3D-characterization of carbon fibre reinforced polymers by Talbot-Lau grating interferometry computed tomography

Johann Kastner[1], Sascha Senck[2], Jonathan Glinz[2]

[1]CT-group, University of Sciences Upper Austria, Austria, [1]CT-group, University of Applied Sciences Upper Austria, Austria

Carbon fibre reinforced polymers (CFRPs) are in high demand in a number of manufacturing industries such as automotive and aeronautic industry, since they provide high strength, durability, and elasticity in combination with lightweight. However, 3D-characterization of CFRP by X-ray radioscopy and X-ray computed tomography (XCT) can be a challenging task because of the limited contrast between the carbon fibres and the polymeric matrix. Conventional absorption-based contrast provides information on the attenuation of the X-ray beam intensity. In the last decade however an important innovation in X-ray technology has emerged by the introduction of Talbot-Lau grating interferometry [1]. This method provides three complementary characteristics in a single scan of the specimen: a) the attenuation contrast (AC), b) the differential phase contrast (DPC), and c) the dark-field contrast (DFC). DPC is related to the index of refraction and DFC reflects the total amount of radiation scattered at small angles, e.g. caused by microscopic inhomogeneities represented by cracks and pores [2]. Within this paper we demonstrate the usefulness of Talbot-Lau grating interferometry XCT (Talbot-Lau XCT; Skyscan 1294) for the 3D-characterization of different CFRP-materials and parts. The applications presented are: • 3D-structure of short carbon fibre reinforced polymers • 3D-Structure of carbon fibre reinforced laminates including flat and more complex parts • 3D-structure of 3D-printed carbon fibre reinforced polymers • 3D-structure of CFRP-laminate with copper mesh • Damage in carbon fibre reinforced polymers TLGI-XCT is very useful in several respects for materials characterisation of CFRP samples providing additional and complementary microstructural information. The applications presented demonstrate that TLGI-XCT is beneficial in the following respects: • Since the X-ray absorption coefficients of matrix and carbon fibres in CFRP are similar AC contrast gives a very limited information. Here, DFC and DPC provide additional information concerning fibre bundle orientation and the extent of resin-rich areas in the specimen. The delineation of resin-rich areas in CFRP specimens can be significantly improved by TLGI phase-contrast imaging. The simultaneous detection of fibre orientation, resin reach areas, and cracks in carbon fibre reinforced laminates by combination of AC, DPC, and DFC is possible. • Based on DFC data, it is possible to identify the orientation of carbon fibres and of carbon fibre yarns, the general lay-up of FRP-samples can be characterized. For laminates the weave pattern, the size of the fibre bundles and the resin content can be analysed nicely. No segmentation algorithm for identifying individual fibre bundle orientation is required. The fusion of the two scatter dark field CT-scans with different sample orientation is sufficient. • The characterization of a multi-material system (metal and polymer) by DPC XCT leads to less artefacts in comparison to conventional attenuation based XCT. • Dark-field imaging is more sensitive in the detection and identification of micro cracks and damage in CFRP samples compared to conventional XCT. The most prominent advantage of TLGI-XCT is the ability to three-dimensionally visualize and quantify the distribution of micro cracks. [1.] F. Pfeiffer, T. Weitkamp, O. Bunk, C. David, Phase retrieval and differential phase-contrast imaging with low-brilliance X-ray sources, Nature Physics, Vol 2, page 258 (2006). [2.] Bech, M., Bunk, O., Donath, T., Feidenhans'l, R., David, C., Pfeiffer, F.: Quantitative x-ray dark-field computed tomography. Phys. Med. Biol. 55, 5529–5539 (2010). [3.] Kastner, J; Gusenbauer, C; Plank, B; Glinz, J; Senck, S., Challenges for Grating Interferometer X-ray Computed Tomography for Practical Applications In Industry, Insight - Non-Destructive Testing and Condition Monitoring, Vol 61, 149-152 (2019) [4.] Senck, S., Scheerer, M., Revol, V., Plank, P., Hannesschläger, C., Gusenbauer, C., Kastner, J., Microcrack characterization in loaded CFRP laminates using quantitative two- and three-dimensional X-ray dark-field imaging, Composites Part A 115, 206–214 (2018)