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INFLUENCE OF THE STACKING SEQUENCE ON THE NONLINEAR MATERIAL BEHAVIOR OF COMPOSITE LAMINATES RELATED TO LARGE DEFORMATIONS

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Summary: Several demands for design require the structural ability for large deformations. This motivates in particular the application of angle-ply laminates. These laminates show a matrix dominated constitutive behavior and thus, offer the ability to employ their ductile mechanical characteristics. Various concurrent mechanisms are responsible for the degree of nonlinearity: viscoplasticity, fiber rotation and damage processes.
Within the presented study special emphasis is placed on the investigation of damage processes in dependence on the stacking sequence. A test setup is defined to distinguish experimentally the nonlinear mechanisms and to separate the influence of damage accumulation on the stress-strain response. For a reliable evaluation, two influencing effects have to be eliminated.
As shown in [1], free edge effects could increase the threat of delamination failure and thus significantly reduce the feasible deformations. The conducted tests with wide specimens ensure that the width not affects the failure mode and a comparison of specimens with similar damage mechanisms is provided. Seven different angle-ply laminates of carbon/epoxy IM7-8552 material were tested under uniaxial tensile load. Tests with un-clustered plies [(+θ/-θ)_4]_s and with double clustered plies [(〖+θ〗 _2/ 〖-θ〗 _2)_2]_s were conducted for angles of θ=15°,30°,40°,45°,50°,60°,75°. Both, the constitutive behavior during loading and unloading cycles were investigated. Before re-loading, the tests were interrupted for a time period of about 500h. The relaxation is essential, to avoid a rate-dependent interaction on the re-loading response due to strain retardation in the material. In consideration of the actual fiber re-orientation and inelastic strain accumulation a determination of the stiffness reduction due to damage mechanisms can be provided. The validation for several angle-ply laminates is essential to incorporate damage progression in a modeling approach.
The evaluation of the results indicates that the nonlinear response of laminates barely influenced by damage mechanisms is independent of clustered plies in the stacking sequence. In contrast, especially for the [±45°] laminate, that exhibits significant intra-ply damage, the constitutive response is dependent on the clustering. For laminates with clustered plies the stiffness and the maximum achievable strain is more considerably reduced. The study identifies damage as the primary driver for a stacking sequence influence on the constitutive behavior of composite laminates. Accompanying micrographs at different axial strains additionally validate the damage state in the specimens.
The experimental results are evaluated for the development of a macromechanical model. For the numerical prediction of the smeared representation of the damage state it accounts for the dependence of the damage state on the nonlinear constitutive behavior.

References
[1] Wisnom, M.R., 1999. Review: Size Effects in the Testing of Fibre-composite Materials. Composite Science and Technology 59: 1937–1957.