THE INFLUENCE OF STEEL FIBER PLASTICITY ON KINK-BAND FORMATION

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Summary In the search for a replacement of glass fibres in structural composite components, the compression of steel fibre reinforced polyester is investigated. Both numerical predictions using a smeared out non-linear composite material law and experimental measurements based on a novel compression fixture has been performed. The interaction of the overall global buckling and the local kink-band formation for a square block of material loaded in compression is investigated. The plasticity of the steel fibres was found not to play an important role on the kink-band formation even though it has a significant influence on the overall structural plastic buckling. On the other hand, the plasticity of the matrix material and the fibre misalignment is important for kink-band formations.

INTRODUCTION

The capability of using steel fibres in continuous fibre reinforced polymers under compressive loading is investigated. The stiffness properties of steel fibres lay between the stiffness of glass fibres and carbon fibres, while the strength is of the same order of magnitude for the three fibre types. The relevant failure mode in compression is buckling driven delaminations, kink-band formation or overall structural buckling. Uni-directional carbon fibre composites is known to fail at a load as low as 50-60% of the tensile load carrying capacity where the compression strength highly depended on the fibre misalignment and the plastic deformation of the matrix material. For steel fibre composite, also the fibre plasticity may play an important role. Taken into account the weak elastic non-linearity of carbon fibres, only a negligible influence on the kink-band formation has been observed [1,2]. Nevertheless, the non-linearity of the steel fibres is much more pronounced and general structural buckling is known to depend largely on material non-linearity where the buckling load depends on the instantaneous tangent stiffness of the material. In addition, the non-linearity of the steel fibre material is possible to tailor by controlling the draw ratio of the fibres. In the present study, steel fibres with a draw ratio in the range of 95-97% area reduction resulting in a tensile strength on 2.6-3.0GPa, has been studied. The corresponding tensile yield strength was found in the range of 1.9-2.3GPa with a hardening exponent on $n_f = 7$. The Young modulus and the Poisson's ration was found to 210GPa and 0.3, respectively.
The steel fibre has been used to reinforce a polyester matrix with a fibre volume fraction in the range of 40-45%. By testing the resulting composite in compression, it is possible to extract the compression properties of the fibre material from the pre-failure part of the compression curve. The compression test has been performed using a novel test fixture [3]. With compression yield strength was found in the range of 1.0-1.2GPa with a hardening exponent on $n_f = 2$. Therefore, the fibre material show significant different behaviour in compression compared with tension. Together with the measured tensile properties for the polyester, the compression failure of the test coupons was predicted using a smeared out non-linear composite material law [4,5] implemented as a user defined material model [6,7] in the commercial finite element model Abaqus. The prediction is compared with the actual measured compression strength where the fibre misalignment of the fibres was taken into account. Based on this, the interaction between the overall structural buckling and the kink-band formation in the composite material was predicted

PREDICTIONS

In the numerical model, a block of material with a width to length ratio H/L=3/10 was analysed. In order to initiate the kink-band formation, a small fibre misalignment angle has been introduced in the centre of the composite block, see e.g. [8]. For a polyester matrix with a yield strength on 35MPa and a hardening exponent on $n_m = 5$, where the fibre misalignment angle was $\phi = 5^\circ$, a vanishing influence of the fibre material yield strength on the load carrying capacity in compression is observed. This is the case even for fibre materials with very low yield strengths. In figure 1, the normalised compressive load versus shortening curve is shown for two cases $\sigma_{y,f} = 100\text{MPa}$ and $\sigma_{y,f} = 700\text{MPa}$. The initial yield point for the fibre and the matrix material is indicated with a star and a square mark on the curve, respectively. The low fibre yield stress is found to result in a composite which in the uploading part will respond with a softer material behaviour resulting in a higher degree of shortening before failure. In addition, the lower stiffness will give possibilities for overall structural buckling depending on the geometry of the structural component. In both cases, the kink-band will first form after the matrix material is yielding resulting in a load carrying capacity which are rather independent on the fibre non-linearity. Suppressing the matrix yielding completely will prevent the material to kink and therefore force the block of material to fail in an plastic Euler buckling mode. In figure 2, the transition from the Euler buckling mode for a hardening exponent of the matrix material near 1.0, to a kink-band formation in the case of a little higher hardening exponent. Note that $n_m = 1$ correspond to a purely elastic material response. In figure 2, the deformed mesh for the two cases $n_m = 1$ and $n_m = 5$ is shown together with graphs of the normalized transverse deflection for cases in the range $n_m \in [1.0;5.0]$.

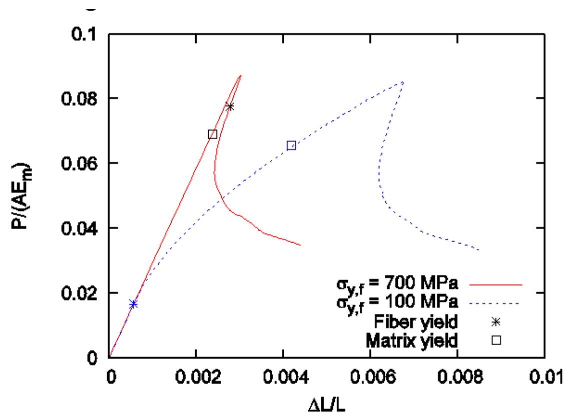

Figure 1 Load versus shortening curve for a block of material under compression, see [8]

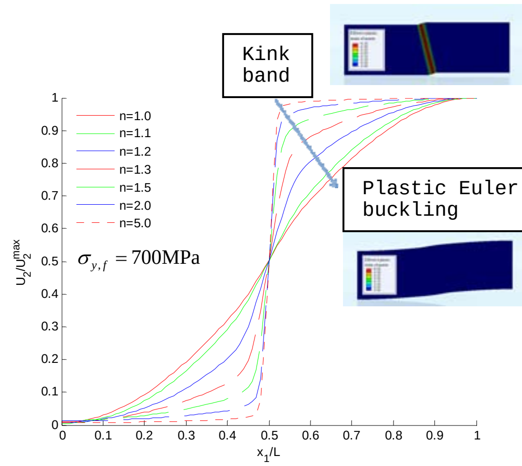

Figure 2 Kink-band to plastic Euler buckling transition

COMPARISON AND CONCLUSIONS

The predictions have been compared with experimental measurement and the predictions have been found in the range of the scatter of the measurements. In the comparison, the fibre misalignment has been measured using the Fourier Transform Misalignment Analysis [9] based on surface digital photographs of the steel laminates. The smeared-out non-linear composite law is found to capture the kink-band formation whereby it is possible to e.g. investigate the kink-band versus buckling interaction. Predictions, which otherwise would require a full micromechanical model of the fiber/matrix material system.

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