I. INTRODUCTION

The mechanical behaviour of high-performance composite materials is, on the macroscopic level, quasi-elastic and largely linear, with an elongation to fracture on the order of a few percent. A rough comparison with elastoplastic metallic materials, for which the elongation to fracture is on the order of tens of percent, leads to the assumption that composite materials must be classified as brittle solids.

In fact, this would be a mistake. Although quasi-elastic, the fracture of composites is preceded by microscopic damage which advances slowly and can be anticipated; this is not the case in, for example, the cleavage fracture of steels.

The first damage that can be observed with an optical microscope are microcracks that appear in the matrix of the composite material at about one-third of the fracture load. The damaging of the reinforcements, the fibers, does not occur until the moment of fracture. Between these two stages of damage a third stage exists that results from the interaction of the fibers with the matrix: the cracking of the fiber/matrix interface. Thus the fracture of composites combines these three types of damage.

All of these damages are internal, even in the case of fatigue where the surface has practically no role to play, contrary to what is observed in metals. The criteria for damage and fracture of composites must necessarily take into account their three-dimensional nature. On a phenomenological level, the study of this damage relies on such classical methods of observation as microscopy, but also on specific methods such as radiography, tomography, or holography that allow better three-dimensional observations than those obtained with microscopy.

Finally, the ambiguity of the notion of damage in composite materials should be emphasized because, as a matter of fact, all of the microcracks that appear in the matrix do not always lead to a weakening of the composite's residual strength. Sometimes, even the opposite occurs. A priori, a microcrack in the resin should be considered as a deterioration or an alteration of the geometry before looking at the concept of damage. The image of cracked wood is a good illustration of this remark. It would seem that there must be a damage...
threshold for the matrix cracking of composites characterized by, for example, the crack density.

In this text we will successively examine the different types of damage, the fracture in the presence of a notch, the models, and the methods of observation of composite materials.

II. THE DIFFERENT TYPES OF DAMAGE IN TENSION AND IN TORSION

2.1. General remarks

Considering only polymer-matrix composites reinforced by long fibers, it is known that the first damages that appear under loading are matrix cracks, before the fracture of the fibers. These are microcracks with an initial size of the thickness of one layer, and their presence constitutes the initiation of damage. Propagation will develop next, by a multiplication of cracks building to a critical density and resulting in the development of delamination, until the eventual fracture of the fibers, should that arise.

The initiation and propagation of damage depends on the stacking of the composite layers. In cross-worked layers the first microcracks are produced in the layer for which the fibers are the most disoriented with respect to the tensile axis (a layer at 90°, for example) and then in the least disoriented layers (layers at 45° and 0°, for example).

According to the stacking sequence of the layers, the interlaminar tensile stresses $\sigma_{33}$ and the interlaminar shear $\tau$ eventually result in the formation of cracks between the layers; this leads to delamination, a serious type of damage because it will spread, separate the layers of the composite and allow, in time, the fracture of the fibers.

The series of elementary matrix cracking-delamination-fracture of fibers takes place with all sorts of variations, depending on the orientation of the layers, the geometry, and the introduction of forces. Before entering into detail, it should be noted that there is no basic difference between the phenomenon of delamination and the cracking of the matrix. To see this, let us consider some specific cases in which delamination is initiated and propagates in mode I or mode II, both simple modes of deformation. Such an approach cannot be applied to a plate subjected to tension because the local forces are mixed (tension and shear). It is thus reasonable to study delamination with a DCB (Double Cantilever Beam) specimen.

2.2. Mechanisms of damage by delamination

Damage by intralaminar delamination is produced by an interfacial plane decohesion that causes the composite to be separated in its thickness. This type of plane damage that propagates along a front, under tensile or shear loading, can be successfully handled by fracture mechanics. Several authors (1-29) have shown the advantages and limitations of the application of the concept of the strain-energy release rate $G$ to delamination. In particular, the orientation of the notch and of the plane of propagation must be known with respect to the principal axes of symmetry of the composite and of the mode of deformation. When these conditions are met, delamination can