MESO SCALE ANALYSIS OF DAMAGE PROPAGATION IN TEXTILE COMPOSITES

D.S. Ivanov, S.V. Lomov, I. Verpoest

Department of Materials Engineering, Katholieke Universiteit Leuven, Kasteelpark Arenberg, 44 B-3001 Leuven Belgium. Dmitry.Ivanov@mtm.kuleuven.be

KEYWORDS:
Damage mechanics, property degradation, textile architecture, meso scale, energy release rate, carbon-epoxy composites

INTRODUCTION

Meso-scale (level of fibre bundle) modelling of damage in textile composites attracts a great interest since it directly accounts for the yarn geometry and employs input data provided by relatively simple tests on unidirectional composites. Hence, various structures (braided, woven, and knitted) may be treated with a unified approach. The latter proved its efficiency in prediction of stiffness, surface strain fields and damage initiation, however the simulation of the damage development in textile composites still remains a challenge.

The damage accumulation mechanism in textile composites is specific due to the crimp of the yarns and interweaved yarn interaction. As well as in the other composite structures, at the initial stage of deformation transverse inter-yarn cracks occur (brittle carbon-epoxy composites are mainly discussed further). Their density increases along with the applied load until delamination starts. In the non-crimped laminated composites these cracks are "tunnelling" (propagate through the entire specimem). On contrast to the laminated structures, crack propagation in textile composites can be stopped due to the internal architecture of the material. The cracks propagate step-wise: in the beginning they are comparable to textile unit cell size; their development depends on the architecture and interaction with other developing cracks. Hence, there is a competitive mechanism of damage accumulation: by crack density and/or by crack length growth (Figure 1). Experiments on triaxial braided composite revealed that the density of the cracks grows together with the mean length of the cracks [1]. Dispersion of the crack length is proportional to the applied load. Close to the on-set of delamination few long tunnelling cracks are observed as well as a dense pattern of short and intermediate size cracks. From the point of view of macro description the crack density governs the deterioration of stiffness and the crack step-wise behaviour adds to the fracture toughness of the material. Hence both the parameters are important.

The crack density growth is well-studied for laminated composites; however modelling of the "competitive" damage accumulation is a challenge. The most popular approach at the meso-scale is to employ the damage mechanics where the damage propagation criterion is assumed to be the same as the local failure criterion for damage initiation [2-5]. The post-failure property degradation scheme describes a response of the damaged region. However, as it was shown [6-7], the major problem of this approach is non-physical widening of the damage zone and wrong directions of the damage propagation. It does not correspond to the reality: neither intensive micro debonding is observed in experiments nor does the dense meso crack pattern (3-4 cracks per yarn at most are found, 0.5 – 1 crack per mm). The modelling paradox is caused
by particularities of stress distribution around the damage zone and is particularly pronounced in presence of shear deformation in yarns. Locally, due to the yarn interaction, the shear deformation can be present even under the macroscopic tensile loading (e.g. in triaxial braided composite the shear will arise in whatever direction the composite is loaded). Another important factor is that the damage initiation criterion is designed for homogeneous stress distribution. An existent crack or a damage zone creates a significant stress concentration, which limits the predicting ability of the initiation criterion.

In order to handle the problem, several approaches are combined. The first crack occurrence is predicted by a local criterion for unidirectional composites (e.g. those benchmarked by World-Wide Failure Exercise). Once the initial failure in the yarn cross-section is indicated, this cross-section is considered locally as a ply in a laminate. Crack density within the cross-section is governed by the damage mechanics of Ladeveze [8]: degradation of cross-section stiffness is a function of energy release caused by the damage. The dependence is considered as a material property. A fictitious crack is introduced in the cross-section. The latter is presented by a degraded region through the entire thickness of the yarn. The properties of the degraded region are chosen in such a way to balance out the stiffness response of the entire cross-section in accordance to the damage mechanics. The further degradation of the cross-section affects only the degraded stiffness of the fictitious crack. It is determined to propagate along the fibres only. The propagation of the fictitious crack is governed by the fracture mechanics parameter: a critical energy release rate around the damage zone. The latter is determined by the link between the J-integral for the damage zone and J-integral for the crack of the same length and position. It is shown that J-integral around the damage zone converges to the J-integral around the crack, when the width of the damage zone tends to zero. Consequently, the J-integral can be presented in the form of Tailor’s expansion by the width of the damage around the zero width of the damage zone.

The results of the numerical modelling are compared with the experimentally found macro-response of the damaged structure, damage initiation onset, and mean damage length at two stages of damage accumulation.

REFERENCES