UDC 539.4

Prediction by a Genetic Algorithm of the Fiber–Matrix Interface Damage for Composite Material. Part 1. Study of Shear Damage in Two Composites T300/914 and PEEK/APC2

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УДК 539.4

Прогнозирование повреждения композита на стыке матрицы и волокон с помощью генетического алгоритма. Сообщение 1. Анализ повреждений от сдвиговых напряжений в двух композитах T300/914 и PEEK/APC2

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Для композитных материалов, армированных волокнами, актуальной является оптимизация размещения последних, что обеспечивает минимальное повреждение на стыке волокон и матрицы. Исследована кинетика развития повреждений в направлении действия максимальных сдвиговых напряжений с помощью генетического алгоритма, ранее разработанного авторами. Для двух композитов типа T300 и PEEK с использованием предложенного генетического подхода получены расчетные данные для различных скоростей сдвиговых деформаций на стыке волокон и матрицы, которые хорошо согласуются с полученными на основании математических моделей Кокса и Вейбулла. В дальнейших исследованиях планируется изучение влияния термомеханического нагружения на сдвиговое повреждение зоны стыка волокон и матрицы.

Ключевые слова: стык, сдвиговое повреждение, волокно, матрица, композит, генетический алгоритм.

Introduction. Nowadays the enormous use of polymer materials is attributed to their extraordinary combination of properties, low weight and ease of processing. However for improvement of some properties such as thermal and mechanical stability, large numbers of additives were added to polymeric matrix and formed polymer matrix composite [1, 2].

A composite is defined as a combination of two or more materials with different physical and chemical properties and distinguishable interface. Composite materials have a wonderful and different range of applications. Important advantages of composites over many metal compounds are high specific stiffness and specific strength, high toughness, corrosion resistance, low density and thermal insulation [1–3].

In most composite materials, one phase is usually continuous and called the matrix, while the other phase called the dispersed phase. On the basis of the nature of the matrices, composites can be classified into four major categories [3, 4]:

1. Polymer matrix composite.
2. Metal matrix composite.
3. Ceramic matrix composite.
4. Carbon matrix composite [4, 5].

Polymer matrix composite can be processed at a much lower temperature, compared to other composite. Depending on the types of polymer matrices, polymer matrix composite are classified as thermosetting composites and thermoplastic composites [6, 7].

Lemaitre and Chaboche [8] consider a damaged solid in which an element of finite volume a notch large enough relative to heterogeneities is defined as follows: S is area representative volume element identified by its norm n, S_e is effective resistance area (if $S_e < S$), and S_d is damaged area, $S_d = S - S_e$.

The mechanical measurement of local damage in relation to n is then characterized by $D = S_d / S$.

If $D = 0$, the material is in a pristine or not damaged.

If $D = 1$, the volume element is broken into two parts along the plane normal n.

If $0 < D < 1$, D characterizes the state of damage defined, the macroscopic elastic behavior of the damaged material can be calculated using D through the stiffness.

In this study, we present a genetic approach of shear damage to the interface of two composites materials T300/914 and PEEK/APC2, using the Weibull probability model. This model accounts for the damage of the two main constituent fibers and matrix, the results are compared with those obtained by the Cox model.

Reminder on Analytical Models.

Modeling of the Interface. D_{12} and D_{22} internal variables of damage [9–11], D_{12} is the shear and D_{22} for transverse traction.

Once the elastic deformation energy of damage is established, the dual variables $Y_{D_{12}}$ and $Y_{D_{22}}$, variables of damage D_{12} and D_{22}, and evolution variables are

$$Y_{eq} = \sqrt{Y_{D_{12}} + bY_{D_{22}}}.$$

Laws of damage are

$$\begin{cases} \delta_{12} = f_i(Y_{\delta_{12}}), \\ \delta_{22} = h(Y_{\delta_{22}}). \end{cases} \tag{1}$$

The interface has the following behavior:

(i) linear elastic, brittle, tensile, transverse;

(ii) elastic, damageable, shear.

Two new damage variables are introduced: δ_{12} and δ_{22}. The same way as the matrix, the elastic strain energy and damage variables associated $Y_{D_{12}}$ and $Y_{D_{22}}$ are defined and, finally, the laws of evolution [9–11]. For a single fiber surrounded by matrix, many analytical solutions have been proposed. One of the first [12] provides the shape of the shear stress along the fiber length as the form [13, 14]

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

To simplify calculation, we put:

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

where G_m is shear modulus of the matrix, E_f is the Young modulus of the fiber, ε is deformation, a is radius of the fiber, R is distance between fibers, and τ is shear stress of the interface.

These variables related to the components of a composite material (fiber and matrix) are all taken into account through formula (2). These variables allow us therefore to appreciate the resulting sets of genetic algorithm.

Model Based on the Statistical Approach. Damage to the matrix, when the stress is uniform, is given by [15]:

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

where σ is applied stress, σ_m^T is heat stress, V_m is the ratio volume of the matrix, and σ_{0m} and m_m are the Weibull parameters.

After creation of a crack, a fragment of length L will give rise to two fragments of size $L = L_1$ and $L_2 = XL(1-X)$ (X being a random number between 0 and 1) [16, 17]. 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. [16, 17].

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

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

where $\sigma_{\max}^f$ is the maximum stress applied and L_{eq} is the length of the fibers would have the same break in a consistent manner.

Numerical Simulation by the Genetic Algorithm (GA).

Development. Our work involves modeling the damage in shear D_{12} interface fiber matrix of a composite material. To do so, we chose to use a genetic optimization which allows us to see the evolution of the damage along the fiber.

This approach is based on the probabilistic model of Weibull. The principle begins with a random generation of an initial population and the choice of D_m and D_f as two random variables, then it is necessary to change this population (numbering 100 with a maximum generation equal to 50 as a stop criterion) by a set of genetic operators (selection, crossover and mutation) and each time is varied the shear rate of the interface to determine the damage D_{12}. The population is composed of the genes on chromosome represent the following variables: the shear rate τ which is between 80 and 120 N as defined by the maximum value of stress tests, the D_m and D_f. These three variables allow us to locate the shear damage D_{12} interface, this one compare to damage transverse D_{22}, and find the optimum value of the damage [18].

The evaluation of each generation is made by an objective function after the Cox and Weibull model reflecting all the variables set at the beginning of the algorithm (the mechanical properties of each constituent of the composite) by a shear damage interface.

Figure 1 presents the flowchart of genetic algorithm.

Simulation Results. A calculation was performed on two types of composite materials T300/914 and PEEK/APC2. We examined the variation of shear rate for different load values ($\tau = 80$, 100, and 120 N), which allowed us to calculate the shear damage of the

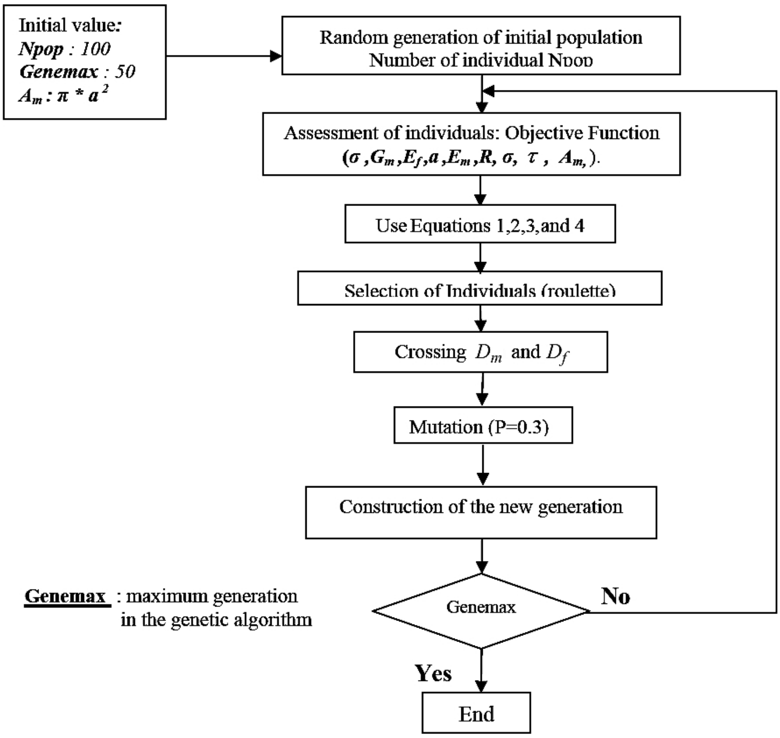
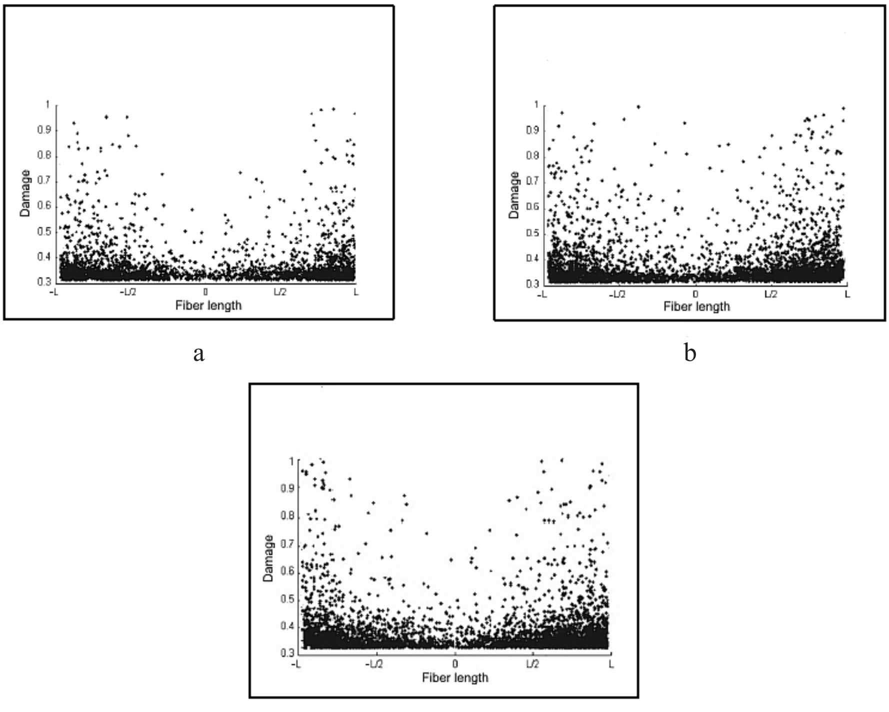


Fig. 1. The genetic algorithm flowchart.



a

b

c

Fig. 2. Influence of shear stress on the damage to the interface by GA for T300/914 composite: (a) $\tau = 80$ N; (b) $\tau = 100$ N; (c) $\tau = 120$ N.

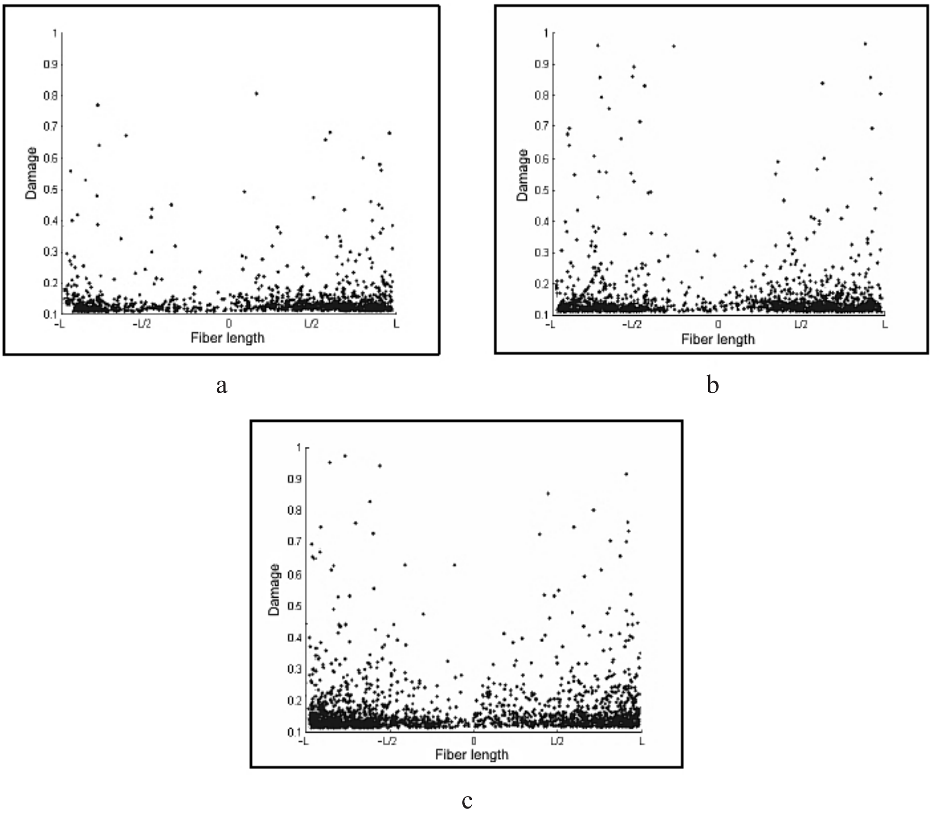


Fig. 3. Influence of shear stress on the damage to the interface by GA for PEEK/APC2 composite: (a) $\tau = 80$ N; (b) $\tau = 100$ N; (c) $\tau = 120$ N.

interface. Figures 2 and 3 show each value of τ for the level of shear damage to the interface of two materials.

T300/914. Figure 2 shows that the damage D interface starts at 0.3 for $\tau = 80$ N, then increases to a maximum value of 0.7 for $\tau = 120$ N, 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. One can say that the stress concentration along the length of the fiber creates a strong degradation of the interface and which is greater at the ends relative to the center.

PEEK/APC2. Figure 3 shows that the damage D interface starts this time at 0.1 for $\tau = 80$ N, then increases to a maximum value of 0.5 for $\tau = 120$ N, we note the presence of a symmetry of the damage to the interface, zero in the middle of the fiber and dense at the ends. We can say that the stress concentration along the length of the fiber creates a strong degradation of the interface most important at the ends relative with the middle; values are lower compared to those found for the T300.

Conclusions. The results obtained in this study via the genetic algorithm coincide perfectly with the results at the meso level of Ladevèze, which showed that the shear rate leads to a significant reduction in the degradation of the interface. These results show that the level of damage in shear of interface is more important than the level of the transverse damage for both materials studied T300 and PEEK, which provides a good agreement between the numerical simulation and the actual behavior of the two materials. Numerical simulation shows that the PEEK is stronger than the T300. We can therefore say that the model is applicable to the phenomenon of damage of a unidirectional composite as a function of applied stress. Finally, we can conclude that the shear loading of interface is dominant compared to transverse loading. In future studies we'll analyze the thermo-mechanical effect on shear damage of interface.

Резюме

Для композитних матеріалів, армованих волокнами, актуальною є оптимізація розміщення останніх, що забезпечує мінімальне пошкодження на стику волокон і матриці. Досліджено кінетику розвитку пошкоджень у напрямку дії максимальних зсувних напружень за допомогою раніше розробленого авторами генетичного алгоритму. Для двох композитів типу Т300 і PEEK з використанням запропонованого генетичного підходу отримано розрахункові дані для різної швидкості зсувних деформацій на стику волокон і матриці, які добре узгоджуються з отриманими на основі математичних моделей Кокса і Вейбулла. У подальших дослідженнях планується вивчення впливу термомеханічного навантаження на зсувне пошкодження зони стику волокон і матриці.

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Received 07. 11. 2013