Analysis of the plane elasticity assumptions and the use of plasticity coupled with damage for the micro-scale analysis of composite materials

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Micro-mechanical analysis has its roots in the analysis of a single fibre embedded in a matrix mainly under transverse tensile loading. This problem has been extensively studied; using analytical models, experimental studies and later on, using numerical tools such as the Finite Element Method and the Boundary Element Method.

According to the experimental results in [1, 2], fibre debonding due to transverse tensile load is a 3D phenomenon that starts at the free surfaces in the locations of maximum normal tensile stress. Martyniuk et. al [1] state that interface debonding and crack kinking both start at the free surface and then progress into the specimen's volume. In contrast to the main conclusions of [1, 2], the trend in numerical and analytical studies on a single fibre embedded in a matrix is to use a 2D plane-strain assumption. The main contradiction comes from the fact that most studies that consider plane-strain always compare the results with in-situ observations in SEM, which are observations on the free surface where the stress state is closer to plane-stress. Only a few authors consider the 3D effects of interface damage under transverse loads, and no publication was found to study the 3D initiation and progression of kinking. This is one of the main knowledge gaps within this type of analysis, there is not a deep understanding of the role of the stress concentration of the free surface on the debonding and kinking and the way this could affect the measurement and approximation of interface strength, interface fracture toughness, potential plasticity effects in the matrix and micro-scale strength of the matrix.

The present work gives a detailed analysis of the consequences of plane elasticity assumptions on the study of failure initiation and propagation in single-fibre models under transverse loading. The present investigation uses cohesive damage to model interface damage and Phase-Field fracture to account for damage inside the polymer matrix. This work focuses on two main aspects, the influence of the out-of-plane thickness of the model and the differences between linear elasticity and pressure-dependent/independent plasticity models. It is found that if a 3D model is used there is a minimum required thickness in order to obtain representative results, these dimensions are controlled by the fibre diameter and interface properties mainly. On the other hand, it is found that linear elastic and plastic behaviour assumptions are affected in different proportions when the modelling approach moves from plane-stress to plane-strain-dominated conditions. In particular, pressure-dependent plasticity models combined with a plane-strain condition may result in unrealistic underestimations of the composite strength.

References

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