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Analysis of the Through-Thickness Material and Failure Behaviour of Textile Composites

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ABSTRACT

Generally it is well known that the performance of fibre reinforced composite structures is mainly dependent on the in-plane material behaviour. Non Crimp Fabric (NCF) composites provide the potential to increase the out-of-plane material performance by introducing full through thickness reinforcements. Especially the delamination resistance can be increased by stitching or tufting.

Appropriate standardised tests are available that determine the in-plane behaviour of composites. Furthermore over the years numerous experimental tests have been developed to characterise the out-of-plane laminate properties [2]. Most of these tests are relative simple and generate inter-ply shear failure using four point bending of relative short thick specimens, the Iosipescu, or double notched shear test (figure 1, a, b, c). Generally these tests are used to provide shear properties. Through-thickness tension and compression material properties are mainly determined by waisted block specimens or tensile opening of curved laminates (figure 1, d, e). This test does apparently produce a poorly defined tensile stress distribution. Therefore these tests are basically unreliable for accurate failure data due to non-uniform stress distributions.

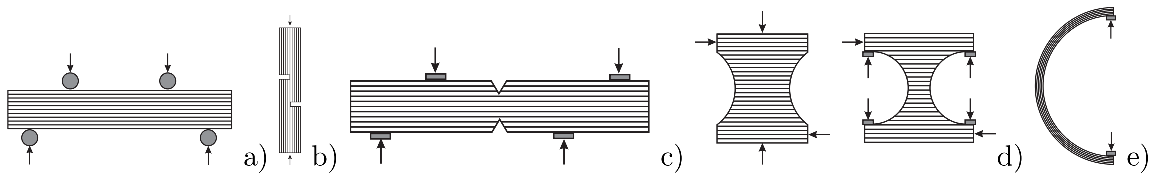

Figure 1: Out-of-plane tests: a) four point bending, b) double notch, c) Iosipescu, d) waisted block, e) C-specimen.

In order to obtain a more reliable through-thickness failure data a new test using waisted block specimens is presented. A promising through-thickness test for pure normal (tension, compression), pure shear and mixed mode (tension-compression-shear) loading is the Arcan test [1]. A modified Arcan test device was developed with a waisted block specimen to analyse

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the through-thickness failure behaviour of textile laminates (figure 2, b). The test is relatively simple and involves two halves of a disc which can be rotated and loaded in different directions to impose the required load conditions. Generally this test provides both the potential to determine the pure out-of-plane material failure properties and the failure behaviour under combined in- and out-of-plane load conditions.

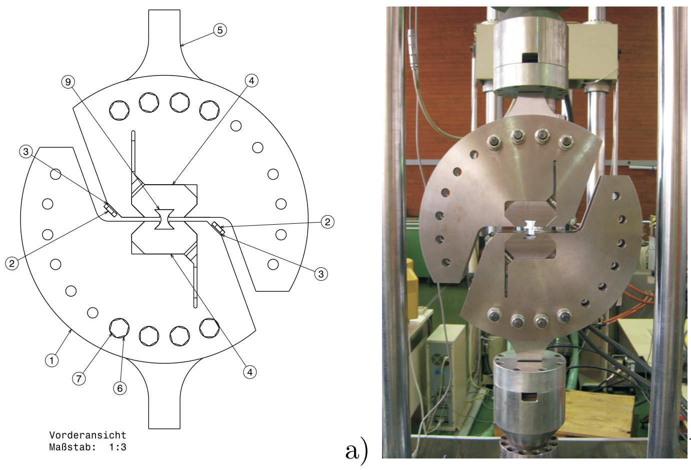

Figure 2: Modified Arcan test device.

The specimen (figure 2, a, position 2) is mounted in an inset (figure 2, a, position 4) in the centre of the rig, which facilitates the installation of different specimen geometries. The geometry is restricted by the ability to produce three dimensional reinforcements in NCF laminates. These reinforcements can only be applied to a moderate plate thickness of approximately 30 mm by tufting or stitching. This restricted plate thickness of tufted materials is a challenging problem to design feasible specimen geometries. Therefore for each load case different geometries were analysed by FEA and optimised in order to ensure a most possible homogenous stress distribution.

The experimentally determined through-thickness material properties and parameters serve as a basis for a material model to describe the deformation and failure behaviour of three-dimensional reinforced laminates. Numerical simulations of the conducted experiments and structural analyses of a thick double holed plate demonstrate the applicability of the material model and its implementation in an appropriate finite element discretisation. For these purposes finite volume p-elements based on hierarchical shape functions providing anisotropic ansatz spaces are being developed. Due to control the spatial adaptivity of polynomial order of the shape functions a posteriori error estimation is evaluated.

References

[1] M. Arcan and Z. Hashin and A. Voloshin, *A Method to Produce Uniform Plane-stress States with Applications to Fiber-reinforced Materials.* Experimental Mechanics, 18, 141 – 146, 1977.

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