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MODELLING OF FATIGUE BEHAVIOUR IN COMPOSITE LAMINATES

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INTRODUCTION

The fatigue behavior of a composite laminate is first characterized by initiation and multiplication of the cracks rather than by their quasi-instantaneous growth. Cracks multiply during the cycles until reaching a saturation state. This phenomenon was first modeled by Reifsnider [1] and Garret and Bailey [2]. In this approach to transverse cracking under fatigue loading, the cracks are assumed to have the same geometric characteristics as those occurring under quasi-static loading [3]. In particular, it is assumed that they go through the thickness of the plies and that their propagation is quasi-instantaneous.

WRITING OF THE FATIGUE EQUATION

The criticism that can be made of the conventional expression for the fatigue equations is that they include loading explicity through the mean or maximum stress, the amplitude, etc ... This remark applies both to metals and to composites. For instance, the evolution equation proposed by Beaumont [4] uses the amplitude of the external loading. Another equation, written by Ye [5], uses the maximum longitudinal load applied to the edges of the structure. Such evolution equations are therefore very difficult to apply in the case of complex structures, when the loadings vary over time both in intensity and in point of application. If the behavior of the volume element depends on external factors, the equations do not have an intrinsic character. Also most of the cases are based on uniaxial tests providing a uniaxial model whose extension to the multiaxial case is not necessarily justified. A more logical approach is to formulate a multiaxial model developed and identified on tests which could be uniaxial.

We therefore directly construct an evolution equation from an energy formulation making it unnecessary to have a 3D generalization which is difficult to achieve. In addition, the aim is to take into account the fatigue effects as well as static effects. Thus, we attempt to write an evolution equation as follows $d\alpha = g(\varepsilon, \alpha)\, d\varepsilon + h(\varepsilon, \alpha)\, dN$, where ε denotes the strain state in the volume element when the loading reaches maximum value, N the number of cycles and α the scalar damage variable [3].

It is important to point out that the validity of the damage variable (α = crack density / thickness of the damaged ply) is experimentaly show in the case of fatigue loading. Thus, the intrinsic character of this variable is now demonstrate in the case of quasi-static loading [6] as well as in the case of fatigue loading [7].

COMPARISON BETWEEN EXPERIMENTAL RESULTS AND NUMERICAL SIMULATIONS FOR TWO LEVELS LOADING TESTS

We compare the numerical and experimental response of a ($0°_2$, $90°_4$, $0°_2$) carbon/epoxy laminate submitted to two level loading tests :

- first, a weak loading followed by a strong one (0.5 σ_r during 1000 cycles followed by 0.8 σ_r during 1000 cycles);
- second, a strong loading followed by a weak one (0.7 σ_r during 1000 cycles followed by 0.5 σ_r during 1000 cycles).

In the first case (Fig. 1), we notice an increase of damage due to the application of the strong loading. In fact, the amount of damage at the end of the weak loading is less than the damage occured by the first cycle of the second loading level. In the second case (Fig. 2), we do not record an increase of the damage due to the second loading level. This is explained by the fact that the damage which is created by the first loading is higher than the damage which should be created by the first cycle or the the static loading at the level of the second one. In the both cases, the good correlation between numerical simulations and experiments.

CONCLUSION

For this approach of fatigue in laminated composites we arrived at a new form of the transverse cracking damage evolution equation. The originality of the work resides in three points :

- first, in the evolution equation, which can take possible static loadings into account. This makes it very flexible for simulations as regards the diversity of possible applied loadings;
- next, in the process by which the equation was established. The assumption that the defects created in a structure are similar for quasi-static loading and for cyclic loading makes it natural to extend the quasi-static model to the fatigue model;
- finally, the parameters of the equation do not explicitly include the external loading applied to the structure. This makes the model intrinsic to the material and therefore applies to all types of loadings and structure.

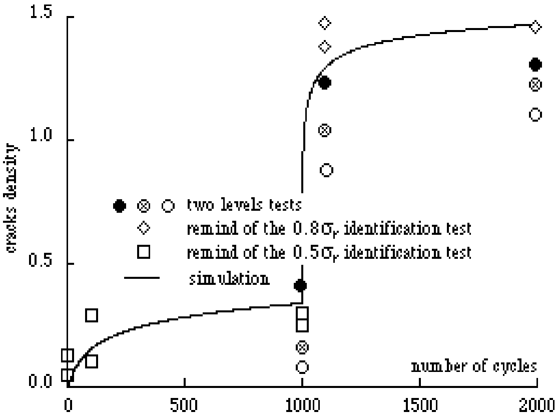

Fig. 1 - Weak loading followed by strong loading

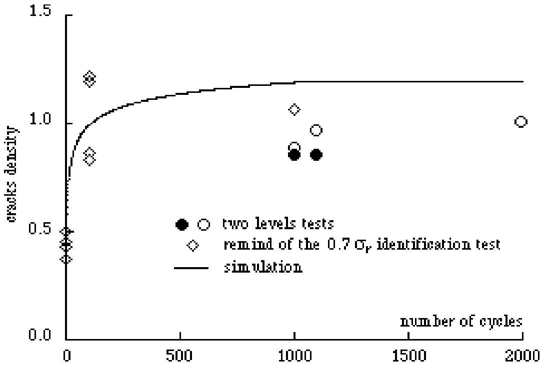

Fig. 2 - Strong loading followed by weak loading

REFERENCES

1 Reifsnider K.L., "Some fundamental Aspects of Fatigue and Fracture Response of Composite Materials". *Proc. of 14th Meeting of Society of Engineering Science,* Bethlehem, U.S.A., 1977

2 Garret K.W., Bailey J.E., "Multiple Transverse Fracture in 90° Cross-Ply Laminates of Glass/Fiber reinforced Polyester". *Journal of Materials Science*, vol. 12, 1977.

3 Thionnet A., Renard A., "Laminated composites under fatigue loadings : a damage evolution law of transverse cracking", *Composites Science and Technology*, vol. 52, 1994.

4 Beaumont P.W.M., "The Failure of Composites an Overview". *Journal of Strain Analysis,* vol. 24, 4, 1989.

5 Ye L., "On the Damage Accumulation and Material Degradation in Composite Materials". *Composites Sciences and Technology*, 36, 1989.

6 Renard A., Habilitation à diriger des recherches, Université Paris 6, 1997.

7 Chambon L., "Endommagement de fatigue dans les composites stratifiés', Rapport de stage, Ecole des Mines, 1998.