Stiffness degradation in Non-Crimp fabric composite in tension due to damage

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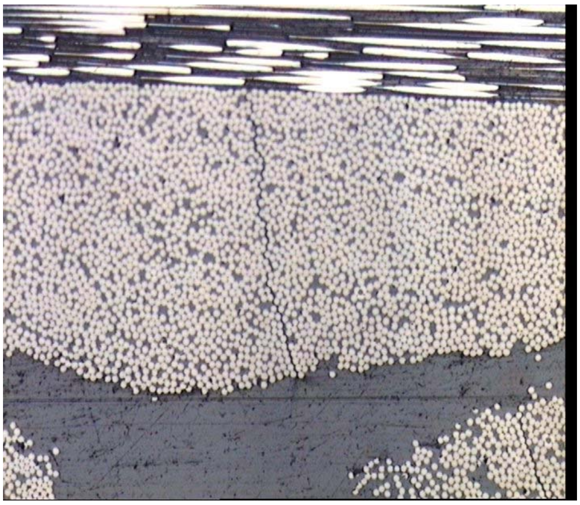
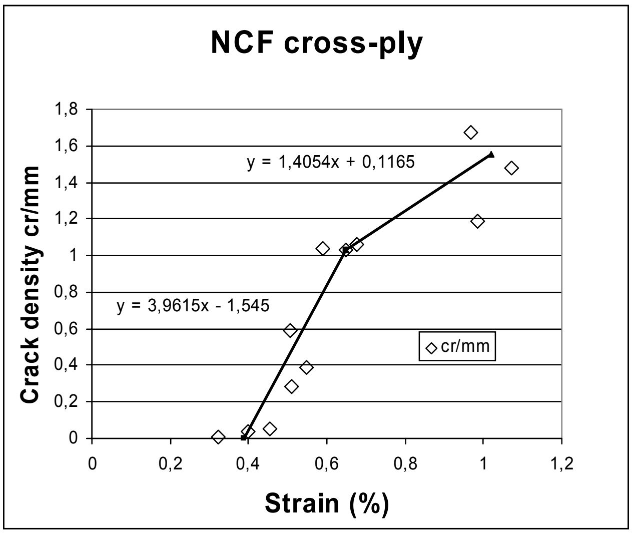
Non Crimp Fabric (NCF) composites, manufactured by resin infusion techniques, are one of the most promising materials for aerospace and marine applications. Due to non-crimp nature of reinforcement they have excellent mechanical performance similar to prepreg tape laminates and relatively low production costs. The fabric blankets contain several layers with a bundle meso-structure stitched together during the manufacturing of the fabric. Stitches, that make the composite plate inherently more damage tolerant with respect to out-of-plane loads, lead to significantly more complex laminate meso-structure where the gauge length and stitch density affect the shape of the bundles, the fiber volume fraction inside the bundle and the gaps.
Before NCF can be used in a more extensive way, detailed understanding of governing micro mechanisms and their effect on mechanical performance must be accumulated and described by predictive models.
The objective of this paper is using experimental and theoretical methods to study response of NCF composite cross-ply plates to in-plane tensile loading. Under these conditions damage develops in the laminate: intra-bundle or intra-layer cracks running parallel to the fibers, see Fig.1a; delamination between bundles of different orientation etc. All described types of damage develop with load and lead to macroscopically inelastic response of the NCF composite. Evolution of the microdamage expressed in terms of density of different types of damage entities versus strain level applied to the plate is described using optical microscopy on damaged specimens, see Fig.1b.



a)



b)

Figure 1 a) a micrograph of an intrabundle crack; b) crack density versus strain curve.

Degradation in mechanical properties caused by intralaminar cracks in bundles with 90º orientation has been monitored and quantified. Several existing models are adapted to predict the stiffness changes due to damage. They main approach there is to replace the layer which has a bundle structure with homogenized layer with the same average fiber content and to apply the best models developed for prepreg laminate case. This approach leads to rather accurate predictions of the damage effect on stiffness if the gaps between bundles are small, see Fig.2. Theoretical analysis of the damage effect on NCF composite stiffness is performed using approach developed for laminates in [1]. The influence of the damage entity on the stiffness reduction is through the displacements (crack opening displacement and sliding) of the crack surfaces. The dependence of average crack surface displacement (normalized with respect to load and crack size) on the laminate meso-architecture and the constraint of surrounding fiber bundles are studied using FEM.

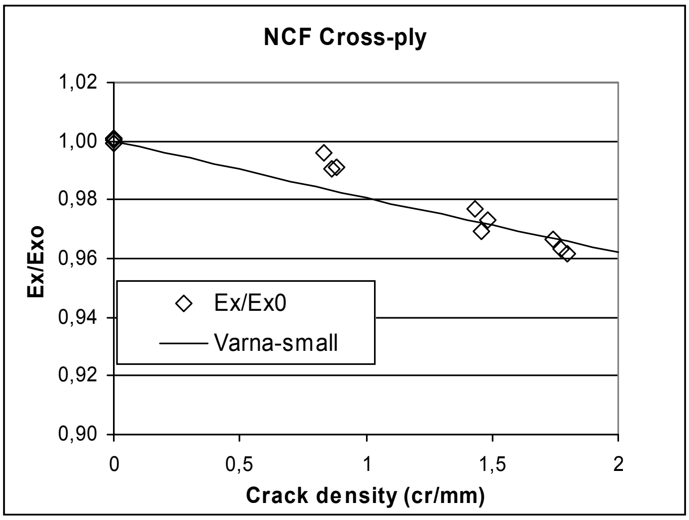


Figure 2 Predicted and experimentally measured elastic modulus reduction in NCF cross-ply plate due to cracks in bundles.

It has been shown that the average surface displacement is a rather robust parameter and simple semi-empirical law may describe the dependence on the above factors.

Damage evolution model, accounting for the non-homogeneous strain state due to the bundle structure of the layer and including the statistical nature of strength distribution has been developed and used in simulations. The variation of the average bundle strain due to constraint of surrounding materials and bundle geometrical parameters is studied using FEM. Geometrical imperfections like bundle waviness are also considered.

References

1. J.Varna, "*Effective properties of damaged laminates reinforced with continuous UD fibers*", Proceedings of ECCM-10, Brugge, 2002, 7 p.