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Finite element analysis of the damage occurring in the sliding contact between a metallic ball and a composite plate

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ABSTRACT – The goal of this paper is to model the damage which occurs at the contact interface between a metallic ball and a laminate composite material. For this 3D Hashin's damage model was implemented in the Finite Element Method (FEM) software Abaqus. The obtained damage is in good agreement with the experimental results.

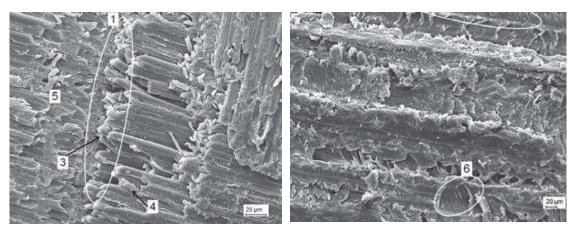
1. INTRODUCTION

The fiber-reinforced polymers (FRP) composite materials have many applications in industry and have been extensively investigated thanks to aeronautical developments in last few decades. Continuous unidirectional fibre- reinforced polymers are also being introduced for a variety of mechanical and biomedical applications, due to their greater wear resistance either normal or parallel to the sliding direction. The wear process of fibre composite materials is a very complex one. A diversity of fibres, both with respect to their properties and their fiber volume ratio, makes the analysis of this process even more difficult. Although it was suggested that the dominant wear process during the rubbing of fibrous composites is the adhesion one [1], depending on the type of fibres and friction conditions, other wear mechanisms may also be present. However, in a set of fundamental factors that influence the wear of fibrous composite materials, the most important are fibre type, its fiber volume ratio in the composite, as well as the structure of inter-phase between the fibre and the matrix.

To well understand the wear mechanisms, it is necessary to simulate the damage which appears in the contact zone. Traditional ply-based failure criteria, such as Tsai-Wu and Tsai-Hill, consider a yarn-matrix system as a whole and, therefore, they are not suitable to predict whether the failure occurs inside a yarn, a matrix, or at their interfaces. In contrast, some mode-dependent failure criteria take into account interactions between stresses and strains (they are called interactive failure criteria), including Hashin [2], Puck and Schürmann [3] and micro mechanics-based failure (MMF) criteria. In this paper, we propose to study the wear mechanims with the help of failure criterion. Hashin's criterion has been chosen to take into account the kind of damages (fibre or matrix) which occur in the contact zone.

2. EXPERIMENTAL STUDY

Composites based on Polyetherimide resin and unidirectionally reinforced carbon fibers (polyacrylonitrile-PAN based high modulus) in 80% by volume were developed by compression moulding after optimization of various parameters [5]. Since fiber orientation with respect to loading direction is a decisive factor in controlling the performance of the composite, the testing of composite was done in various fiber orientation angles such as 0°, 15°, 30°, 45°, 60°, 75° and 90°. Classically the composites evaluated for their mechanical and tribological performance showed strong dependence on the orientation of fibers [5]. Tribological evaluation was done in abrasive wear mode in a single-pass condition, linear and unidirectional forward motion on a Universal Wear Tester. SEM studies on worn surfaces were done to understand the wear mechanisms. Following the angle of the fibres with the sliding direction different kinds of damage can be observed on the worn surfaces (Figures 1(a) and 1(b)).



(a) (b)

Figure 1 (a) Fibre damage and breakage for fibres parallel to sliding direction (b) matrix damage for an angle of 45° between fibres and the sliding direction.

3. FINITE ELEMENT MODEL

Finite element modeling is made on Abaqus Software. Hashin's model is used to model the damage occurring at the contact interface. The damage's model was implemented with the help of UMAT's subroutine.

3.1 Hashin's model

Hashin proposed different failure modes associated with the fibre tow and the matrix, considering, in both modes, differences in tension and compression [2]. The values of initiation damage criteria F_I for each type of failure mode I are as follows:

Fibre tensile failure F^t_f ($\sigma_{11} \geq 0$) :

$$F_f^t = \left(\frac{\sigma_{11}}{X_T}\right)^2 + \alpha\left\{\left(\frac{\sigma_{12}}{S_{12}}\right)^2 + \left(\frac{\sigma_{13}}{S_{13}}\right)^2\right\} = 1$$

Fibre compressive failure F^c_f ($\sigma_{11}<0$) :

$$F_f^c = \left(\frac{\sigma_{11}}{X_C}\right)^2 = 1$$

Matrix tensile failure F^t_m ($\sigma_{22}+\sigma_{33} \geq 0$) :

$$F_m^t = \left(\frac{\sigma_{22}+\sigma_{33}}{Y_T}\right)^2 + \left\{\left(\frac{\sigma_{23}^2 - \sigma_{22}.\sigma_{33}}{S_{23}^2}\right)^2 + \left(\frac{\sigma_{12}}{S_{12}}\right)^2 + \left(\frac{\sigma_{13}}{S_{13}}\right)^2\right\} = 1$$

Matrix compressive failure F^c_m ($\sigma_{22}+\sigma_{33}<0$) :

$$F_m^c = \left(\left(\frac{Y_C}{2S_{23}}\right)^2 - 1\right)\left(\frac{\sigma_{22}+\sigma_{33}}{Y_C}\right) + \left(\frac{\sigma_{22}+\sigma_{33}}{2S_{23}}\right)^2 + \left\{\left(\frac{\sigma_{23}^2 - \sigma_{22}.\sigma_{33}}{S_{23}^2}\right)^2 + \left(\frac{\sigma_{12}}{S_{12}}\right)^2 + \left(\frac{\sigma_{13}}{S_{13}}\right)^2\right\} = 1$$

X_T and Y_T denote tensile strengths in the longitudinal (X) and transverse (Y) directions of a UD composite, respectively. X_C and Y_C are compressive strengths in the X and Y directions of the composite, respectively. Indices 1, 2 and 3 are used to describe X, Y and Z directions, respectively. Hence, S_{12}, S_{13} and S_{23} signify in-plane and two out-of-plane shear strengths, respectively. All the mechanical properties have been defined from standard tests [5].

4. RESULTS AND DISCUSSION

The contact between a metallic ball with a UD laminate composite was simulated. Rigid and 3D (brick) elements have been used respectively for the ball and the composite material. A refined zone is defined in the contact zone to well evaluate the stress and the damages.

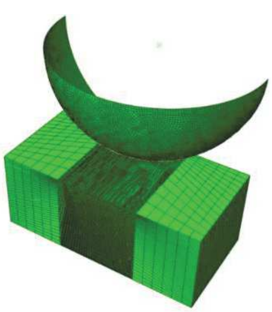


Figure 2 Finite element model.

A normal of 40N is applied and a friction coefficient depending of the angle between the fibres and the sliding direction is used (obtained from experimental data).

Due to the anisotropy of the composite material and the sliding, the stress distribution is not axisymmetric (Figure 3). The maximum of von Mises stress is at the entry of the contact.

From Figure 4, fibre and matrix damages are given in the case of the UD composite parallel to the sliding direction. We can observe that the highest values of the both damages do not appear where the stress is maximal. Fibre breakage appears at the exit of the contact zone (Figure 4(a)). Matrix damage occurs all around the contact zone and the maximum value of the damage is obtained for an angle of 45° with the sliding direction (Figure 4(b)). These results are in agreement with the experimental observations.

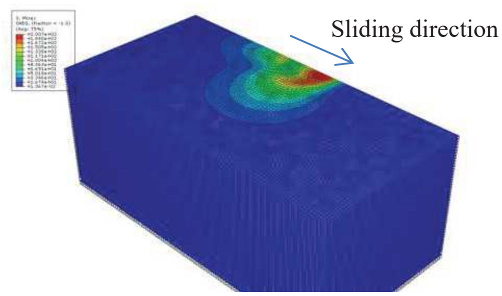
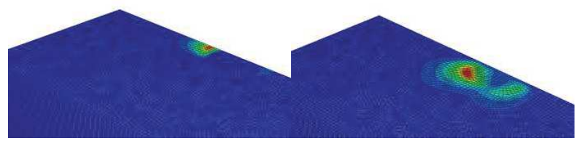


Figure 3 Von Mises stress distribution.



(a) (b)

Figure 4 (a) Fibre damage and (b) matrix damage obtained in the case of a sliding parallel to the fibres.

5. CONCLUSION

A finite element simulation using a failure criterion based on the matrix and fibre damages was performed to evaluate the damage occurring at the contact interface. From theses simulations, further works will be done to define a wear model based on the observed damages (fibre and matrix). For this, a progressive damage evolution model has to be used [6].

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