MICROMECHANICAL MODELLING OF DAMAGED SMC COMPOSITE BEHAVIOUR BY INTRODUCING A LOCAL STATISTICAL INTERFACE FAILURE CRITERION

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The objective of this paper is to predict the entire stress-strain curves and the loss of stiffness with damage by developing a statistical micro-macro relationship of Mori and Tanaka's type based on microstructural parameters. In the case of an SMC composite with a 32% fiber volume fraction, debonding at the fiber/matrix interfaces is the predominant " microdamage " mechanism. In order to relate the microstructure and its local perturbations, to the macroscopic damaged behaviour, we introduce a statistical local damage criterion and the notion of equivalent damaged inclusion in the micro-macro relationship of Mori and Tanaka. This paper shows the relation between the statistical interface failure criterion and the dispersions observed on the macroscopic mechanical tests results.

INTRODUCTION

The very large usage of short fiber reinforced composites in industries such as the automobile manufacters attracts the attention of engineer and leads to the study of this class of materials. In order to ensure the structural integrity and reliability of these composites, the study of damage behaviour comes an active domain in current researches.

S.M.C (Sheet Molding Compound) composites consists of randomly oriented short bundles of glass fibers (25 mm length) in a continuous polyester matrix containing mineral charge (CaCO3). So, the composite is quasi transversally isotropic. The nominal volume fraction is 32%.

Several study shows the relation between the non-linear macroscopic stress-strain curves and the nature of damage within the material at the microscopic scale (1), (2), (3). Moreover the dispersion of microstructural parameters such as the local volume fraction, the orientation distribution of fibers, the presence of randomly distributed porosity or the variation of the fiber sizing strongly influence the macroscopic response.

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The object of this paper is first, to integrate the damage processes at the micro scale in a micromechanical modelling based on the Mori and Tanaka approach in order to predict the macroscopical response. In this model, the initiation of the local interface failure is predicted by using a local interface failure criterion. In the second part of this paper, the local criterion is modified by introducing two statistical parameter in order to relate the dispersion of the microscopic parameter to the dispersion observed on the macroscopic tensile tests results.

MACROSCOPIC AND MICROSCOPIC EXPERIMENTAL ANALYSIS

In order to understand the mechanisms governing deformation in an SMC composite, tensile tests are performed. SMC stress-strain curves can be devided in three parts. One linear part corresponding to the elastic behaviour is followed by an non linear stage. Finally, another linear zone takes place until final fracture. It can be shown that the non-linearity corresponds to the first decrease of the elastic moduli and also to the appearance of damage at the fibre-matrix interface.The other damage mechanisms can be neglected (4). In the further parts, we will focus on the study of the dispersion observed on the macroscopic tensile test results which can be related to several type of dispersion at the microscopic scale.

MICROMECHANICAL MODELLING

A micromechanical calculation based on the stiffness prediction by the Mori and Tanaka approach and integrating the local damage mechanisms is proposed.

Mori and Tanaka undamaged stiffness prediction and interfacial stress calculation. This approach is an alternative to find an estimation of the elastic moduli and local stress and strain fields in each component of the composite as a function of their elastic constants, their geometry, their volume fraction and their orientation. In our case, matrix and fibers are isotropic. A phase 'i' other than matrix is defined as a collection of inhomogeneities (here fibers) whose orientation, shape ratio and elastic moduli are identical. The glass fibers are assumed to be infinitely long ellipsoid (cylinder). So, the expression of the Eshelby tensor given in the Mura's book for this case can be used (5). A combination of the Mori and Tanaka back stress analysis, the Eshelby equivalent inclusion method and homogeneization technic leads to the expression of the composite stiffness as a function of its microstructure (4). In the same time, the model gives an estimation of the average stress inside the fibers and on the interface

Local interfacial damage initiation criterion. Decohesion occurs at a point of the fiber/matrix interface when a combination of normal, σ, and shear stress, τ, reaches a certain ultimate value, Ri, related to the interface resistance. This

coupled effect is introduced in the model at the microscopic scale in the form of a linear criterion of Coulomb type : $\sigma + \beta\ |\tau|\ = Ri$ (1)
where β and Ri are the parameters which characterise the interface resistance identified by a specific method coupling experimental analysis with an inverse calculation (6).

In the case of an SMC composite, the model should take into account at the microscopic scale some effects like non homogeneous local fiber volume fraction, randomly dispersed porosity, dispersion of interfacial resistance and fiber resistance. So, the local interface failure criterion is introduced in our micromechanical modelling in a statistical form as follow :

$$P^r(\Sigma) = 1 - \exp\left[\left(\frac{\sigma + \beta\tau}{<Ri>}\right)^m\right] \tag{2}$$

where P^r give the failure probability of the interface for a given macroscopic stress Σ. In this expression <Ri> corresponds to the average interfacial resistance and m characterise the dispersion around <Ri>. We define Ri^{max} and Ri^{min} by the minimum and maximum values for which $Pr(\Sigma)=1$ and $Pr(\Sigma)=0$ respectively.

Damage evolution. Damage effect is introduced in the model, at the fiber scale, by changing the elastic properties of the fibers. When the criterion is activated on a fiber/matrix interfacial point, the corresponding debounded fiber is replaced by an equivalent anisotopic inclusion taking into account the loss of stiffness due to the propagation of the crack around the interface (1), (4). The equivalent stiffness tensor is given as a function of tree "microparameters" of damage caracterising the progression of the interfacial microcracks all around the fibers as well as the local stress field on the interfaces : d (percentage of debonded interface), δ (percentage of frictional sliding interface) and γ (percentage of debonded and on traction interface) (1). At each loading step, the local damage criterion can be activated and the micro damage parameters are calculated for each orientation of fiber and so the new stiffness tensors. A new composite material composed of damage and non-damage fibers is defined and its stiffness tensor is estimated again.

RESULT AND DISCUSSION

Deterministic interface failure criterion. In this part, the statistical parameter, m, takes a very high value (infinite in theory)

In the case of two SMC composites (same composition) under prescribed deformation, simulated tensile tests are reported in figure 1 and superposed with experimental data. Moreover, the evolution, with damage, of the Young modulus of the SMC n°2 was evaluated by performing discharges and compared to simulated results in figure 2. The comparison shows a quite good agreement.

Statistical interface failure criterion. In this part, we study the effect of a variation of the statistical parameters, m and <Ri>, on the simulated stress-strain curves in the case of a tensile test. First, we study the effect of a variation of <Ri> with a parameter m equal to 3. This type of variation leads to simulated tensile tests shown in figure 3 on which we can observe a dispersion very similar compared to that obtained on experimental stress-strain curves of two specimens cutted out from two SMC (same composition but different sizing). A variation of the average interface resistance, <Ri>, comes from a different sizing of the fiber. This effect can be simulated by an evolution of the statistical parameter <Ri>.

We study now the effects of the variation of m for <Ri> equal to 65 MPa. This type of variation leads to simulated tensile tests shown in figure 4 very similar to that experimentaly observed on a collection of specimens all issued from the same plate. Choosing a small value of m means that the interface of a large number of fibers presenting the same orientation will not break simultaneously. Only a fraction of them related to the probability $P^r(\Sigma)$ will debond. The non homogeneous local fiber volume fraction or the presence of porosity more or less distant from the interfaces will lead to some small variations of the average local stresses and conscequently of $Pr(\Sigma)$ and so, the proportion of broken interfaces. This effect can be simulated by a variation of the statistical parameter, m.

CONCLUSION

The micromechanical modelling presented here is based on the micro-macro relashionship of Mori and Tanaka. To predict the damaged behaviour of two SMC composites, we introduce in the model a local interface failure criterion. The microstucture is very complex and the geometrical distristribution of the components is not homogeneous. The local variation of the micostructure is not taken into account in the classical models. The consequences are that the macroscopic stiffness tensor is well predicted but the local fluctuations of the local stresses are not taken into account. So, the calculated values reached by σ and τ which are involved in the local interface failure criterion are not correct. Moreover, the fiber sizing can change between two identical SMC. The introduction of an interface failure probability in the local criterion, proposed in this paper, is an alternative method to resolve these problems relative to the microstructure dispersion. We show that the experimental dispersion observed on the macroscopic tensile tests results can be predicted by changing the statistical parameters of the local interface failure criterion.

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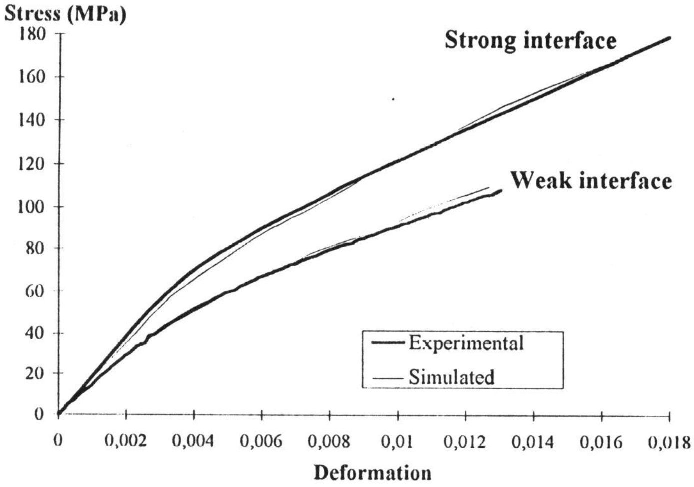

Figure 1 : Comparison between experimental and simulated tensile test in the case of two SMC composites (same composition but different sizing)

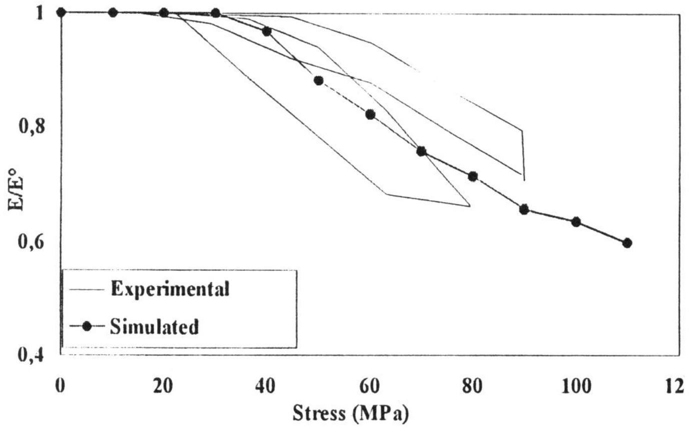

Figure 2 : Evolution of the residual Young's modulus, comparison between experimental and simulated results, deterministic criterion

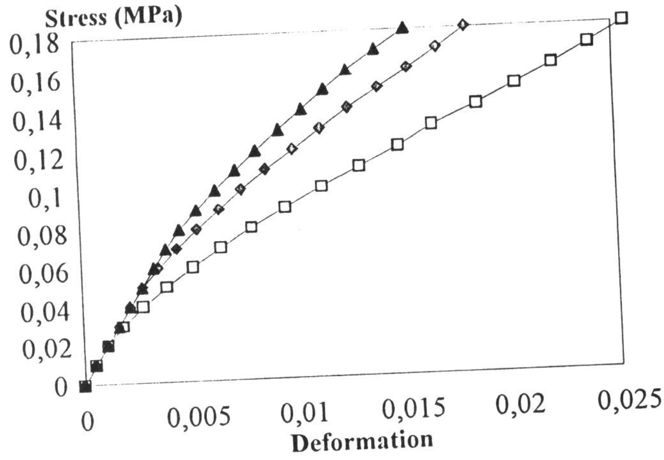

Figure 3 : Stress-strain curve, comparison between experimental and simulated results, statistical criterion with a variation of <Ri>.

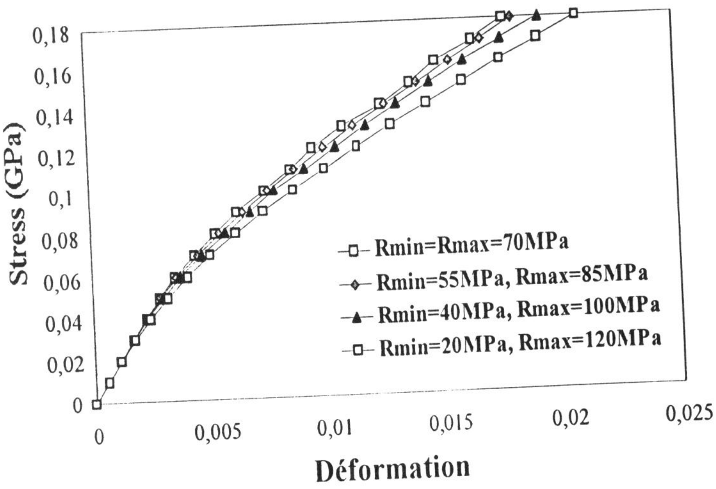

Figure 4 : Stress-strain curve, comparison between experimental and simulated results, statistical criterion with a variation of m.