Fast Detection of Local Fiber Shifts by X-Ray Scattering

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Abstract : Glass fabric reinforced thermoplastic (GFRT) are composite materials, which combine low weight and resilient mechanical properties rendering them especially suitable for automobile construction. However, defects in the glass fabric as well as in the polymer matrix can occur during manufacturing, which may compromise component lifetime or even safety. One type of these defects is local fiber shifts, which can be difficult to detect. Recently, we have experimentally demonstrated the reliable detection of local fiber shifts by X-ray scattering based on the edge-illumination (EI) principle. EI constitutes a novel X-ray imaging technique that utilizes two slit masks, one in front of the sample and one in front of the detector, in order to simultaneously provide absorption, phase, and scattering contrast. The principle of contrast formation is as follows. The incident X-ray beam is split into smaller beamlets by the sample mask, resulting in small beamlets. These are distorted by the interaction with the sample, and the distortions are scaled up by the detector masks, rendering them visible to a pixelated detector. In the experiment, the sample mask is laterally scanned, resulting in Gaussian-like intensity distributions in each pixel. The area under the curves represents absorption, the peak offset refraction, and the width of the curve represents the scattering occurring in the sample. Here, scattering is caused by the numerous glass fiber/polymer matrix interfaces. In our recent publication, we have shown that the standard deviation of the absorption and scattering values over a selected field of view can be used to distinguish between intact samples and samples with local fiber shift defects. The quantification of defect detection performance was done by using p-values ($p=0.002$ for absorption and $p=0.009$ for scattering) and contrast-to-noise ratios ($CNR=3.0$ for absorption and $CNR=2.1$ for scattering) between the two groups of samples. This was further improved for the scattering contrast to $p=0.0004$ and $CNR=4.2$ by utilizing a harmonic decomposition analysis of the images. Thus, we concluded that local fiber shifts can be reliably detected by the X-ray scattering contrasts provided by EI. However, a potential application in, for example, production monitoring requires fast data acquisition times. For the results above, the scanning of the sample masks was performed over 50 individual steps, which resulted in long total scan times. In this paper, we will demonstrate that reliable detection of local fiber shift defects is also possible by using single images, which implies a speed up of total scan time by a factor of 50. Additional performance improvements will also be discussed, which opens the possibility for real-time acquisition. This contributes a vital step for the translation of EI to industrial applications for a wide variety of materials consisting of numerous interfaces on the micrometer scale.

Keywords : defects in composites, X-ray scattering, local fiber shifts, X-ray edge Illumination
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