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A phenomenologically based damage model for 2D and 3D-textile composites with non-crimp reinforcement

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ABSTRACT

The application of textile-reinforced composites for safety-relevant structural components requires reliable predictions about their damage and failure behaviour. The potential of these materials for engineering applications has not been fully exploited so far since practical design rules disallow the occurence of any damage in the material even if the damage is not critical. In this context, the paper presents a novel damage model for textile composites with quasi-unidirectional reinforcement. A failure criterion based on the failure mode concept is adopted to describe the quasi-brittle fracture behaviour. To take into account the subsequent non-linear stiffness degradation, this approach is combined with a continuum damage mechanics model. The capability of the damage model is shown for biaxially reinforced weft-knitted glass fibre–epoxy composites.

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1. Introduction

Conventional composite materials made of unidirectional and bidirectional plies have found a broad distribution in recent years especially in aerospace and automotive engineering. However, industrial demands on high-tech applications increasingly require the use of load-adapted materials with a high function integration. Traditional fibre–reinforced plastics (FRP) fulfill this requirement profile only on a small scale because they often meet their limits due to complex loading conditions, see [1]. In this context, novel textile-reinforced composites in combination with adapted manufacturing technologies provide promising alternatives [2]. Besides classical composites with woven reinforcement, composites reinforced with weft-knitted fabrics, non-crimp fabrics or tailored fibre placement (TFP) are counted among this new material group [1,3].

For an application of such textile-reinforced composites in safety-relevant components, it is of utmost importance to be able to supply information about their failure and damage behaviour. The resulting questions regarding the mechanical description of damage initiation and damage growth as well as the experimental identification of the damage process have been insufficiently investigated so far so that only rare industrial application examples exist.

The *World-wide Failure Exercise* (WWFE) [5–7] has shown that for a realistic description of the failure behaviour of FRP, the failure criterion by Cuntze [8–10] which is based on the failure mode concept, shows very good results for the proposed test cases. It has been proven that this physically based failure criterion could be applied also for textile-reinforced composites if some certain modifications are made [11–14]. This approach is picked up and enhanced in this paper. Other authors use the failure criterion of [15] to determine failure in 3D-reinforced composites, see [16,17]. These approaches are based on extensive computational effort.

The paper of Matzenmiller et al. [18] is of vital importance for the description of anisotropic stiffness degradation in FRP because physically based failure criteria have been combined with a continuum damage mechanics model for orthotropic plies there. This methodology is utilised here and will be extended with the objective of using it for textile-reinforced composites. Of course, it is conceivable that other continuum damage mechanics models can also be applied to textile-reinforced composites, too. The damage models developed by the group of Ladevèze [19–21] and Allix [22] should be mentioned as representatives for the multitude of existing damage models. However, the so-called mesomodel is based on a high computational effort, too.

Within the framework of this paper, a novel phenomenological damage model is presented which allows a degradation analysis of 2D and 3D textile-reinforced composites with non-crimp reinforcement. The primary objective of the degradation model is a fast material-specific prediction of the complex damage mechanisms and their influence on the mechanical properties dependent on matrix type, fibre class and fibre architecture. The proposed degradation model is based on fracture mode related failure criteria and a continuum damage mechanics model.

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