Mechanics and Mechanical Engineering
Vol. 20, No. 3 (2016) 331–345


# Comparative Studies by a Genetic Algorithm on the Mechanical Properties of PLA and Expoxy Biocomposite Materials Reinforced with Alfa Natural Fiber

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Received (15 January 2016)
Revised (27 January 2016)
Accepted (28 May 2016)

The natural fibers are indeed a renewable resource, biodegradable and naturally with technical qualities and very high mechanical properties. The mechanical properties of reinforcement biocomposites as alfa / polylactic acid (PLA) are largely conditioned by the interfacial bond between the two materials (fiber and matrix). To characterize this link and locate damage to the fiber-matrix interface, we used a genetic approach based on the Cox model and formalism of Weibull. This model taking into account the micromechanical behavior of the three composite and biocomposites materials: Glass/epoxy, alfa / epoxy and alfa / PLA. The results of this simulation show that the damage level of the interface is related to the nature of the materials used and the applied mechanical stress, and has shown that the green material alfa / PLA is stronger than the biomaterial alfa / epoxy. The results of this modeling are in agreement with those obtained experimentally by Antoine et al. So the natural fibers have a very important role in enhancing the mechanical strength of composite and biocomposites materials.

*Keywords*: glass, interfaces, biocomposites, PLA, alfa, epoxy.

## 1. Introduction

The use of biocomposites materials in the industrial and medical sectors continues to increase. These materials give designers the possibility of combining forms and functions within systems and innovative structures. Innovation is largely substitute petrochemical compounds or organic origin by renewable biological source compounds [1–5].

Few studies describe the properties of the fiber–matrix interface of a biocomposites while improving the mechanical performance requires a better understanding of this area [1–9].

It is well known that for environmental reasons, research on ecological materials experienced during the past two decades a very important development. It is in this context that fits the work we present and describes the development of a number of fully biodegradable composite materials [2–7].

Plant fibers (flax, hemp, wood, alfa) are increasingly used as reinforcement in plastic materials and optimizing the properties of these materials constitute a considerable challenge because it helps meet two objectives: the use of biodegradable materials that are part of an eco–design (the recycling of composites is a major issue for this class of materials) and the valuation of certain agricultural resources for emerging countries [10–17]. These fibers are indeed a renewable resource, naturally biodegradable and have high technical qualities. The composite thus formed are such applications in the automotive industry (bumpers, door panels, dashboard) and construction housing (insulation, baseboards, door frames, garden furniture) [8–11].

The properties of these composite materials are intimately related to the properties of its components, but also at the interface. [1–5]. Cohesion between vegetable fibers and the polymer matrix remains a technological obstacle for the development of these materials. Indeed, the cellulose, the main component of plant fibers, is generally not or hardly compatible with the thermoplastic matrix. Many studies have therefore focused on improving these properties, especially through physical or chemical treatment of the fibers [2–15].

It has been shown, for example, treatment in autoclave or by cold plasma increased the water resistance of the fibers [14–19]. If these studies have clearly demonstrated an increase in desired properties, the exact nature of these improvements, the nanoscopic and microscopic scales, are still subject to debate.

This work aims to compare the resistance of the fiber–matrix interface between three composites and biocompositess materials glass/epoxy, alfa / epoxy and alfa / PLA by measuring the different mechanical properties.

## 2. Review of analytical models

### 2.1. *Model based on the micromechanical approach*

For a single fiber surrounded by matrix, many analytical solutions have been proposed by Cox. [20], provides the shape of the shear stress along the fiber length as the following form:

$$\tau = \frac{E_f a \varepsilon}{2} \beta \, th\left(\beta \, \frac{l}{2}\right) \tag{1}$$

To simplify calculations, we take:

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

with:

($G_m$) – shear modulus of the matrix;

($E_f$) – Young's modulus of the fiber;

($\varepsilon$) – deformation;

(a) – radius of the fiber;

($R$) – distance between fibers;

($\tau$) – shear stress of the interface.

These variables relating to the components of a composite material (fiber and matrix) are all taken into account through the formula 3. Therefore these variables will allow us to appreciate the result sets of genetic algorithm.

## 2.2. *Model based on the statistical approach*

Damage to the matrix, when the stress is uniform, is given by formula (2) [21]:

$$D_m = 1 - \exp\left\{-V_m \left[\frac{\sigma + \sigma_m^T}{\sigma_{0m}}\right]^{m_m}\right\} \tag{2}$$

with:

($\sigma$) – applied stress,

$(\sigma_m^T)$ – heat stress,

($V_m$) – the ratio volume of the matrix,

($m_m$ and $\sigma_{0m}$) – Weibull parameters.

A broken fiber is discharged along its entire length. That is to say it can not break once. The rupture follows a law similar to that described for the matrix.

$$D_f = 1 - \exp\left\{-A_f * L_{equi} * \left[\frac{\sigma_{\max}^f}{\sigma_{0f}}\right]^{m_f}\right\} \tag{3}$$

with:

($\sigma_{\max}^f$) – The maximum stress applied

*(Lequi)* – is the length of the fibers

would have the same break in a consistent manner.

## 3. Mechanical properties of composites studied

### 3.1. *Structure and morphology of fibers alfa*

In general, the fiber structure is heterogeneous. Smaller parts in the fibers are cellulosic filaments or fibrils having lengths of 2 to 5 mm and diameters of from 5 to 10 um. These fibrils are bonded to a dense manner by hemicellulose in the fiber forming.

Their cross section has an irregular shape as shown in the photo taken with an optical microscope (Fig. 1). The fibers have a diameter of about 50 um (Fig. 2). The bond between the fibers is provided by the lignin and pectin to give the fiber bundles, that is to say technical fibers. The cross section of the fiber bundles shows that the section is not circular and the diameter is approximately 200 um (Fig. 3). The binding of fiber bundles finally gives the stem (Fig. 4) [22–26].

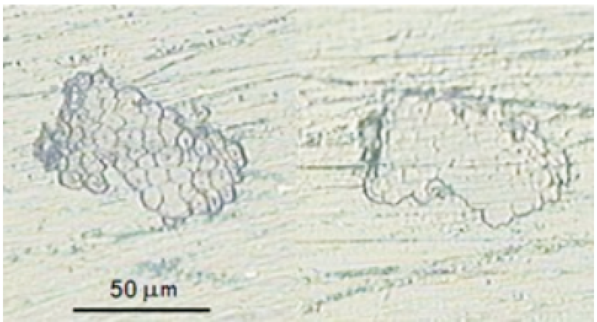


**Figure 1** Image by optical microscopy fibers composed of cellulose filaments

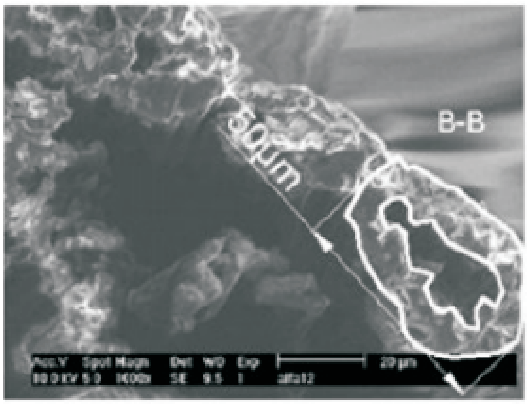


**Figure 2** MEB image of the cross section of the fibers

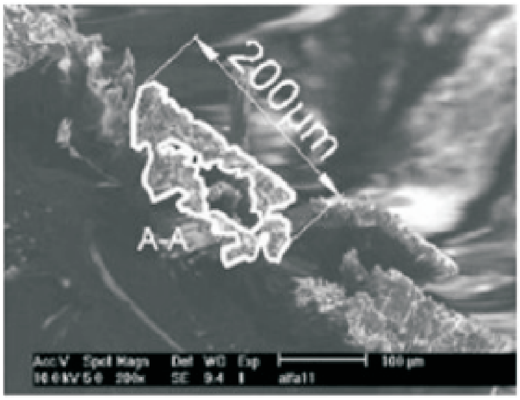


**Figure 3** MEB image of the cross section of beam esparto fibers

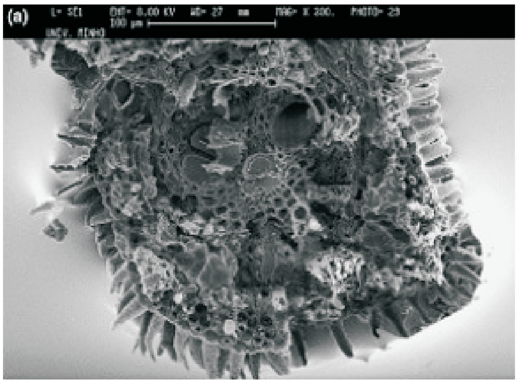


**Figure 4** MEB image of the cross section of the rod alfa

### 3.2. *The mechanical properties of alfa fibers (esparto fibers) compared to other natural fibers*

Tab. 1 gives the tensile properties for the main natural and synthetic fibers. Regarding alfa, it is the properties of the technical alfa, that is to say, fiber bundles. Regarding the elongation at break, its value for technical alfa (1.5–2.4%) is close to that of jute (1.5–1.8%), hemp (1.6%) and sisal (2–2.5%). Technical alfa has a breakdown voltage between 134 and 220 MPa, comparable to that of cotton (191–398 MPa). As to the Young's modulus, which has an indication for the stiffness value for the technical alfa (13–17.8 GPa) is close to that of flax (18 GPa) and hemp (17 GPa) and is greater than that cotton (3.6–8.4 GPa) and agave (4.2 GPa). The

**Table 1** The tensile mechanical properties of the main natural and synthetic fibers

| **Fibers** | **density** [g /cm$^3$] | **deformation at break** [%] | **constraint at break** [MPa] | **Young's modulus** [GPa] |
|---|---|---|---|---|
| Alfa | 1.4 | 1.5-2.4 | 134-220 | 13-17.8 |
| agave | 1.4 | 20 | 350 | 4.2 |
| cotton | 1.5 | 7 - 8 | 191 - 398 | 3.6 - 8.4 |
| jute | 1.3 | 1.5 - 1.8 | 300 - 600 | 20 |
| linen | 1.5 | 2.7 - 3.2 | 230 - 690 | 18 |
| hemp | 1.5 | 1.6 | 460 | 17 |
| ramie | 1.5 | 3.6 - 3.8 | 266 - 630 | 42 - 86 |
| sisal | 1.5 | 2 - 2.5 | 340 - 423 | 6 - 14 |
| wood | 1.5 | - | 666 | 26 |
| E glass | 2.6 | 2.5 | 770 - 1345 | 27 |
| S glass | 2.6 | 2.8 | 1750 | 33 |
| Kevlar | 1.4 | 3.3 - 3.7 | 2140 - 2250 | 45 - 48 |
| carbon | 1.7 | 1.4 - 1.8 | 2350 | 140 |

tensile mechanical properties of technical alfa are generally similar to those of jute, flax, hemp and sisal [22–25].

### 3.3. *Polylactic acid (PLA)*

Polylactide or poly (lactic acid) is generally an aliphatic polyester is synthesized by condensation from an $\alpha$–hydroxy acid (lactic acid) or by ring-opening polymerization from a cyclic monomer: the lactide (Fig. 5) [23–26].

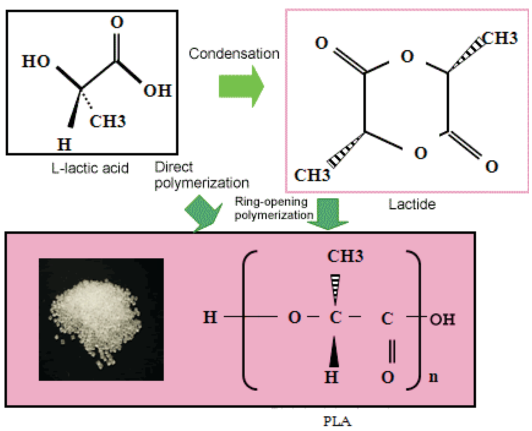


**Figure 5** Production process of the polylactic acid (PLA)

This is a bioresorbable polymer with thermoplastic properties, modulus and high resistance. However, its mechanical properties strongly depend on the route of synthesis and the quality of the synthesized polymer (composition, purity, molecular weight). Can be prepared from lactic acid in large quantities (up to 105 tonnes per year) from any polysaccharide according to a biotechnological process. Thus the production of polylactide may be based on renewable resources and be independent of the price or the supply of oil. The physical properties (including mechanical) of polylactide can be controlled easily by changing the composition of the mixture of isomers L or D. The area of PLA application extends from the packaging industry to biomedical applications (sutures, implants, controlled release) [13–26].

Usually, commercial PLA is a poly–L–lactic (PLLA) and poly–DL lactic (PDLLA) acid copolymers [14–27].

We presented in Tab. 2 the mechanical properties used in our genetic model for the various constituents of the biocomposites materials.

**Table 2** The mechanical properties of various constituents of biocomposite materials

| Designation | | **Thermal expansion coefficient [1/°C]** | **Radius [m]** | **Young's modulus [MPa]** | **Density [g/cm$^3$]** | **Poisson coefficient** |
|---|---|---|---|---|---|---|
| **Fiber** | **ALFA** | / | 13-30*$10^{-6}$ | 12.7*$10^{+3}$ | 1.51 | 0.30 |
| **Matrix** | **PLA** | 7.85*$10^{-5}$ | 40*$10^{-6}$ | 3.5*$10^{+3}$ | 1.25 | 0.36 |

## 4. Numerical simulation by a genetic algorithm (GA)

### 4.1. *Development*

The desired objective is to show the effect of alfa natural fiber on resistance of the fiber–matrix interface of composite and biocompositess materials. Our approach is to change the structure of our material by replacing the epoxy matrix PLA every step of calculating damage to the interface. Our genetic simulation is to use the values of each mechanical properties to calculate each time the level of damage to the interface using the Weibull equations (2, 3) and Cox equation (1). The Damage to the interface is determined by the intersection of the alfa fiber damage and damage of the each matrix selected (epoxy and PLA). 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, the Young's modulus of fiber). [27–28] Finally we determine the damage to the interface fiber length for all three materials used. Numerical calculations are performed using the Matlab R2012a release software.

### 4.2. *The flowchart*

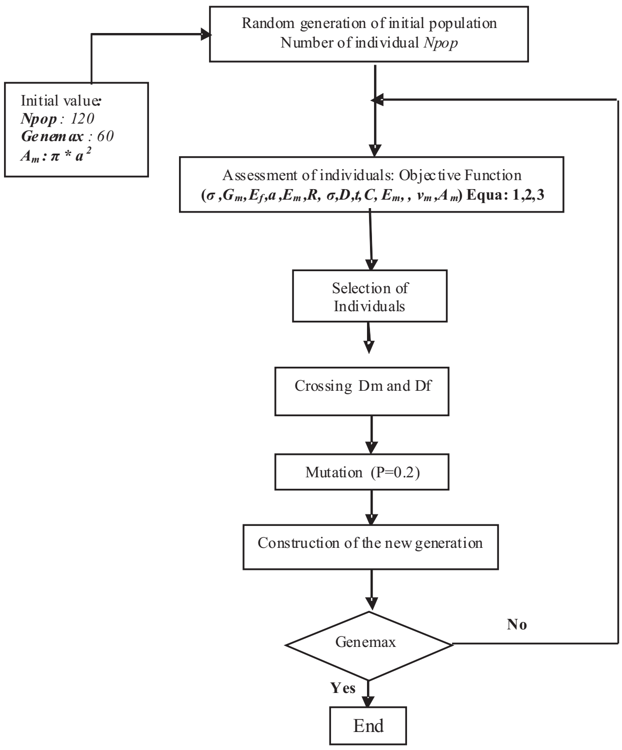


**Figure 6** The flowchart of genetic algorithm

## 5. Simulation results

According to the simulation results by a genetic algorithm. The strength of the three composite and biocomposites materials is examined after the application of different constraints ($\sigma = 80$ N $\sigma = 100$ N $\sigma = 120$ N) to calculate the damage to the fiber matrix interface. Fig. 7–15 respectively show the level of damage to the interface of Glass / epoxy, Alfa / epoxy and Alfa / PLA.

### 5.1. *Glass / Epoxy*

Figs 7–9 show that the damage to the interface begins at 0.3 for $\sigma = 80$ N, then increases to a maximum value equal to 0.56 for $\sigma = 120$ N, we note the presence of a symmetry of the damage to the interface, which dense in the middle and low at the ends, this means that the deterioration of the medium interface is greater relative to the ends because of the stress concentration. The value of the damage that we found in this material is higher than those found for Alfa / Epoxy and Alfa / PLA.

### 5.2. *Alfa / Epoxyde*

Figures 10–12 show that the damage to the interface begins at 0.28 for $\sigma = 80$ N, then increases to a maximum value equal to 0.48 for $\sigma = 120$ N, we note the presence of a symmetry of the damage to the interface, which dense in the middle and low at the ends, this means that the deterioration of the medium interface is greater relative to the ends because of the stress concentration. The value of the damage that we found in this material is higher than those found for the Alfa / PLA.

### 5.3. *Alfa / PLA*

It is observed in Fig. 13–15 that the damage to the interface begins at 0.2 for $\sigma = 80$ N, then increases to a maximum value equal to 0.35 for $\sigma = 120$ N is observed also the existence of a symmetry of the damage at the interface, dense in the middle and low at the ends, this means that the deterioration of the medium interface is greater relative to the ends because of the stress concentration. The level of damage in this material is lower comparing with the other materials composite (Glass / Epoxy) and biocomposites (Alfa / Epoxy).

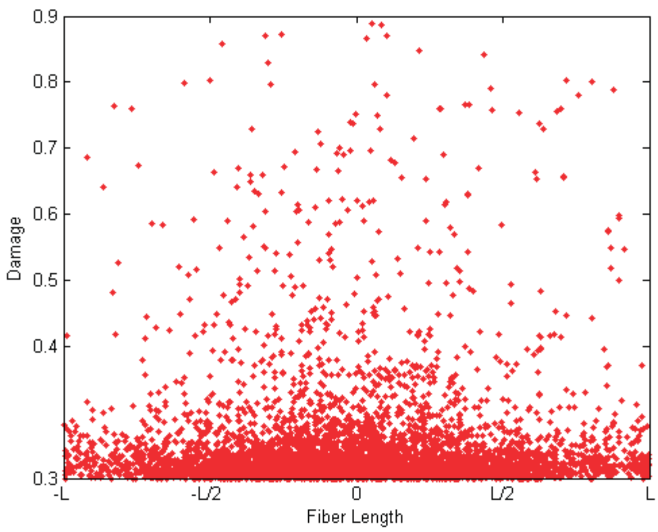


**Figure 7** Level of damage to the interface of Glass / Epoxy for $\sigma = 80$ N

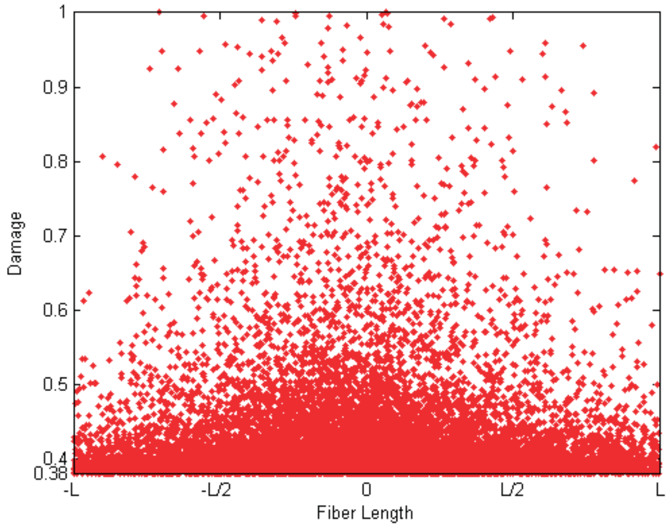


**Figure 8** Level of damage to the interface of Glass / Epoxy for $\sigma$ = 100 N

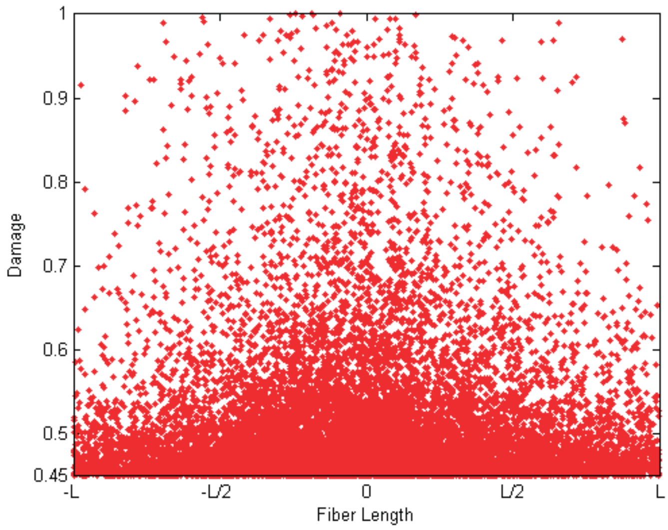


**Figure 9** Level of damage to the interface of Glass / Epoxy for $\sigma$ = 120 N

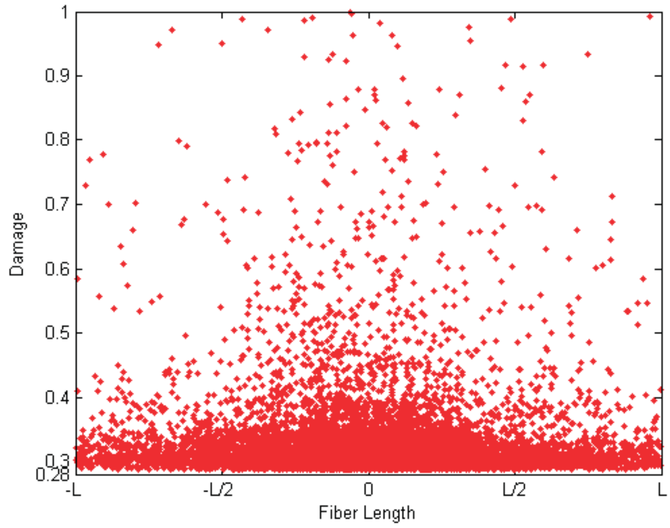


**Figure 10** Level of damage to the interface of Alfa / Epoxy for $\sigma$ = 80 N

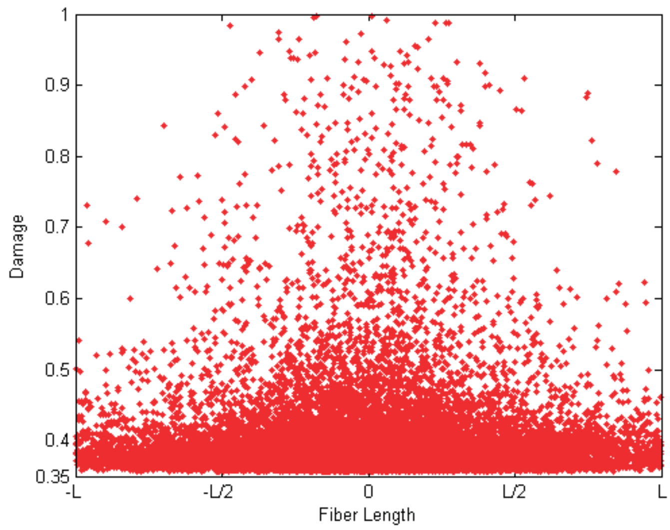


**Figure 11** Level of damage to the interface of Alfa / Epoxy for $\sigma$ = 100 N

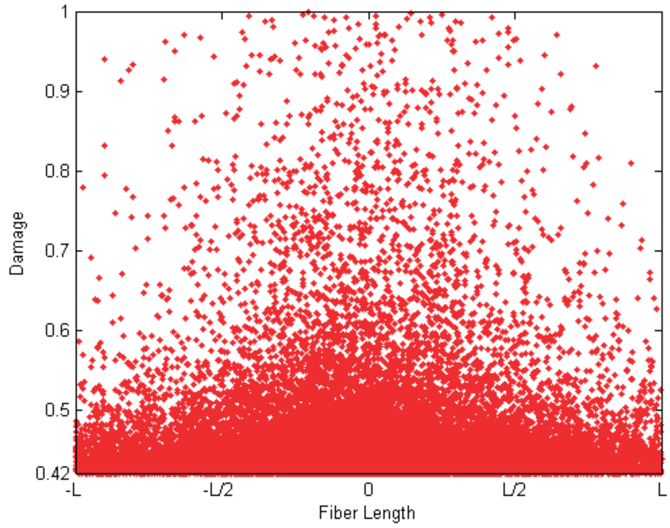


**Figure 12** Level of damage to the interface of Alfa / Epoxy for $\sigma = 120$ N

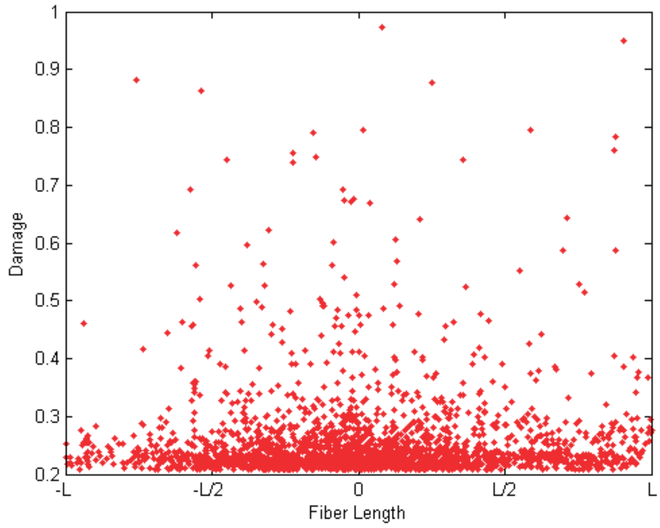


**Figure 13** Level of damage to the interface of Alfa / PLA for $\sigma = 80$ N

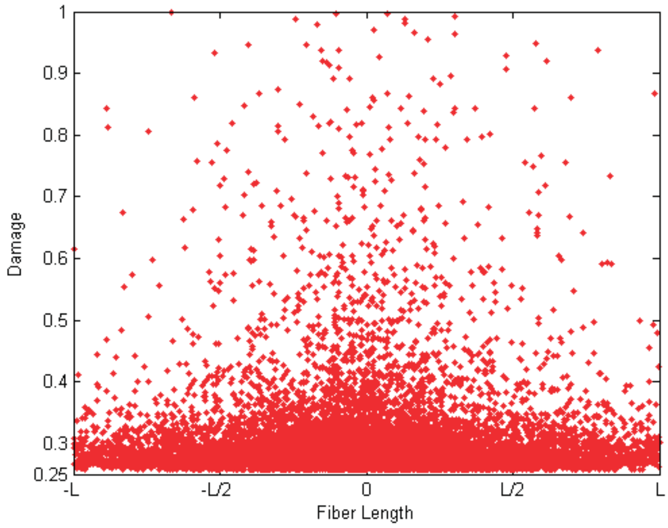


**Figure 14** Level of damage to the interface of Alfa / PLA for $\sigma$ = 100 N

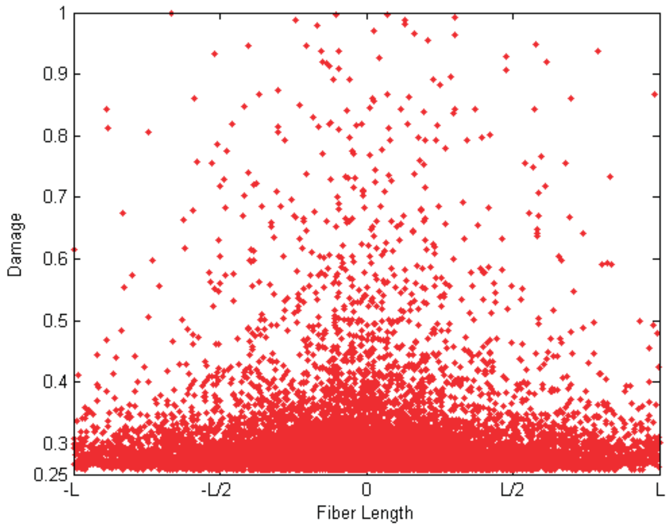


**Figure 15** Level of damage to the interface of Alfa / PLA for $\sigma$ = 120 N

## 6. Conclusion

The results found after genetic algorithm calculation, show that the level of damage is related to the mechanical stress applied, for materials that were studied the Glass / Epoxy, Alfa / Epoxy and Alfa / PLA. Our simulation shows that the Alfa / PLA is stronger than the Alfa / Epoxy and the Alfa / Epoxy is more resistant than Glass / Epoxy. This result coincides perfectly with the experimental study by Anthony et al. [5] Thus, we can conclude that natural fibers have an important role in enhancing the mechanical strength of biocomposites materials.

## References

[1] **Arbelaiz, A., Cantero, G., Fernández, B., Mondragon, I., Gañán, P. and Kenny, J. M.**: Flax fiber surface modifications: Effects on fiber physico mechanical and flax/polypropylene interface properties, *Polymer composites*, 26, 324–332, **2005**.

[2] **Baley, C.**: Analysis of the flax fibres tensile behaviour and analysis of the tensile stiffness increase, *Composites. Part A : Applied Science and Manufacturing*, 33, 7, 939–948, **2002**.

[3] **Baley, C., Busnel, F., Grohens, Y. and Sire, O.**: Influence of chemical treatments on surface properties and adhesion of Flax fibre Polyester resin, *Composites. Part A : Applied Science and Manufacturing*, 37, 1626–1637, **2002**.

[4] **Beldzki, A. K. and Gassan, J.**: Composites reinforced with cellulose based fibers, *Polymer science*, 24, 221–274, **1999**.

[5] **Le Digou, A., Davies, P. and Baley, C.**: Etude de la liaison interfaciale fibre de lin/acide poly(L–lactique) = Study of interfacial bonding of Flax fibre/Poly(L–lactide), *Philippe OLIVIER et Jacques LAMON*, 10, **2009**.

[6] **Butt, H. J., Cappella, B. and Kappl, M.**: Force measurements with atomic force microscope: Technique, interpretations and applications Surface, *Science reports*, 59, 1–152, **2005**.

[7] **Eichhorn, S. J., Baillie, C. A., Zafeiropoulos, N., Mwaikambo, L. Y., Ansell, M. P., Dufresne, A., Entwistle, K. M., Herrera–Franco, P. J., Escamilla, G. C., Groom, L., Hugues, M., Hill, C., Rialsand, T. G. and Wild, P. M.**:Review: current international research into cellulosic fibres and composites, *Journal of Materials Science*, 36, 2107–2131, **2001**.

[8] **Marais, S., Gouanvé, F., Bonnesoeur, A., Grenet, J., Poncin–Epaillard, F., Morvan, C. and Métayer, M.**: Unsaturated polyester composites reinforced with flax fibers: effect of cold plasma and autoclave treatments on mechanical and permeation properties, *Composites Part A*, 36, 975–986.

[9] **Holmberg, M., Berg, J., Stemme, S., Odbesrg, L. and Rasmusson, J.**: Surface Force studies of Langmuir-Blodgett Cellulose Films. *Journal of colloid and interface science*, 186, 369, **1997**.

[10] **Elouaer, A.**: Contribution à la compréhension et à la modélisation du comportement mécanique de matériaux composites à renfort en fibres végétales, PhD Thesis, in French, **2011**.

[11] **Bouzouita, S.**: Optimisation des interfaces fibre–matrice de composites à renfort naturel, *Ecole Centrale de Lyon; Ecole Nationale d'Ingénieurs de Monastir*, in French, **2011**.

[12] **El Abdi, L.K.**: Etude des fibres extraites de la plante Alfa, *Rapport de stage de fin d'études - ENSISA Mulhouse*, 32–37, **2008**.

[13] **Bessadok, A., Marais, S., Roudesli, S., Lixon, C. and Métayer, M.**: Influence of chemical modifications on water–sorption and mechanical properties of Agave fibres, *Composites, Part A*, 39, 29–45, **2008**.

[14] **Bessadok, A., Roudesli, S., Marais, S., Follain, N. and Lebrun, L.**: Alfa fibres for unsaturated polyester composites reinforcement: Effects of chemical treatments on mechanical and permeation properties, *Composites, Part A*, 40, 184–195, **2009**.

[15] **Nadji, H., Diouf, P. N., Benaboura, A., Bedard, Y., Riedl, B. and Stevanovic, T.**: Comparative study of lignins isolated from Alfa grass (Stipa tenacissima L.), *Bioresource Technology*, 100, 3585–3592, **2009**.

[16] **Bouiri, B. and Amrani, M.**: Production of dissolving grade pulp from Alfa, *Bioresources*, 5(1), 291–302, **2009**.

[17] **Brahim, S. B. and Cheikh, R. B.**: Influence of fibre orientation and volume fraction on the tensile properties of unidirectional Alfa–polyester composite, *Composites Science and Technology*, 67, 140–147, **2007**.

[18] **Paiva, M. C., Ammar, I., Campos, A. R., Cheikh, R.B. and Cunha, A. M.**: Alfa fibres : Mechanical, morphological and interfacial characterization, *Composites Science and Technology*, 67, 1132–1138, **2007**.

[19] **Rwawiire, S. and Tomkova, B.**: Morphological, Thermal and Mechanical Characterization of Sansevieria trifasciata Fibers, *Journal of Natural Fibers*, 12, 201–210, DOI: 10.1080/15440478.2014.914006, **2015**.

[20] **Cox, H. L**: The elasticity and strength of pape rand other fibrous materials (Elasticté et résistance du papier et autres matériaux fibreux), *British Journal of applied Physics*, 72–79, **1952**.

[21] **Weibull, W.**: A Statistical Distribution Function of Wide Applicability, *Journal of Applied Mechanics*, 293–297, **1939**.

[22] **Rogge, E.**: Extraction and study of the physical and mechanical properties of Esparto grass fibres in order to find textile applications", Ecole Nationale Supérieure d'Ingénieurs Sud–Alsace (UHA), **2010**.

[23] **Caillol, S.**: Synthese et caracterisation de nouveaux copolymeres potentiellement autoassociatifs, *Material chemistry*, Universite Sciences et Technologies - Bordeaux I, in French, **2002**.

[24] **Maghchiche, A.**: Characterisation of Esparto Grass Fibers Reinforced Biodegradable Polymer Composites, *Biosciences Biotechnology Research*, Asia, 10(2), 665–673, **2013**.

[25] **Pras, O.**: Utilisation de cellulose pour l'_elaboration de mat_eriaux photoluminescents ou conducteurs, *Université de Grenoble*, in French, **2011**.

[26] **Wertz, J-L.**: Les biocompositess et composites polymère-chanvre en particulier. *Unité de Chimie biologique industrielle*, Université de Liège – Gembloux Agro-Bio Tech., **2014**.

[27] **Mokaddem, A., Alami, M., Doumi, B. and Boutaous, A.**: Prediction by a genetic algorithm of the fiber matrix interface damage for composite material. Part1 : study of shear damage to two composites T300/914 and Peek/APC2, *Strength of materials*, 46, 4, 543–547, **2014**.

[28] **Mokaddem, A., Alami, M., Ziani, N., Beldjoudi, N. and Boutaous, A.**: Prediction by a genetic algorithm of the fiber matrix interface damage for composite material. Part2 : study of shear damage to Graphite / Epoxy nanocomposite, *Strength of materials*, 46, 4, 548–552, **2014**.