compressive strength, MPa	Tensile strength in bending, MPa
1.3 ± 0.05	> 70	25

At the microscopic scale of damage, two variables are defined:

- D_m - Damage to the matrix
- D_f - Damage to the fibre.

Model based on the statistical approach

Damage to the matrix, when the stress is uniform, is given by formula (1) Weibull [11]:

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

With:

- D_m - damage to matrix

σ - stress applied;
σ_m^T - heat stress;
V_m - volume of matrix;
m_m and σ_{0m} - Weibull parameters.

After the creation of a crack, a fragment of length L will give rise to two fragments of size $L = L_1$ and $L_2 = X \times L \times (1 - X)$ (X being a random number between 0 and 1). At each crack up a fibre, a fibre-matrix debonding length $2l$ will occur with a corollary decrease in creating a new crack in part because the matrix unloaded. At each increment of all stress, the break is calculated. All blocks which break reaching 0.5 give rise to new cracks under different stress [12, 13].

A broken fibre is discharged along its entire length Lissart [12 - 14, 15]. That is to say, it cannot break once. The rupture follows a law similar to that described for the matrix [16, 17].

$$D_f = 1 - \exp\left\{ -A_f * L_{equi} * \left[\frac{\sigma_{\max}^f}{\sigma_{0f}} \right]^{m_f} \right\} \quad (2)$$

with:
- D_f - damage to fibre.
  $\sigma^{f}_{\max}$ maximum stress applied
- L_{equi} - length of fibres would have the same break in a consistent manner.

Model of Cox

For a single fibre surrounded by matrix, many analytical solutions have been proposed. One of the first, that of Cox, provides the shape of the shear stress along the fibre length in the form [18]:

$$\beta^{2} = \frac{2G_m}{E_f r_f^{2} \ln(\frac{R}{r_f})} \tag{3}$$

$$\tau = \frac{E_f a \varepsilon}{2} \beta \, th(\beta \, l\!/\!2) \tag{4}$$

with:

β - Simplifying parameter used by Cox
E_f - Young's modulus of fibre;
G_m - shear modulus of matrix;
ε - deformation ;
a - radius of fibre;
R - half the distance;
τ - shear stress of interface;

Numerical simulation by genetic algoritm (GA)

Development

The objective desired is to show the effect of alfa natural fibre on the resistance of the fibre-matrix interface of composite materials. Our approach is to change the structure of our material by the replacement of glass fibre and carbon fibre with the new alfa fibre in every step of calculating damage to the interface. Our genetic simulation is to use the values of each reinforcement to calculate the level of damage to the interface using Weibull equations (1, 2) and Cox equations (3). The damage to the interface is determined by the intersection of the epoxy matrix damage and damage of each fibre selected. The evaluation of each generation is made by an objective function based on the Cox model, which includes all the variables defined at the beginning of the algorithm (mechanical properties of each component of the composite, Young's modulus of the fibre selected, ...) [13, 19]. Finally we determine the shear damage to the interface fibre length for all three fibres used.

The flowchart

The genetic algorithm directs research through the creation of new individuals (damage to the interface) from old ones (damage to the fibre D_f and the matrix D_m). More specifically, the genetic algorithm identifies the performance patterns of individuals already travelled and builds new individuals by combining these patterns between them (cross between D_m and D_f). An efficient scheme is defined as a group of genes that when present in an individual, allows one to obtain a high level of performance in relation to other individuals in the population [19].

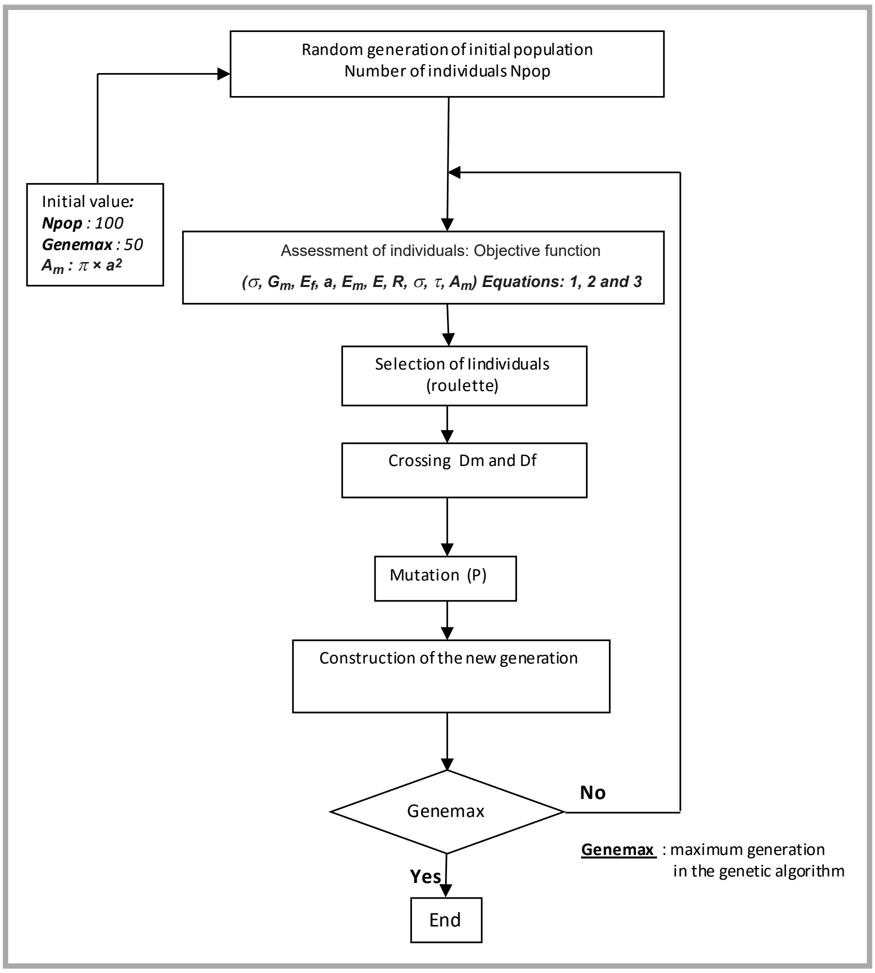

***Figure 2.** Flowchart of genetic algorithm.*

Finally it is by a pseudo-random process that the genetic algorithm succeeds in finding and combining together the performance patterns, and hence damage to the interface. This is done by promoting reproduction of the most powerful individuals who can then pass on their good patterns to their offspring (D_m and D_f). When playing, it is possible that children combine performance and distinct patterns of both parents to form a new, more efficient scheme, which will then tend to be more present in the population, given its performance, and to increase the quality of individuals [18, 19]. This algorithm is defined by the flowchart in ***Figure 2.***

Simulation results

A calculation was performed for three (3) types of composite materials: carbon/epoxy, glass/epoxy and alfa/epoxy. We calculated the shear damage to the interface for all composite materials. ***Figures 3, 4, 5, 6, 7*** and ***8*** show, respectively, each value σ for the level of damage to the interface of carbon/epoxy, glass/epoxy and alfa/epoxy :

Alfa-epoxy

Figures 3 and ***4*** show that the damage "D" to the interface starts at 0.18 for $\boldsymbol{\sigma}$ = 100, and then increases to a maximum value of 0.22 for $\boldsymbol{\sigma}$ = 120 N; we note the presence of a symmetry of the damage to the interface.

Glass/epoxy

Figures 5 and ***6*** show that the damage "D" to the interface starts this time at 0.25 for $\boldsymbol{\sigma}$ = 100, and then increases to a maximum value of 0.4 for $\boldsymbol{\sigma}$ = 120 N; we note the presence of a symmetry of the damage to the interface.

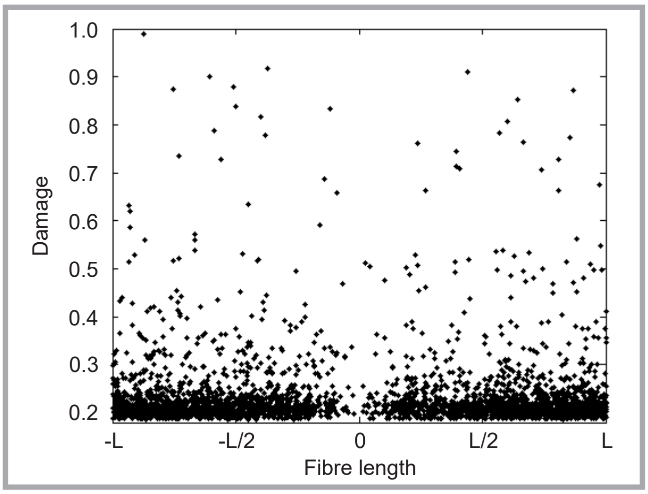

Figure 3. Level of shear damage to the interface of alfa/epoxy (σ = 100 N).

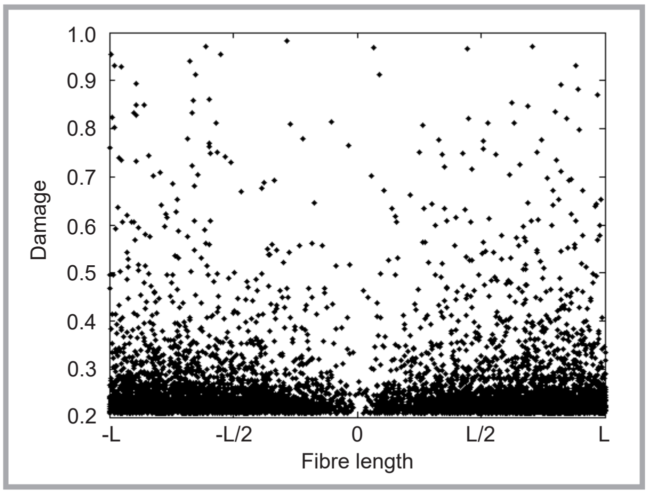

Figure 4. Level of shear damage to the interface of alfa/epoxy (σ = 120 N).

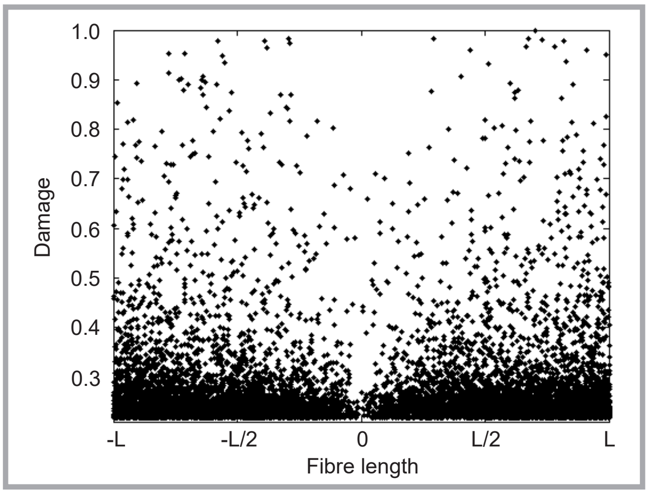

Figure 5. Level of shear damage to the interface of glass/epoxy (σ = 100 N).

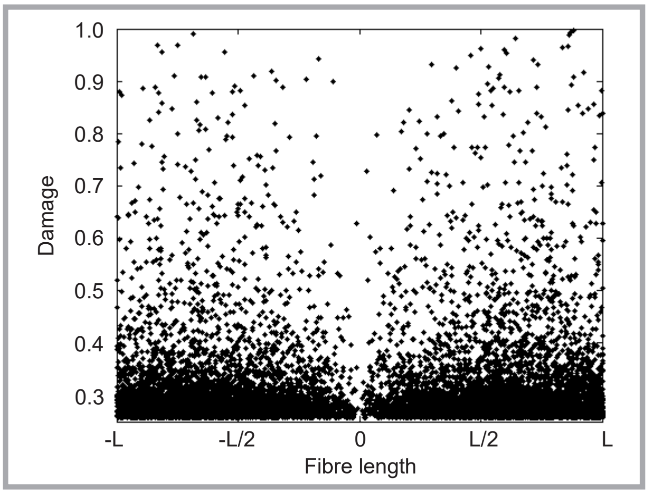

Figure 6. Level of shear damage to the interface of glass/epoxy (σ = 120 N).

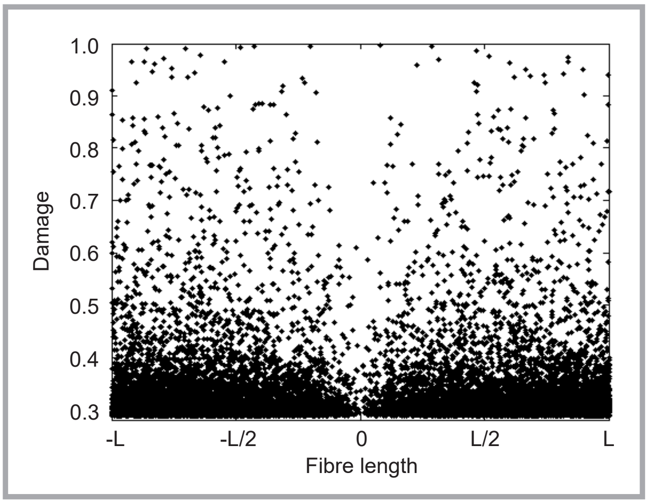

Figure 7. Level of shear damage to the interface of carbon/epoxy (σ = 100 N).

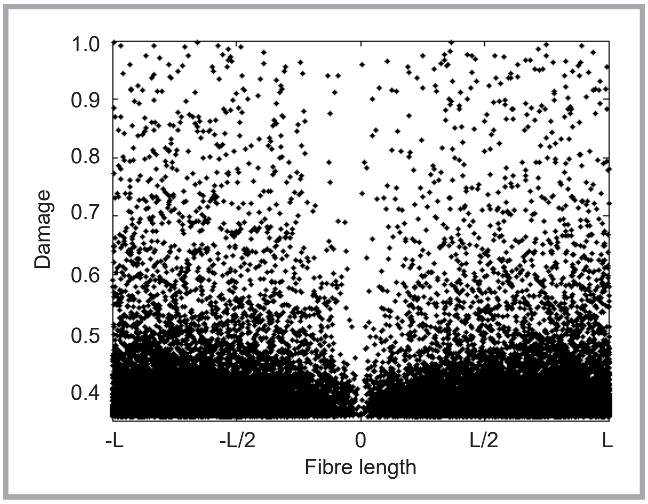

Figure 8. Level of shear damage to the interface of carbon/epoxy (σ = 120 N).

Carbon/epoxy

Figures** 7* and ***8 show that the damage "D" to the interface starts this time at 0.26 for $\boldsymbol{\sigma} = 100$, and then increases to a maximum value of 0.52 for $\boldsymbol{\sigma} = 120$ N; we note the presence of a symmetry of the damage to the interface.

We can say that the stress concentration along the length of the fibre creates a strong degradation of the interface. most importantly at the ends relative to the middle; values of composite material alfa/epoxy are lower compared to those found for glass/epoxy and carbon/epoxy.

Conclusion

The results found after genetic calculation show that the level of damage to the interface is related to the nature of the materials used. The interface of alfa/epoxy has a greater resistance to mechanical stress compared with the interface of glass/epoxy and carbon/ epoxy. The numerical simulation has good agreement with the result obtained from our genetic algorithm calculation, which shows that the alfa/epoxy is stronger than the carbon/epoxy and glass/epoxy; the figures show that the values of interface damage found for alfa/epoxy are far inferior to those for carbon/epoxy and glass/epoxy. The alfa/epoxy composite material has good mechanical resistance and can be used in applications requiring such materials (textiles, industrial, aeronautical ...). Therefore our findings revealed that the model worked well with the phenomenon of damage to unidirectional composite materials.

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Institute of Textile Engineering and Polymer Materials

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Contact:
Institute of Textile Engineering and Polymer Materials
University of Bielsko-Biala
Willowa 2, 43-309 Bielsko-Biala,
POLAND
+48 33 8279114,
e-mail: itimp@ath.bielsko.pl
www.itimp.ath.bielsko.pl