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Modeling of Damage in the Behavior of Fiber-Matrix Interface of a Composite Material with a Genetic Algorithm

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Abstract: The objective of this work is to develop an analytical model to evaluate the influence of thermal stress on the damage of the fiber-matrix interface composite material T300/914; from the properties of the fiber, matrix and interfacial bonding characteristics. The model takes into account the effects of temperature that result in the gradual deterioration of the fiber-matrix interface. This study developed a genetic algorithm has shown the influence of heat stress beyond a critical threshold of damage to the interface and also showed that the gradual deterioration of the matrix has a greater influence on the damage of the interface compared to that of the fiber.

Key words: Composite · Interface · Fiber · Matrix · Shear · Thermal stress · Damage

INTRODUCTION

The number and complexity of the mechanical tests required for the development of an industrial project related to the verification of the mechanical properties of materials used to obtain reliable results by numerical simulation. Indeed, the objective of this contribution is to highlight the evolution of the influence of thermal stress on the damage of the fiber matrix interface of a composite (T300/914) by genetic algorithm.

In a composite material, damage to the matrix and the fibers break the following characteristics Lissart [3]:

- Cracks in the matrix generated by unidirectional tensile stresses are distributed in a completely random, according to the distribution of microstructural defects;
- During the rupture of a fiber within the yarn, the stress borne by the broken fiber is distributed equally on all surviving fibers;
- The ruin of the composite is reached for a critical rate of broken fibers;

In this work, we developed an analytical model using a genetic algorithm. The static model described below, shows the gradual degradation of the matrix and fiber damage to the fiber-matrix interface is based on the Cox [1].

Development

Définitions: Damage to the matrix, when the stress is uniform, is given by formula (1) Weibull [4]:

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

with:

(σ)	:	Applied stress;
(σ_m^T)	:	Heat stress;
(V_m)	:	The volume of the matrix;
$(m_m$ *et* σ_{0m}	:	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 = X * L * (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.

A broken fiber is discharged along its entire length Lissart [3]. That is to say it can not break once. The rupture follows a law similar to that described for the matrix.

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

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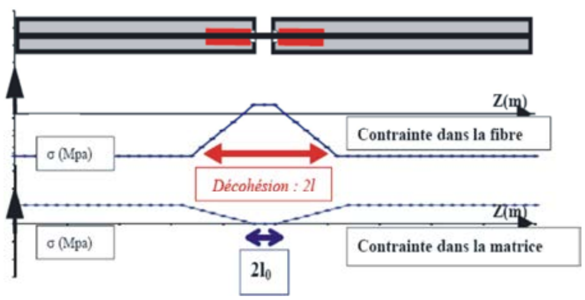

Fig. 1: Profile of a constraint in the vicinity of a fiber

with:

(σ^f_{max}) : The maximum stress applied
($Lequi$) : is the length of the fibers would have the same break in a consistent manner.

Interface Behavior: Interfacial shear stress τ reflects the transfer of forces through the fiber-matrix debonding. The corresponding stress field in a composite is depicted in Figure 1. The applied load is fully supported by the fibers at the cracks over a length 2l0 gradient linear constraint exercised in adjacent regions of the decohesion length 2l.

Thermal Stresses: The field of thermal stresses resulting from differential expansion of the fiber and matrix during cooling after preparation of the composite at high temperature. It is given by the following equations Lebrun [2]:

$$\sigma_f^T = E_f \frac{a}{1+a}\left(M_2 - M_0\right) \quad (3)$$

$$M_0(T) = \int_{T_0}^{T_e}\left(\alpha_m - \alpha_f\right)dT \quad M_0(T) = \int_{T_0}^{T_e}\left(\alpha_m - \alpha_f\right)dT \quad (4)$$

T_0 room temperature, the temperature Te of development, T the test temperature and finally α_f α_m and expansion coefficients of the fiber and matrix.

So it would be interesting to see the influence of thermal stress on the damage of the interface based on the Cox [1]:

$$\beta_1^2 = \frac{2G_m}{E_f r_f^2 \ln(\frac{R}{r_f})} \quad (5)$$

$$\tau = \frac{E_f a\varepsilon}{2}\beta_1 th(\beta_1 \, l/2) \quad (6)$$

with:

(G_m) : Shear modulus of the matrix;
(E_f) : Young's modulus of the fiber;
(ε) : Déformation ;
(a) : Radius of the fiber;
(R) : Half the distance;
(τ) : Shear stress of the interface;

Numerical Simulation by a Genetic Algorithm

Development: Our job is to maximize the damage of fiber-matrix interface of composite carbon / epoxy (T300/914) by a genetic algorithm using an analytical model based on the theory of Cox. The principle of this algorithm relies on the use of 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 stress, the temperature varies between T To = 30°C and the temperature of preparing the epoxy matrix Te = 150°C, the thermal stress generated is calculated using the formula (3) taking into account the expansion coefficients of carbon fibers and epoxy matrix. 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). This allows parents to select who will then be crossed via a crossover operator. The 'children' are modified resulting in a random probability defined at the outset (probMut = 0.5) and thus form a new generation, the process is repeated until convergence.

The Flowchart

Simulation Results: The data used in the simulation by a genetic algorithm (GA) are Young's modulus of the fiber, the shear modulus of the matrix, the fiber length, the radius of the fiber, the coefficients of thermal expansion, thermal stress and mechanical stress. It was noted the influence of mechanical stress on the damage of the matrix T300/914 (Fig. 3) and found the same way that heat stress at a great influence on the progressive degradation of the matrix (Figure 4). Figure 5 shows the influence of mechanical stress on the damage of the fiber, we found that damage to the matrix is more important compared to the damage of the fiber. We conclude that thermal stress beyond a critical threshold to a great influence on the damage of the interface and it is perfectly linked to damage of the matrix and less important compared to the damage to the fiber (Fig. 6).

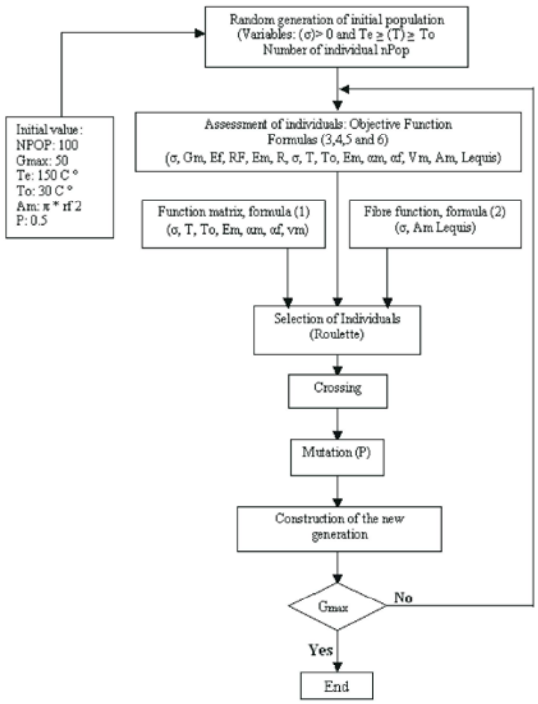

Fig. 2: The flowchart of genetic algorithm

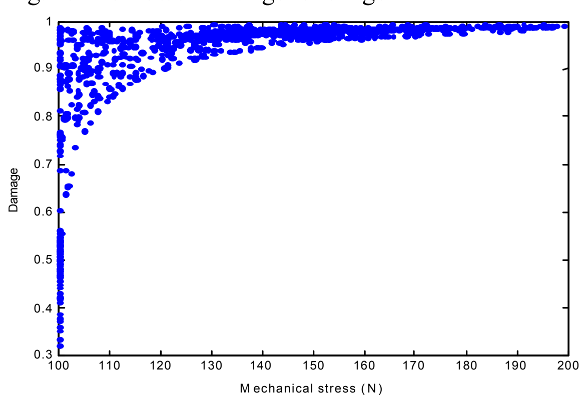

Fig. 3: Influence of mechanical stress on the damage of the matrix

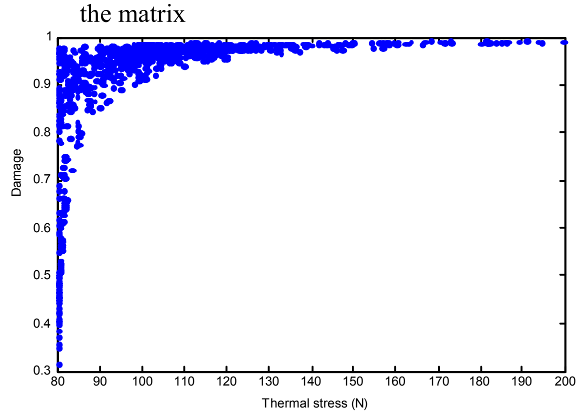

Fig. 4: Influence of heat stress on the damage of the matrix

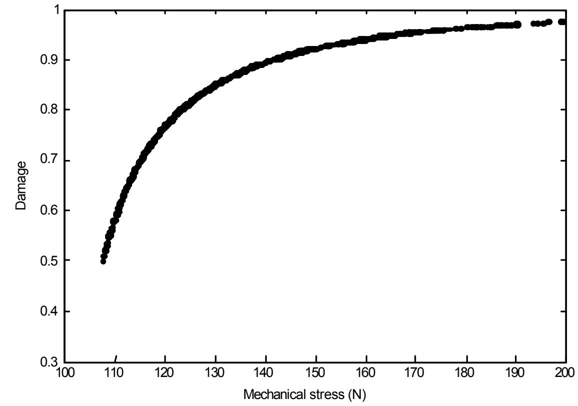

Fig. 5: Influence of heat stress on the damage of the fiber,

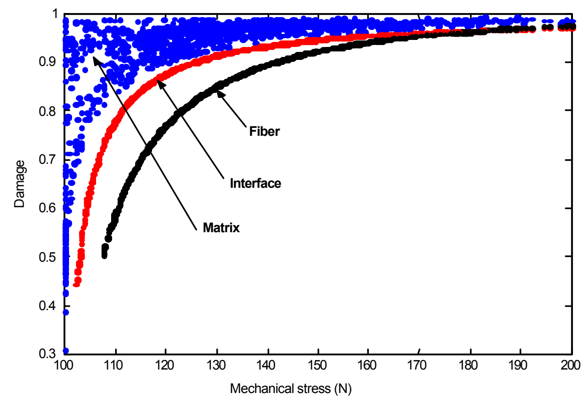

Fig. 6: Influence of thermal stress on the damage of the fiber-matrix interface

CONCLUSION

Our simulation model by a genetic algorithm has shown that thermal stress beyond a critical threshold induces a rapid and severe damage of the interface and that damage to the interface is much more linked to the progressive degradation matrix to damage the fiber. We plan to validate this model by experimental measurements on materials more sensitive to high temperature.

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