Characterization of short glass-fibre reinforced polypropylene composites in tension and compression

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1 Introduction
Glass-fibre reinforced polypropylene (PP-GF) composites have been widely used in technical applications, particularly in the automotive and sports industry [1]. To explore their full mechanical potential (lightweight design), in-depth knowledge of the structure-property correlation is essential. Furthermore, understanding of the experimental behaviour facilitates the development of appropriate material models for numerical component design. Due to the anisotropic behaviour of PP-GF composites, knowledge of the orientation distribution of fibres (FOD) is the key to correlate the experimental findings to the microstructure. Since bending, biaxial impact or multiaxial loading are typical load situations for engineering structures, measuring only uniaxial tension is not appropriate. In contrast to unidirectional laminates (continuous fibres), only limited data is available for PP-GF composites to fully describe the strength surface as a function of FOD and to choose a suitable strength criterion. For this reason, in this research work the behaviour in uniaxial tension and compression was investigated for a series of specimens with different fibre orientations. A computed tomography device was utilized to determine FOD for all specimens characterized. Furthermore, bending tests for selected microstructures were conducted and compared to the tensile and compressive tests.

2 Materials and Methods
The commercial grade GD301FE from Borealis with a fibre content of 32 w% was investigated. Multipurpose specimens (MPS) according to ISO 3167-1A and plates (size A5) were injection moulded, see Fig. 1. Both geometries have a thickness of 4 mm. From the plate, small tension and compression specimens were machined at different positions as indicated in Fig. 1. To correlate the mechanical results to the microstructure, FOD of all samples were measured via computed tomography (CT) using the Nanotom device (GE Phoenix x-ray, Germany) [2]. As to the MPS, tensile, flexural and compressive tests were conducted as a function of strain rate (0.0001 s⁻¹ - 0.01 s⁻¹) at 23°C. Tensile and compressive tests were carried out on the small specimens from the plate at the same strain rate range, accordingly. To increase the test accuracy and to allow for a detailed analysis of Poisson’s ratio and volume strain as damage indicator, a 3D Digital Image Correlation system was utilized [3]. This also enables to correlate the material behaviour in 3-point bending to tension and compression.

3 Selected Results and Conclusions
Based on the CT result where every single fibre in the measurement volume was recorded, accurate calculation of FOD as a position-resolved value was carried out. At two different positions of the plate, FOD in the injection direction is depicted in Fig. 2. While at the edge a high degree of fibre orientation can be found with typical values above 0.6, a distinct layered microstructure was observed at the plate centre with high degree of orientation at the skin and perpendicular fibre arrangement at the core. Remarkably, the determined degree of orientation varies between 0.1 and 0.9.

The macroscopic mechanical behaviour in tension and compression of these specimens is depicted in Fig. 3 for a strain rate of 0.001 s⁻¹. Firstly, specimens cut out from the edge exhibited significantly larger stresses than the one from the plate centre, which is
in agreement with the microstructural observations. Secondly, the maximum compressive stresses exceeded the maximum tensile stresses, clearly showing the effect of mean pressure on the stress-strain response. Interesting to note, not only the stresses but also the strain values at failure are higher in compression than in tension. This can be attributed to different micro-mechanisms of deformation; void initiation and growth at the fibre tip, fibre pull-out and breakage in tension and mainly interfibre shear failure in compression.

Similar to the extensive testing procedure for unidirectional laminates where compressive and tensile tests are conducted as a function of laminate (fibre) orientation to select the best failure criterion, the ratio between the maximum stresses in compression and tension was calculated and compared with the corresponding microstructural state, i.e., the average fibre orientation. As can be seen from Fig. 4, the dependence of the material on mean pressure decreases with increasing fibre orientation. A value of 1.2 was found for highly orientated samples, while doubling of the maximum stress in compression was found for low orientated samples. For the neat matrix a value of 1.4 was determined. This result shows that based on the assumption of a constant compression/tension ratio irrespective of the microstructure, a thorough selection of the failure criterion may not be possible and may cause misleading result interpretations.

4 References

