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Simulating the Non-Linear Response of Fiber-Reinforced Laminates Using a Combined Damage / Plasticity Model

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Summary

The present work is concerned with modeling the non-linear response of fiber reinforced polymer laminates. Recent experimental data suggests that non-linearity under matrix dominated loading is not only caused by matrix cracking but also by matrix plasticity due to high shear stresses. To capture the effects of both of these mechanisms, a ply-level model is developed that combines a plasticity formulation with continuum damage mechanics to simulate the non-linear response of laminates under plane stress states. The plasticity law is based on the assumption that plastic shear strains accumulate in shear bands parallel to the fiber orientation and at a certain angle to the laminate plane. The anisotropic elasticity tensor of a damaged ply is predicted by the continuum damage model using the Mori-Tanaka Method to capture the different degradation of elastic properties in the various directions. The interaction between laminate layers including load redistribution after partial failure of a ply is provided by Classical Lamination Theory which is extended to incorporate thermal, moisture, and plastic strains.

The model capabilities are evaluated in an extensive study where the predicted load response of various laminates is compared to experimental data from two test series by Varna *et al.* [Comp.Sci.Tech. **59**, pp. 2139–2147 and **61**, pp. 657–665]. Depending on the laminate lay-up, the uni-axial tension tests carried out in those two series lead to various ply stress ratios which makes the tests suitable for evaluating the model for a wide range of multi-axial stress states. Furthermore, the evolution of matrix cracks was monitored during the tests which provides a possibility to distinguish between non-linearity caused by cracking and plasticity, respectively. The comparison between experiments and model predictions shows that the qualitative effects of damage and plasticity on the change of axial modulus and laminate Poisson's ratio are captured accurately by the proposed model which supports the validity of the fundamental model assumptions. Quantitatively, the correlation between model and experiments is also very good except for some discrepancies in the damage onset load. To investigate possible influence factors on the predicted damage onset, the effects of residual curing stresses and increased in-situ strengths in thin plies is studied.

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