DAMAGE EVOLUTION UNDER LONG-TERM, HIGH AND CONSTANT LOADING OF A CARBON/EPOXY LAMINATE

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Abstract

When a composite material of carbon fiber and epoxy resin is subjected to mechanical loading, different phenomena can lead to changes in its properties or even irreversible damage (propagation of cracks, debonding between folds, fiber breakage). The objective of this work is to study, under high loads and long periods, the propagation of transverse microcracks (diffuse damage) until the fracture of the laminate under matrix modes (instability). Since long term tests are necessary to characterize the damage evolution as well as the creep and stress relaxation phenomena, a testing machine was carried out. Optimal orientations ($[45°,-45°]_{ns}$ and $[60°,-60°]_{ns}$) and specimen shape have been defined to study this phenomena. Experimental results are presented here and it is observed an evolution of the matrix damage under constant loads. This evolution is compared to the evolution of the matrix damage in the case of cyclic loads (fatigue) which in this latter case is faster.

1. Introduction

The manufacture of cylindrical structures is made by winding of fibers on a mold or a mandrel (Figure 1). This procedure is described as filament winding. Various applications exist for cylindrical structures (pressure vessels, piping ...). These structures can be subjected to static loadings, fatigue and sometimes at high constant loads for long periods.

Figure 1. Cylindrical structures.

The evolution of damage in CFRP under monotonic and cycled load is studied since a long time [1,2]. Transverse micro-cracking appear from static loading, and they multiply under fatigue loading [3]. However, the evolution of damage under constant loading and the existence of a threshold are less well known.

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The objective of this work is to study, in the context of long-term, high and constant mechanical loading, the damage evolution and especially transverse crack propagation of a carbon/epoxy laminate. One of the failure modes of the composite materials is the matrix micro-cracking increasing until a meso-crack at the level of the ply and a macro-crack at the level of the laminate. Compare to a brittle fibber mode fracture, this matrix mode fracture of the laminate correspond to an instability due to the localization of the damage. Damage mechanisms involve at several scales but we limit ourselves to the intra-ply scale. The evolution of this damage depends on the combined transverse and shear loads and can be modelled as part of the mechanical damage [4].

Since long term tests are necessary to characterize the damage evolution as well as the creep and stress relaxation phenomena, a testing machine was carried out. In order to study the evolution of the damage under shear and transverse constant loads, optimal orientations and specimen shape have been defined. The design of the testing machine is presented. Experimental results are presented here and the evolution of the matrix damage under constant loads is compared to the evolution of the matrix damage in the case of cyclic loads (fatigue).

2. Specimen and testin machine

2.1. Specimen shape and optimal orientations

In order to avoid a premature fracture at the level of the grips, we use dumbbell shaped specimen (Fig. 2) which leads to a fracture in the center of the specimen without stress concentrations.

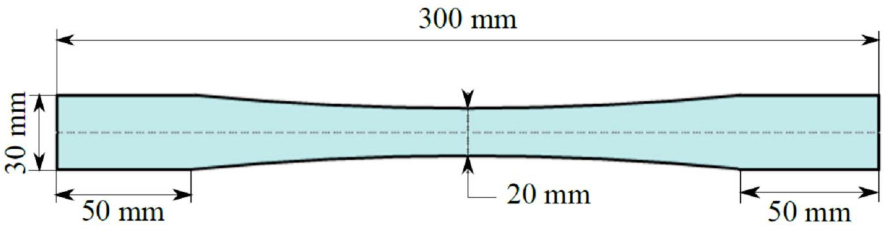

Figure 2. Specimen shape.

Initially, static tensile tests on specimen are performed by varying the orientation of the plies. The goal is to find the optimal orientation to obtain the shear and the transverse behaviour. The optimal orientation to get the shear behaviour is a [45°,-45°]$_{ns}$ (Fig. 3). The transverse behaviour is more complicated to get because the material is very brittle in this direction and is different of the behaviour inside a laminate (Fig. 4).

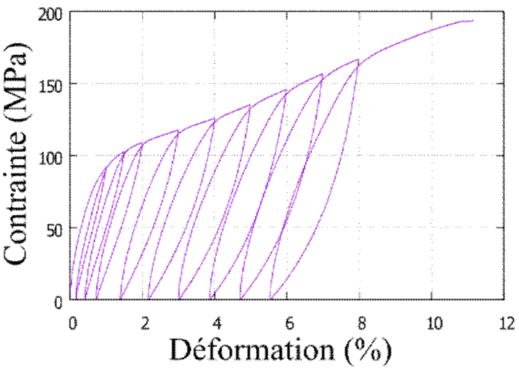

Figure 3. Shear behavior on [45°,-45°]$_{ns}$.

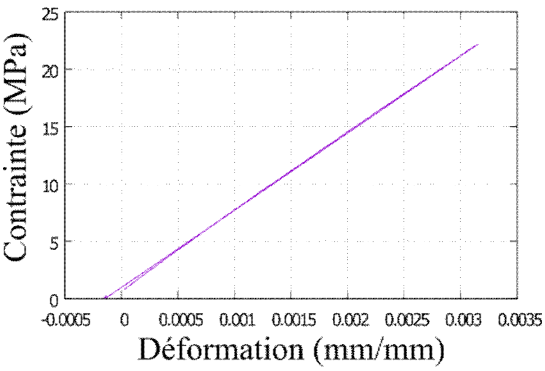

Figure 4. Transverse behavior on [90°]$_{ns}$.

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The classical $[67°,-67°]_{ns}$ [4] is still brittle and, after some experimental tests, we concluded that on $[60°,-60°]_{ns}$ specimens seem to be a good compromise as this orientation limits the shear and avoids premature rupture in the transverse direction (Fig. 5). The specimen rupture is due to an instability.

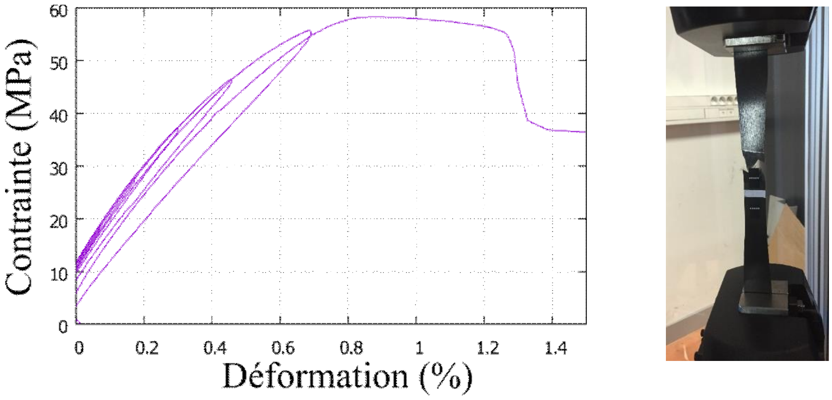

Figure 5. ñTransverse behaviorò on $[60°,-60°]_{ns}$.

2.2. Testing machine

Since long term tests are necessary to characterize the evolution of the damage under constant loads and the creep and stress relaxation phenomena, a testing machine was carried out (Fig. 6). The creep test is performed simply by suspending weights on the specimen, and the relaxation test is performed thanks to a coil system. This system permit to tensioning the specimen. The force is measured with a sensor.

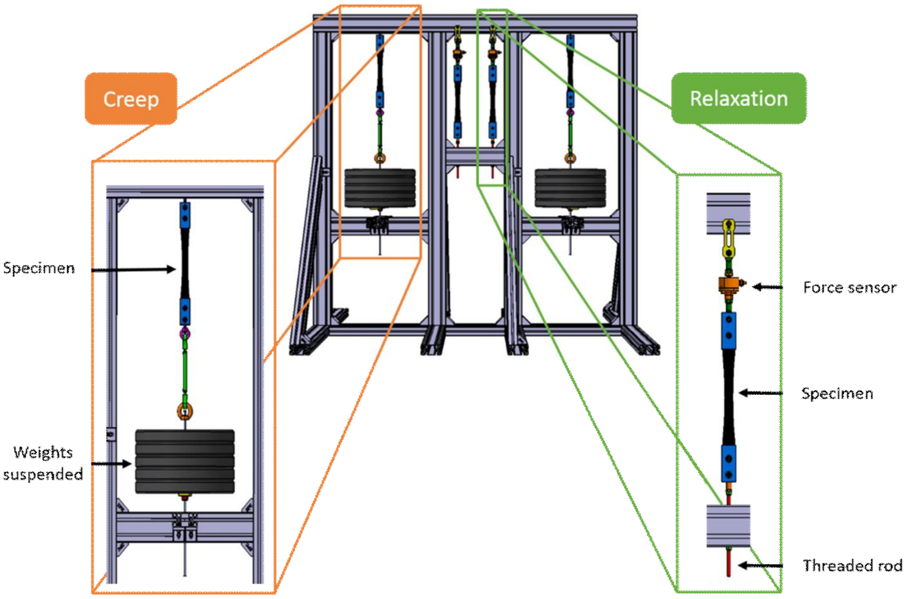

Figure 6. Testing machine.

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3. Fatigue test

In case of cyclic loads (fatigue), the evolution of damage *d* corresponding to the decreasing of the Young modulus ($E=E_0(1-d)$) can be observed. The decreasing of the modulus can be important and the damage can be greater than that obtained for a static loading, generally limited to 0.5 (Fig. 7).

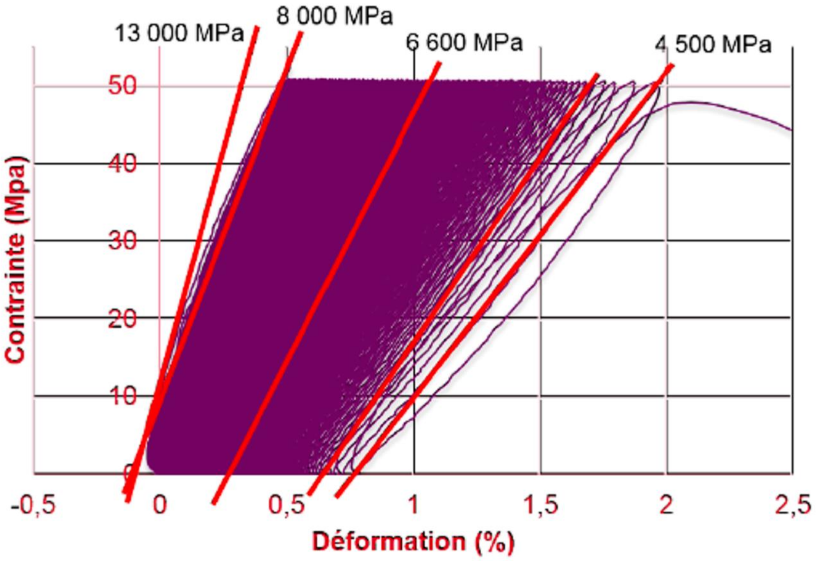
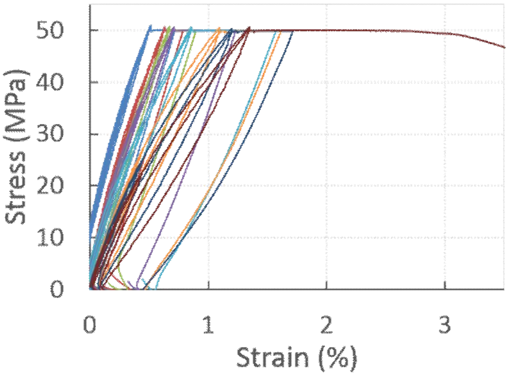


Figure 7. Damage evolution in fatigue.

4. Constant load test

After static tests, ñdamage-creepò test during a relatively long term are achieved. For a constant stress, the strain and damage significantly progress to cause the specimen rupture. The stress in terms of the strain are plotted (Fig. 8) and a ratio in the order of three between the initial and the final modulus are noticed. Damage in terms of the time is also plotted (Fig. 9). Again, the damage rate (0.7) is higher than the static test (0.5).



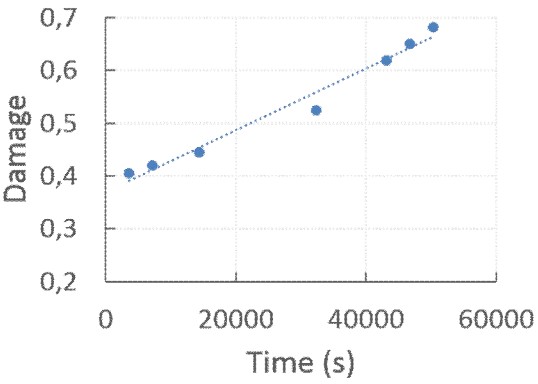


Figure 8. Damage evolution with a contant load.

Figure 9. Damage evolution in terms of time.

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5. Fatigue versus constant load

The comparison of the evolution of the stress level (maximum in case of fatigue) with respect to the time is shown Fig.10. The evolution of the damage until the fracture of the specimen is higher for cyclic loads that for constant laod, when the level of the stress is not to high.

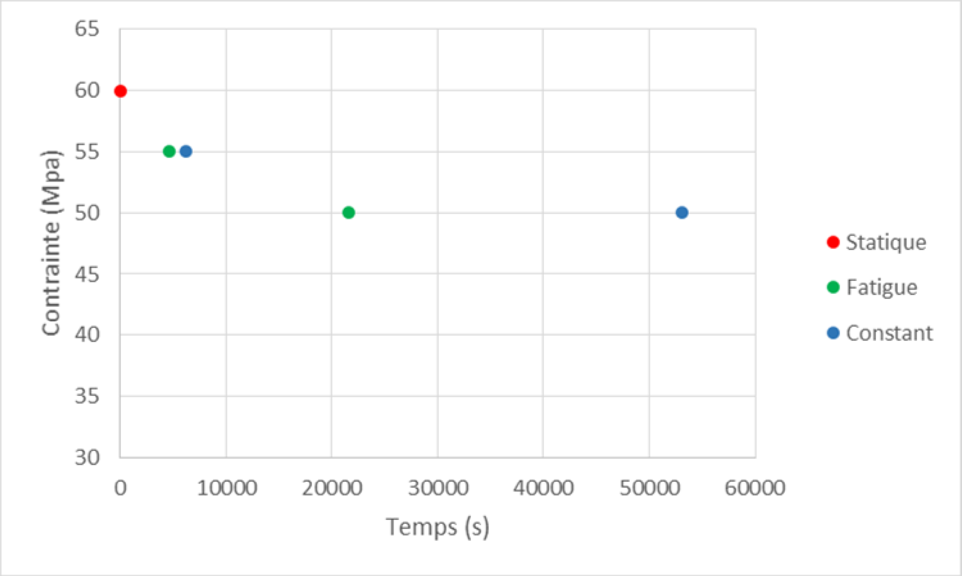

Figure 10. Stress evolution in terms of time.

4. Conclusions

A first experimental study showing the evolution of matrix damage in the case of a constant load is presented here. It is concluded that this evolution exists and is less important (with respect to time) that for cyclic laods. The next step will be the definition of a model at the level of the ply and the validation in case of any laminate.

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