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COMPRESSIVE STRENGTH OF FIBER COMPOSITE WITH POROSITY

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Summary The compression strength of fiber composites is analysed using a finite element model which includes finite strain plasticity. A separate discretization of fiber and matrix is performed using plane strain elements. The sensitivity of the compression strength to the geometric imperfection parameters given by fiber misalignment and kink band angle is investigated. Porosities are included in the model as material imperfections and it is shown that they only have a limited effect on the compressive strength of the composite.

INTRODUCTION

It has been a well known fact for many years that the compressive strength of fiber composites is significantly less than the tensile strength. An explanation for this difference is that a fiber composite in tension normally fails by fiber fracture while compressive stresses can lead to a number of different failure mechanisms. The dominating failure mechanism in polymer matrix fiber composites in compression is failure by fiber kinking [1].
It has been observed that in most fiber composites there are small volumes of air included in the matrix. During manufacturing the amount of porosities is being minimized but it is difficult to totally avoid the presence of them. The influence of these porosities on the compression strength has not been investigated in the litterature.

ANALYSIS

In this work the compression strength of fiber composites is analysed using a finite element model. The composite is modeled with a separate discretization of fiber and matrix using plane strain elements. The fiber material is carbon and the fibers are assumed to be linearly elastic. A polymer material named PEEK is used as matrix and its nonlinear behavior is modeled with a finite strain version of J_2 flow theory as made for shear bands in [2]. The reason for using the finite strain version is the large shear strains in the region around the kink band.
To initiate the development of a kink band an imperfection given by a cosine function is made as a band transverse to the fibers. The boundary conditions are shown in figure 1 where the grey areas are fibers. The initial fiber misalignment angle ϕ_0 can be approximated by $\phi_0 \approx h/L_{kb}$ and the kink band angle is given by β. The width of the specimen is determined by fiber width, fiber volume fraction and number of fibers. To apply the compressive load the end displacement U is prescribed.

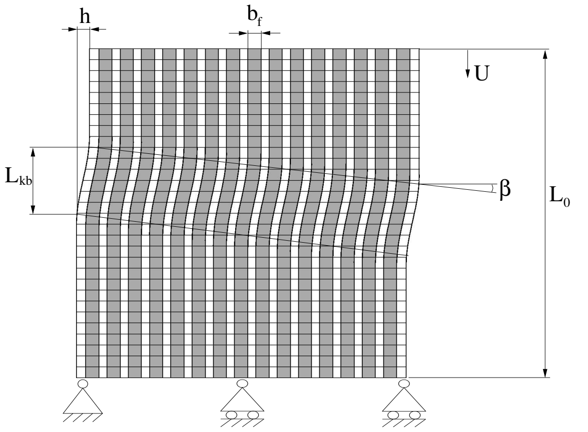

Figure 1: Specimen with 15 fibers showing the boundary conditions and the geometric imperfection.

RESULTS

The sensitivity of the compression strength to the imperfection parameters given by fiber misalignment and kink band angle has been investigated. It has been found that the fiber misalignment angle has a great influence on the compression strength. Furthermore, it was observed that the critical kink band angle changes with fiber misalignment angle, as was also observed by Jensen and Christoffersen [3].

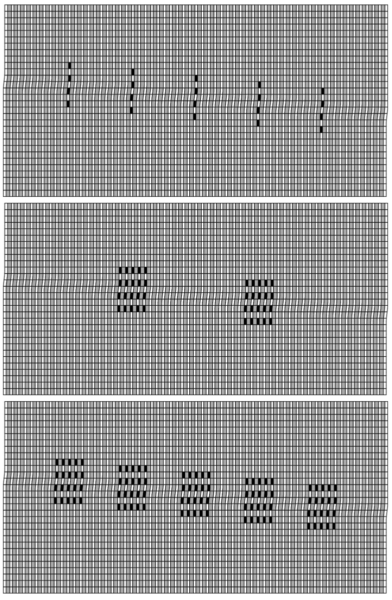

Figure 2: 3 specimens with porosities. From top an d down refered to as 5x1, 2x5 and 5x5.

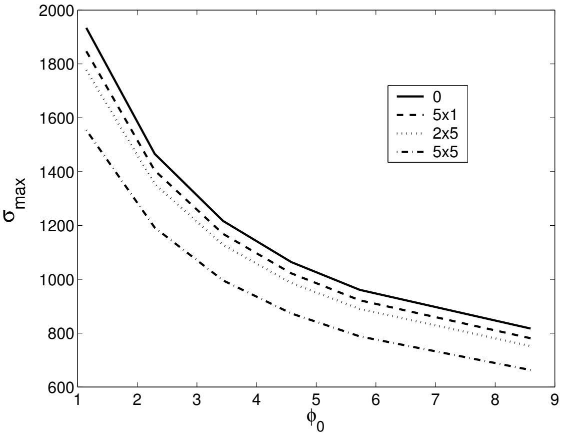

Figure 3: The compressive strength in MPa as a function of the initial fiber misalignment angle.

The behavior of the kink band in the post peak region has also been investigated. After the limit load was reached the average axial stress decreased toward a constant value. During the steady state loading the misalignment angle only changed sligthly and a band broadening was observed. The method used here is somewhat similar to the work of Kyriakides et al. [4] and the results in the absence of porosity show the same tendency.

The main focus here is to investigate how air inclusions in the composite influence the compressive strength. In figure 2 black areas indicate how the porosities are included in the model of a specimen consisting of 60 fibers. As shown, the porosities are placed around the imperfection band in either a single band or in small clusters in the matrix.

The compressive strength is plotted as a function of the initial fiber misalignment angle in figure 3. The solid line represents a specimen without porosities. It is seen that the introduction of porosities reduces the compressive strength as expected. Introducing five single bands of porosities, named 5x1 in figure 3, reduces the compressive strength by 3-5% while the specimen with 2 clusters, named 2x5, reduces the compressive strength by 6-8%. When implementing five clusters in the model, named 5x5, a significantly reduction of 15-20% is seen in the compressive strength. However this high concentration of porosities is not very realistic for fiber composites manufactured with modern manufacturing facilities. Hence the numerical analysis indicates that a limited amount of porosities only has a small influence on the compressive strength of the composites. In addition it is seen from figure 3 that the amount of porosities only has a minor effect on the sensitivity of the compression strength to the misalignment angle.

CONCLUSIONS

The analyses performed show that the fiber misalignment angle has a dominant influence on the compressive strength of the composite and that the critical kink band angle is depending on the initial fiber misalignment angle, as also found in [3] and [4].

The investigation of the influence of porosities on the compressive strength shows a reduction of the compressive strength by up to 15-20% for the porosities considered. Realistic levels of porosity are expected to be smaller.

References

[1] Fleck N.A.: Compressive Failure of Fiber Composites. *Advances in Applied Mechanics* **33**: 43-117, 1996

[2] Hutchinson J.W., Tvergaard V.: Shear Band Formation in Plane Strain. *Int. J. Solids Structures* **17**:451-470, 1981

[3] Jensen H.M., Christoffersen J.: Kink Band Formation in Fiber Reinforced Materials. *J. Mech. Phys. Solids* **45**:1121-1136, 1997

[4] Kyriakides S., Arseculeratne R., Perry E.J., Liechti K.M.: On the Compressive Failure of Fiber Reinforced Composites. *Int. J. Solids Structures* **32**:689-738, 1995.