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Using alfa natural fiber for optimizing the shear damage to the fiber matrix interface of hybrid composites materials by genetic algorithm

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Abstract. This study focuses on the using of alfa natural fiber for optimizing the shear damage to the fiber-matrix interface of glass-carbon/epoxy hybrid composite. This research was carried out by strengthening the epoxy matrix with carbon and glass fibers, to see the level of each damage before replacing glass and carbon fiber by the alfa fiber. Each sample was reinforced with the same volume fraction before undergoing mechanical testing. The results found by a genetic simulation shows that the level of damage to the new hybrid composite alfa-carbon/epoxy or alfa-glass/epoxy are lower by glass-carbon/epoxy. We can say that alfa natural fiber has a high resistance to mechanical stress applied; the question remains whether the new material has the same resistance for of heat stress.

Keywords: damage, interface, alfa, fiber, matrix, genetic algorithm, hybrid composites

1 Introduction

For decades, efforts have been made to the development and characterization of composite materials with organic matrices (epoxy, polyester,$\cdots$) and woven continuous fibers (glass, aramid, carbon,$\cdots$)

In recent years, Natural fiber reinforced composites is an emerging area in polymer technology. Fibers resulting from plants are considered a budding substitute for non-renewable synthetic fibers like glass and carbon fibers. Composite materials are multi phase materials obtained through the artificial combination of different materials in order to attain properties that the individual components by themselves cannot attain. They are not multiphase materials in which the different phases are formed naturally by reactions, phase transformations, or other phenomena.

The mechanical properties of hybrid short fiber composites can be evaluated using the rule of hybrid mixtures (RoHM) equation, which is widely used to predict the strength and modulus of hybrid composites[1, 7, 9, 16]. It is shown however, that RoHM works best for longitudinal modulus and longitudinal tensile strength of the hybrid composites. Since, modulus values in a composite are volume averaged over the constituent microstresses, the overall modulus of the composite has little correlation with the randomness of the fiber location [17]. Strength values on the other hand are not primarily functions of strength of the constituents; they are however dependent on the fiber/matrix interaction and interface quality. In tensile test, any minor (microscopic) imperfection on the specimen may lead to stress build-up and failure could not be predicted directly by RoHM equations[13, 18].

Alfa plant is a plant that grows wild in the Mediterranean region. Alfa its rods are composed of cellulosic filaments bound by the lignin, hemicellulose and pectins. Short fibers are obtained by aggressive extraction

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methods that eliminate binders. They are used for the production of paper or composite reinforcement. See Fig. 1.

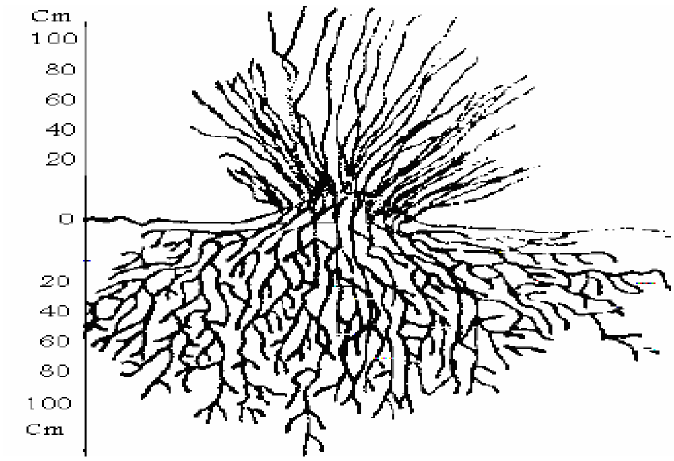

Fig. 1: Representation alfa plant

In this study, we see the influence of the alfa fiber on the optimization of the shear damage to the fiber matrix interface of hybrid composite material glass/carbon/epoxy, using a genetic approach.

2 Mechanical properties of the reinforcement and resin used

2.1 Reinforcement

The table below shows the mechanical properties of the reinforcement (alfa fiber, carbon and glass)[2].

Table 1: Mechanical properties of the reinforcement

Fibre	Density($g/m3$)	Strain at break(%)	Specifie stress at break (MPa)	Specifie Young modulus (GPa)
Alfa	1.4	1.5-2.4	134-220	$13 - 17.8$
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

2.2 Epoxy resin

The resin used is a high-performance organic resin of epoxy type, the characteristics of this resin are as follows [8]:

Table 2: Mechanical properties of the epoxy resin

Density	Compressive strength [MPa]	Tensile strength in bending [MPa]
1.3 0.05	> 70	25

3 Reminder on analytical models

3.1 Modeling of the interface

The fiber matrix interface forms at the time of preparation of the material; its behavior is not reducible to that of the constituent phases. It ensures physical continuity of the component to another throughout the material. The composite fibers work together, the matrix is used to distribute and transmit the force between fibers, but these efforts must go through the interface. The characterization of damage to the fiber-matrix interface is always linked to the behavior of two based components fiber and matrix. Different damage affecting the various components (fiber, matrix and interface), in fact, can be distinguished:

- Damage to the matrix by transverse micro cracking,
- Damage to the fiber-matrix debonding interface[11].

At the microscopic scale of damage two variables are defined:

Dm : Damage to the matrix;

Df : Damage to the fiber.

3.2 Model based on the statistical approach

Damage to the matrix, when the stress is uniform, is given by formula (1) Weibull [19]:

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

With:

σ : applied stress;

σ_m^T : heat stress;

V_m : the volume of the matrix;

m_m and σ_{0m} : Weibull parameters.

After creation of a crack, a fragment of length L will give rise to two fragments of size $L = L1$ and $L2 = X \times L \times (1 - X)$ (X being a random number between 0 and 1). At each crack up a fiber, a fiber-matrix debonding length 2l will occur with a corollary decrease of creating a new crack in part because the matrix unloaded. At each increment of stress, the break is calculated. All blocks which break reaches 0.5 give rise to new cracks[15, 20].

The L1 and L2 are the two segments of the fiber length after fracture.

A broken fiber is discharged along its entire length Lissart [10, 12]. That is to say it can not break once. The rupture follows a law similar to that described for the matrix[6, 14].

$$D_f = 1 - \exp\left\{-A_f \times L_{equi} \times \left[\frac{\sigma^f_{\max}}{\sigma_{0f}}\right]^{m_f}\right\}. \tag{2}$$

With:

$\sigma^f_{\max}$:The maximum stress applied;

Lequi : is the length of the fibers would have the same break in a consistent manner.

3.3 Model of Cox

For a single fiber surrounded by matrix, many analytical solutions have been proposed. One of the first that of Cox [4], provides the shape of the shear stress along the fiber length as the form:

$$\tau = \frac{E_f a\varepsilon}{2}\left(\frac{2G_m}{E_f {r_f}^2 \ln(\frac{R}{r_f})}\right) th\left(\frac{2G_m}{E_f {r_f}^2 \ln(\frac{R}{r_f})} {}^{l}\!/_{2}\right). \tag{3}$$

With:

G_m :shear modulus of the matrix;

E_f :Young's modulus of the fiber;

ε :deformation ;

α : radius of the fiber;

R :distance between fibers;

τ : shear stress of the interface.

4 Numerical simulation by GA

4.1 Development

The desired objective is to show the effect of alfa natural fiber on resistance of the fiber-matrix interface of hybrid composite material. Our numerical simulation is applied to a single representative elementary volume (V.E.R). The approach is to change the structure of our material by replacement of glass fiber, carbon fiber by the new alfa fiber every step of calculating damage to the interface. Our genetic simulation is to use the values of each reinforcements to calculate each time the level of damage to the interface using the 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 the each fiber selected (it takes the optimum value of two damages). 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 selected,$\cdots$) [4, 5, 14]. Finally we determine the shear damage to the interface fiber length for all three fibers used.

4.2 The flowchart

Our job is to optimize the damage of fiber-matrix interface of (4) types of composite and hybrid composites materials carbon/epoxy, glass-carbon/epoxy, alfa-glass/epoxy and alfa-carbon/epoxy by a genetic algorithm. We have used genetic operators to evolve a population of individuals randomly generated number 100 with a maximum generation equal to 50 as stopping criterion. The genes of the chromosome represent the following variables: the mechanical stress which is between 0 and defined as the maximum stress tests, then a selection operator (linearly by dividing the odds by rank individuals in the population, these individuals are ranked and positioned to make the best of them is inserted in the front row and one whose quality is lower in rank or $k = N$) [4, 5, 14]. Before the new generation construction, the selection of the new value (new parents) of the damage to the interface was based on the choice of the best results obtained at each iteration by the genetic mutation operators Dm and Df. This allows parents to select who will then be crossed via a crossover operator. The 'children' (damage to interface) are modified resulting in a random probability defined at the outset (probMut $= 0.3$) and thus form a new generation, the process is repeated until convergence [4, 5, 14]. Finally we determine the damage to the interface fiber length for all materials used. Numerical calculations are performed using the Matlab R2012a release software.

5 Simulation results

A calculation was performed on four (4) types of hybrid composites materials carbon/epoxy, glass/carbon/epoxy, alfa/glass/epoxy and alfa/carbon/epoxy. We calculate the shear damage to the interface for all hybrid materials. Figs. 3, 4, 5 and 6 respectively show each value of E for the level of damage to the interface of carbon/epoxy, glass/carbon/epoxy, alfa/glass/epoxy and alfa/carbon/epoxy :

Fig. 3 shows that the damage "D" interface starts at 0.29 for carbon/epoxy, then increases to a maximum value of 0.58, we note the presence of a symmetry of the damage to the interface. This damage is zero in the middle of the fiber and dense at the ends.

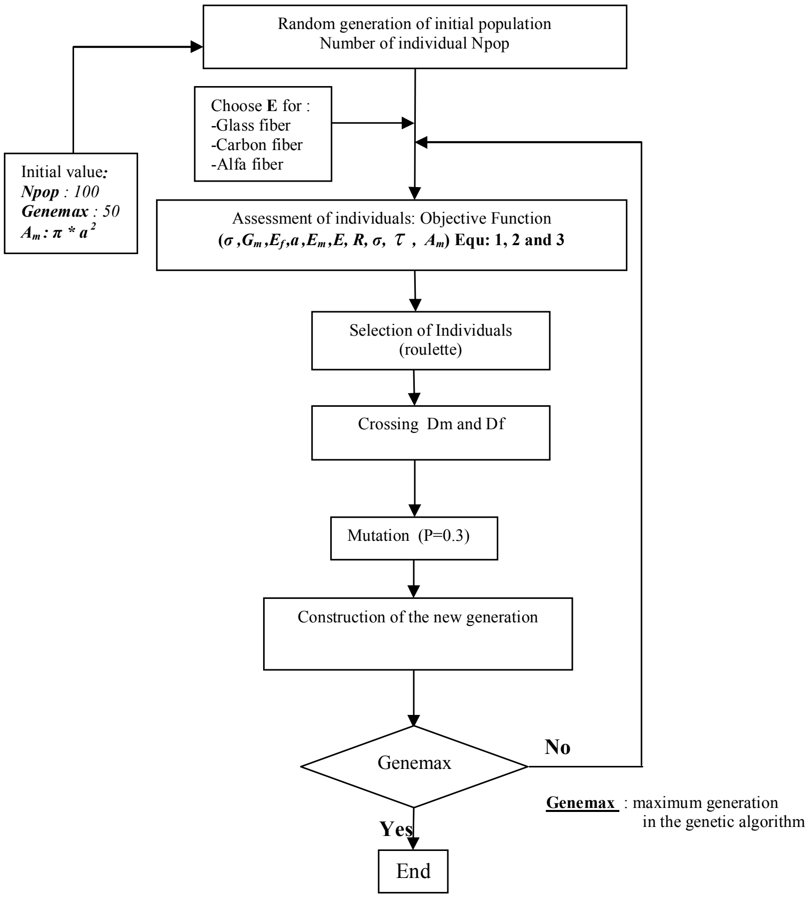

Fig. 2: The flowchart of genetic algorithm

Fig. 4 shows that the damage “D” interface starts at 0.29 for glass/carbon/epoxy, then increases to a maximum value of 0.46, we note the presence of symmetry of the damage to the interface. This damage is zero in the middle of the fiber and dense at the ends.

Fig. 5 shows that the damage “D” interface starts at 0.1 for alfa/glass/ epoxy, then increases to a maximum value of 0.3, we note the presence of symmetry of the damage to the interface. This damage is zero in the middle of the fiber and dense at the ends.

Fig. 6 shows that the damage “D” interface starts at 0.1 for alfa/carbon/ epoxy, then increases to a maximum value of 0.19, we note the presence of a symmetry of the damage to the interface. This damage is zero in the middle of the fiber and dense at the ends.

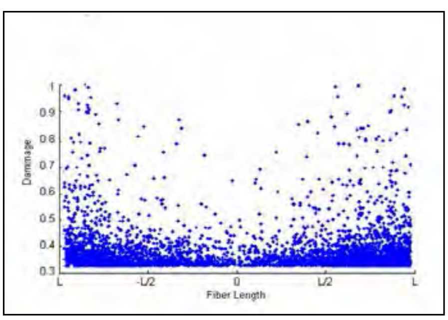

Fig. 3: Level of shear damage to the interface (carbon/epoxy)

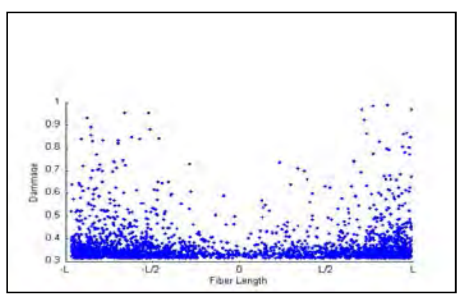

Fig. 4: Level of shear damage to the interface (glass-carbon/epoxy)

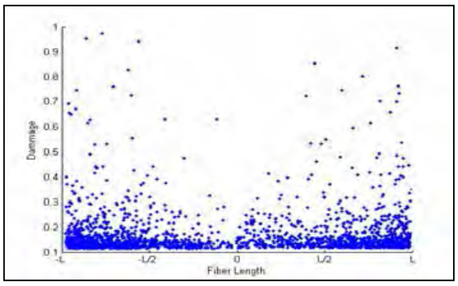

Fig. 5: Level of shear damage to the interface (alfa-glass/epoxy)

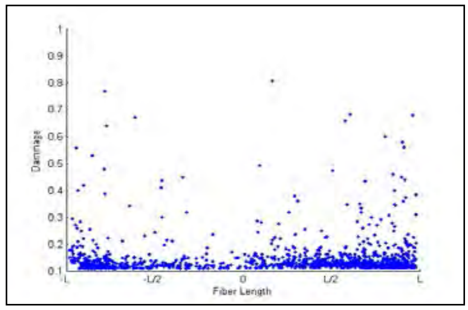

Fig. 6: Level of shear damage to the interface (alfa-carbon/epoxy)

6 Conclusion

The results found by the genetic calculations show that the level of damage is related to the nature of the material used and applied mechanical stress. The hybrid material alfa-carbon/epoxy has a low damage comparing with the other materials glass-carbon/epoxy and alfa-glass/epoxy. This means that this material has a high resistance to applied mechanical stress. The figures also show that the values found for alfa-carbon / epoxy is much less than that of carbon/epoxy, glass-carbon/epoxy and alfa-glass/epoxy.Our genetic results coincides perfectly with the experimental study conducted by Antoine et al.[3] which have conclude that the natural fibers have an important role in enhancing the mechanical strength of biocomposites and hybrid composite materials. So we can say that the model worked well aware of the phenomenon of damage for hybrid composites.

References

[1] AIAA. Hybrid composites - state-of-the-art review: Analysis, design, application and fabrication. *Aiaa Journal*, 1977.

[2] O. Akchiche, M. Boureghda. Esparto grass (stipa tenacissime l.), raw material of papermaking. *First Part, Chimija rastitel'nogo syr'ja*, 2007, **4**: 25–30.

[3] C. B. Antoine Le Digou, Peter Davies. Etude de la liaison interfaciale fibre de lin/acide poly(l-lactique) = study of interfacial bonding of flax fibre/poly(l-lactide). *JNC*, 2009, 10.

[4] H. L. Cox. The elasticity and strength of paper and other fibrous materials. *British Journal of Applied Physics*, 1952, **3**(3): 72.

[5] B. Doumi, A. Mokaddem, N. e. a. Benrekaa. Simulation by a genetic algorithm and locationby the non-linear acoustic technique of the sheardamage to the fiber-matrix interface of a hybridcomposite material alfa-carbon / epoxy. *Hybrid Materials*, 2014, **2**(1): 10–16.

[6] S. Feld-Payet, J. Besson, F. Feyel. Finite element analysis of damage in ductile structures using a nonlocal model combined with a three-field formulation. *International Journal of Damage Mechanics*, 2011, **20**(20): 655–680.

[7] S. Y. Fu, G. Xu, Y. W. Mai. On the elastic modulus of hybrid particle/short-fiber/polymer composites. *Composites Part B Engineering*, 2002, **33**(4): 291–299.

[8] B. B. Hachemane B, Mir A. Elaboration et characterisation mcanique d'un matriau composite hybride. *Matriaux, Dijon-France*, 2006, **Novembre**: 13–17.

[9] C. Hopmann, W. Michaeli, F. Puch. Investigation of the processing, the mechanical properties, and the morphology of short glass fiber-reinforced polypropylene-layered silicate composites. *Science &Engineering of Composite Materials*, 2012, **19**(4): 331–338.

[10] P. Ladevèse, G. Lubineau. Pont entre micro et mso mcaniques des composites stratifies. *Comptes Rendus Mecanique*, 2003, **331**(8): 537–544.

[11] Lem.J, Chaboche.J.L. *Mechanics of solid materials*, vol. 1. Edition Dunod, 1988.

[12] N. Lissart, J. Lamon. Damage and failure in ceramic matrix minicomposites: Experimental study and model. *Acta Materialia*, 1997, **45**(3): 1025–1044.

[13] J. Mirbagheri, M. Tajvidi, I. Ghasemi. Prediction of the elastic modulus of wood flour/kenaf fibre/polypropylene hybrid composites. *Iranian Polymer Journal*, 2007, **16**(4): 271–278.

[14] A. Mokaddem, M. Alami, B. Doumi. Prediction by a genetic algorithm of the fibercmatrix interface damage for composite material. part 1. study of shear damage in two composites t300/914 and peek/apc2. *Strength of Materials*, 2014, **46**(4): 543–547.

[15] A. Mokaddem, M. Allami, L. Temimi. Study of the effect of heat stress on the damage of the fibre matrix interface of a composite material (t300/914) by means of a genetic algorithm. *Fibres & Textiles in Eastern Europe*, 2012, **95**(6): 108–111.

[16] M. A. Shayanfar, M. A. Barkhordari, A. R. Rezaeian. Experimental study of cyclic behavior of composite vertical shear link in eccentrically braced frames. *Steel &Composite Structures*, 2012, **12**(1): 13–29.

[17] Z. Song, J. Xie, P. Zhou. Thermal degradation of epoxy resin grafted with polyurethane. *Design &Manufacturing Using Composites*, 2014, **21**(1): 7–13.

[18] J. R. Vinson. *Emerging technologies in aerospace structures, design, structural dynamics, and materials : presented at the Aerospace conference, Century 2–Emerging Technology conferences, San Francisco, California, August 13-15, 1980*. American Society of Mechanical Engineers, 1980.

[19] B. M. Zhang, L. Zhao. Theory of the strength of materials. *Royal Swedish Academy of Eng. Sci. Proc.*, 1939, **151**(6): 1–45.

[20] B. M. Zhang, L. Zhao. Progressive damage and failure analysis of fiber-reinforced laminated composites containing a hole. *Advanced Materials Research*, 2012, **21**(6): 893–911.