Modelling 3D-woven composites on the macroscale: Predicting damage initiation and inelastic phenomena

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Licentiate thesis, 2020

Composites with 3D-woven reinforcement have been slowly making their way into different industries. The interlacement of yarns, not only in-plane but also through-thickness, means that in many applications 3D-woven composites can outperform their laminated counterparts. In particular, this includes increased out-of-plane stiffness and strength, damage tolerance and specific energy absorption capabilities. The widespread adoption of 3D-woven composites in industry however, requires the development of efficient computational models that can capture the material behaviour.

The current work takes a few steps towards the long term goal of developing a phenomenologically based macroscale model to predict how 3D-woven composites deform and eventually fail under mechanical loading. Following a brief introduction to the research field, the feasibility of extending stress-based failure initiation criteria for unidirectional laminated composites, to 3D-woven composites is explored. In particular it is shown that the extension of the LaRC05 criteria presents a number of challenges and leads to inaccurate predictions. Instead strain-based failure criteria inspired by LaRC05 are proposed. They produce results that are qualitatively more reasonable when evaluated numerically for tensile, compressive and shear tests.

As a next step, a thermodynamically consistent framework for modelling the mechanical response of 3D-woven composites on the macroscale is presented. The proposed framework decomposes the stress and strain tensors into two main parts motivated by the material architecture. This allows for the convenient separation of the modelling of the shear behaviour from the modelling of the behaviour along the reinforcement directions. In particular, this division allows for the straightforward addition and modification of various inelastic phenomena observed in 3D-woven composites.

The framework is then used to simulate experimental results of a 3D glass fibre reinforced epoxy composite. A viscoelastic model is incorporated into the framework to capture non-linear behaviour associated with tensile loading along the horizontal weft reinforcement as well as non-linear shear behaviour. In detail, to capture the shear behaviour, a crystal plasticity inspired approach is considered. As such, it is assumed that inelastic strain strictly develops on localised slip planes oriented by the reinforcement architecture. The viscous parameters are calibrated against experimental results, and a preliminary validation of the model is performed for an off-axis tension test.