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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

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Abstract
The aim of this paper is to develop an analytical model to evaluate the influence of thermal stress on damage to the fiber-matrix interface of a composite T300/914 from the properties of the fibre, as well as from the matrix and characteristics of the interfacial binding. The model developed by a genetic algorithm takes into account the temperature effects that result in the progressive degradation of the fibre-matrix. This work shows the influence of thermal stress beyond the critical threshold of damage to the interface, and that the matrix damage has an important influence on the damage to the interface compared to that of the fiber.

Key words: *damage, interface, fibre, matrix, shear, thermal stress, composite.*

Introduction

The study of the rupture of an object is unidirectional. For many years, investigations of an analytical statistical and numerical nature have rarely taken into account the character of the viscoelastic matrix. One can, for example, include the following works: Rosen [25], Cox [6], Zweben [32], Hedgepeth [11], Ochiai et al. [21], Goree and Gross [7], Harlow and Phoenix [9], Scop and Argon [26, 27], Kong [12], Batdorf [1], Nedele and Wisnom [20], Hedgepeth and Van Dyke [11], Baxevanakis [2], Landis et al. [14] [15], Phoenix [22], Wisnom [31], Van Den Heuvel et al. [28, 29], Lifschitz and Rotem [18], and Lagoudas et al. [13].

The reliability of brittle matrix or quasi-brittle composites is determined by the particular statistical character-probabilistic matrix damage and fibre breakage. The damage of the matrix results from local fractures caused by microstructural defects randomly distributed. The creation of successive cracks form fragments whose volume becomes gradually smaller and smaller as the stress applied increases. Statistical approache proposed by Lissart [19], Guillaumat [8], and Peres [23], which are essentially based on Weibull's statistical theory [30].

Here we study the phenomenon of damage in an unidirectional composite on a microscopic scale that sees the fibres and matrix of the composite as homogeneous media. Blassiau's work [3 - 5] and those of Baxevanakis [2] have identified the microstructure of the Representative Volume Element (RVE) of healthy material (i.e, undamaged, i.e, without breaking fibre).

Verification by simulation of mechanical properties of materials used to obtain reliable results has become necessary because of the number and complexity of the mechanical tests required for the development of an industrial project. Indeed the objective of this contribution is to highlight the evolution of the influence of thermal stress on the damage of the fibre matrix interface of a composite (T300/914) by means of a genetic algorithm.

In a composite material, damage to the matrix and fibre breakage have the following characteristics according to Lissart[3]:

- Cracks in the matrix generated by unidirectional tensile stresses are distributed in a completely random way according to the distribution of microstructural defects;
- During the rupture of a fibre within the yarn, the stress borne by the broken fibre is distributed equally on all surviving fib,res;
- The ruin of the composite occurs at the critical rate of broken fibres;

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 fibre damage to the fibre-matrix interface based on Cox [6].

Development

Definitions

Damage to the matrix, when the stress is uniform, is given by formula (1) Weibull [30]:

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

Where:
σ - applied stress;
σ_m^T - heat stress;
V_m - volume of the 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

$$L = L1 \text{ and } L2 = X \times L \times (1 - X)$$

(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 stress, the break

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is calculated. All blocks whose break reaches 0.5 give rise to new cracks.

A broken fibre is discharged along its entire length according to Lissart [19]; that is to say it cannot break once. The rupture follows a law similar to that described for the matrix.

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

where:

σ^f_{max} - The maximum stress applied,

L_{equi} - The length of fibres that have the same break in a consistent manner.

Interface behavior applied

The interfacial shear stress τ reflects the transfer of forces through the fibre-matrix debonding. The corresponding stress field in the composite is depicted in ***Figure 1***. The load applied is fully supported by fibres at the cracks over a length $2l_0$ of fibre exercised in adjacent regions of the decohesion length $2l$.

Thermal stresses

A field of thermal stresses results from differential expansion of the fibre and matrix during cooling after preparation of the composite at high temperature, given by the following equations, Lebrun [2]:

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

To simplify the calculation, we put:

$$M_0(T) = \int_{T_0}^{T_e} (\alpha_m - \alpha_f)\, dT$$

$$M_2(T) = \int_{T_0}^{T} (\alpha_m - \alpha_f)\, dT$$

Where, T_0 is room temperature,
T_e the temperature of development,
T the test temperature, and finally
α_f and α_m are the expansion coefficients of the fibre and matrix.

Thus it would be interesting to see the influence of thermal stress on the damage of the interface based on Cox [6]:

$$\tau = \frac{E_f a \varepsilon}{2} \beta_1 \, th(\beta_1 \, l/2) \quad (4)$$

To simplify calculation, we put:

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

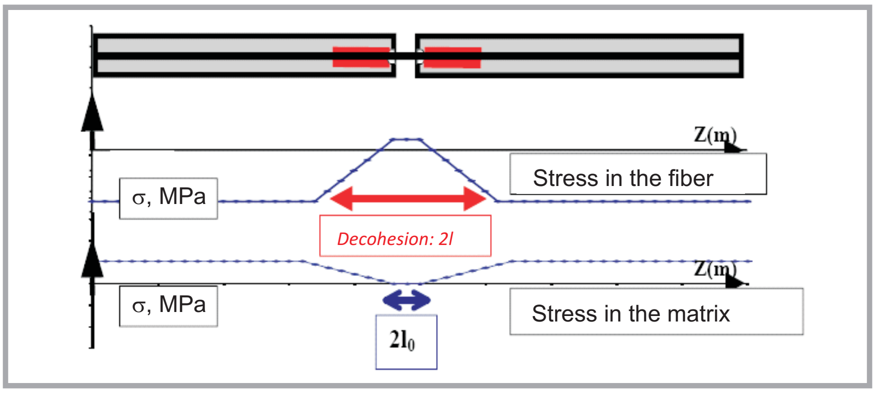

Figure 1. *Profile of a constraint in the vicinity of a fibre.*

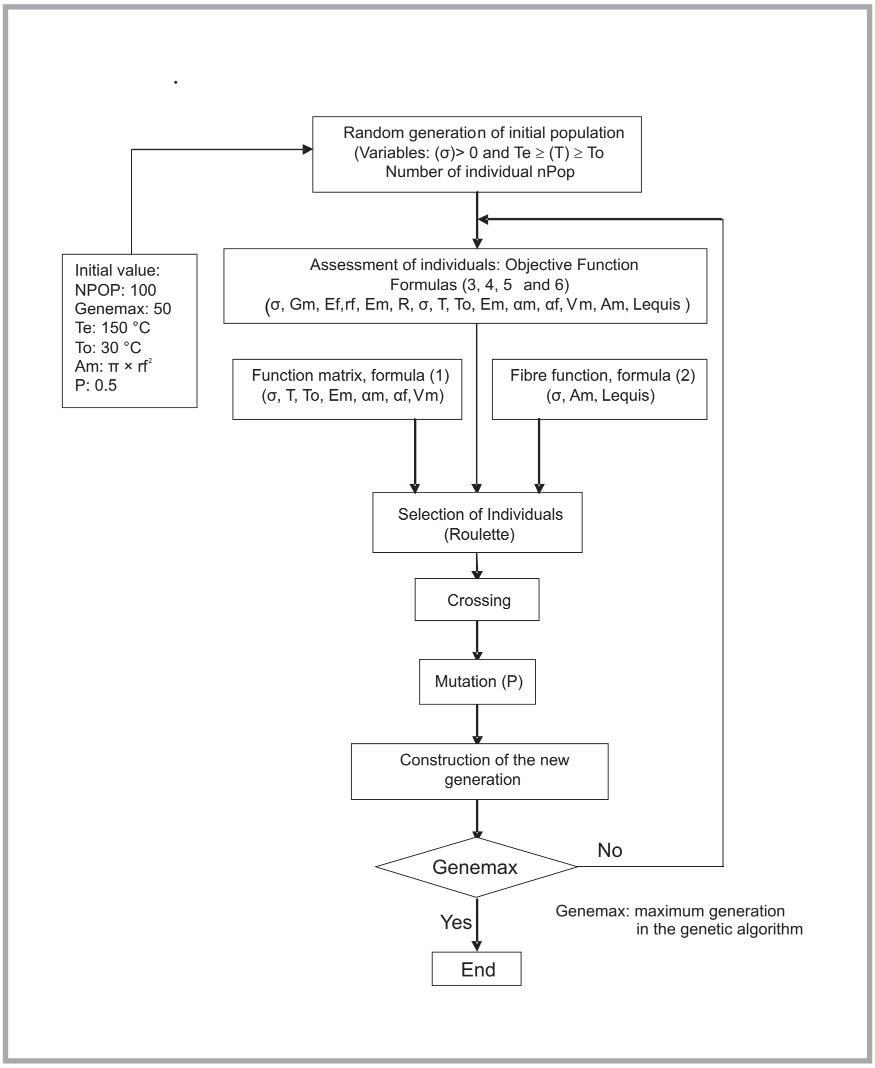

Figure 2. *Flowchart of genetic algorithm.*

where :

G_m - shear modulus of the matrix;

E_f - Young's modulus of the fibre;

ε - deformation ;

α - radius of the fibre;

R - half distance between fibres;

τ - shear stress of the interface;

r_f - distance between fibres of the parity fibre axis.

Damage (D)

Lemaitre.J Lem [17] considers a damaged solid in which an element of finite volume with a notch large enough relative to heterogeneities is defined as follows:

- S - area representative for volume element identified by its norm n (standard orthogonal),

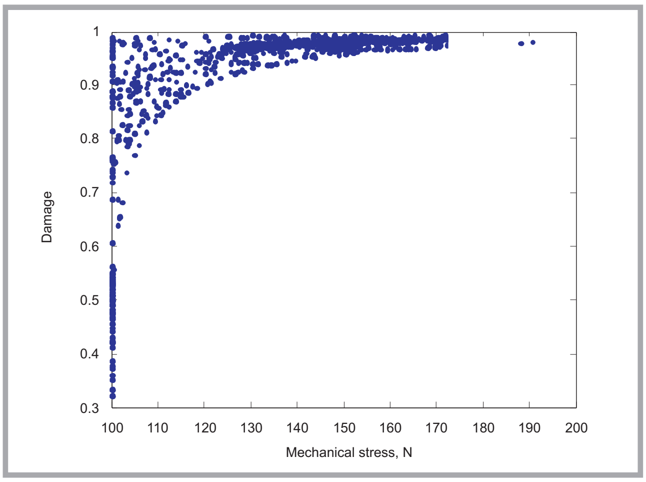

***Figure 3.** Influence of mechanical stress on the damage of the matrix.*

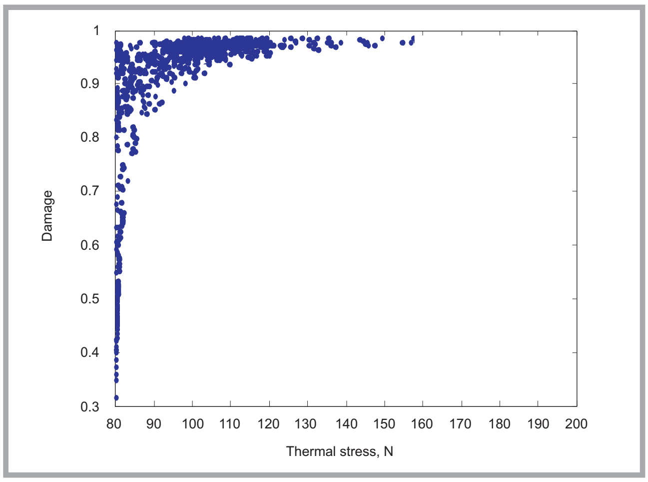

***Figure 4.** Influence of heat stress on the damage of the matrix.*

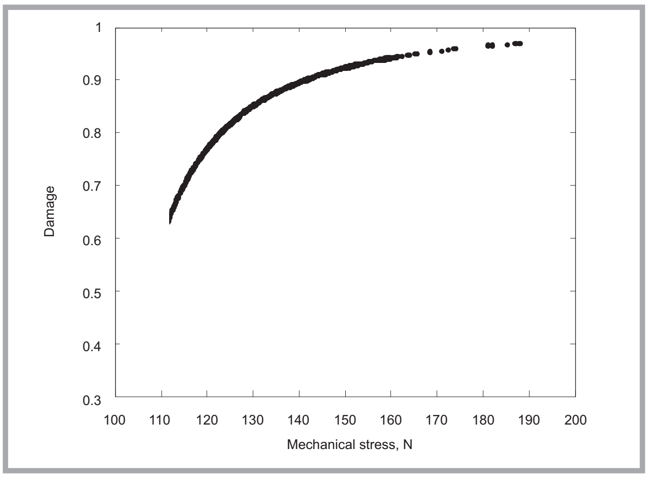

***Figure 5.** Influence of heat stress on the damage of the fibre.*

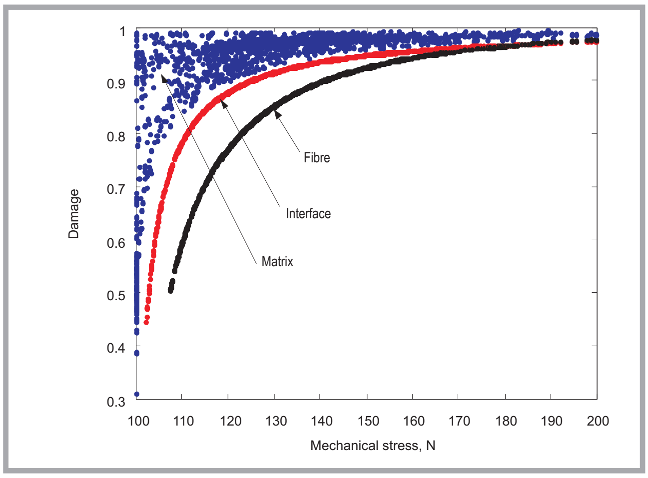

***Figure 6.** Influence of thermal stress on the damage of the fibre-matrix interface.*

- S_e - effective resistance area. (If $S_e < S$) and
- S_d - damaged area, $S_d = S - S_e$.

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

- If $D = 0$ – the material is in a pristine condition or not damaged,
- If $D = 1$ – the volume element is broken into two parts along the plane normal *n*,
- If $0 < D < 1$ – D characterises the state of damage defined; the macroscopic elastic behaviour of the damaged material in terms of D can be calculated by the rigidity.

Numerical simulation by a genetic algorithm

Development

Our work is to maximise the damage to the fibre-matrix interface of composite carbon/epoxy (T300/914) by means of 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, numbering 100, with a maximum generation equal to 50 as the stopping criterion. The genes of the chromosome represent the following variables: the mechanical stress, which is between 0 and the maximum stress of the stress tests; the temperature T varies between $T_0 = 30$ °C and the temperature of preparing the epoxy matrix $T_e = 150$ °C; the thermal stress generated is calculated using formula (3), taking into account the expansion coefficients of carbon fibres and the epoxy matrix. Then a selection operator (linearly by dividing the probabilities according to the rank of individuals in the population, which are classified and positioned in order to place the best of them at the top and the one whose quality is lower in rank 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), thus forming a new generation. The process is repeated until convergence.

The flowchart

The flowchart is presented on ***Figure 2*** (see page 109).

Simulation results

The data used in the simulation by means of a genetic algorithm are the Young's modulus of the fibre, the shear modulus of the matrix, the length of the fibre, the radius of the fibre, the coefficients of expansion, the thermal stress, the shear stress of the interface and the mechanical stress. Noted were the influence of thermal stress on the damage to the matrix T300/914 and the great influence on the progressive degradation of the matrix compared to the mechanical forces; this finding is validated by the cloud presented in ***Figures 3*** and ***4***. In ***Figure 5*** we observe also that thermal stress does not greatly influence the damage of the reinforcement (fibre), and we noticed that the matrix damage is more important compared to that of the fibre. We conclude that the thermal stress beyond the critical threshold has a great influence on the damage of the interface, and it is tightly linked to the matrix damage, but less important compared to that of the fibre (***Figure 6***).

Conclusion

During this research, we explored a way oriented as well as progressive mechanical and thermal stresses induced on the test material - carbon / epoxy T300/914 by means of a genetic algorithm, using profile Weibull's formalism to predict damage to the fibre and the matrix, which is used as an objective function. This approach allowed us to model thermal and mechanical stresses of the environment and to evaluate the fibre matrix interface damage through that to the fibre and matrix, which is determined by a particular statistical character-Weibull probability.

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

These interesting results not only allow us to explore other composite materials and set their thresholds for safe use in various fields but also to design and select new materials in more aggressive environments.

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