CT applied as a reference technique for evaluating active lock-in thermography in characterizing CFRP impact damage test samples

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Abstract
Detection of impact damages in CFRP test samples with active lock-in thermography is fast and non-tactile, but does not easily reveal the 3D geometry. Computed tomography is a holistic technique capable of characterizing most of the occurring impact damages in CFRP samples, but due to measuring envelope limitation and time-consuming data capturing it is inappropriate for mass production. Recent developments have made possible quantifying 3D impact damage geometry properties through thermography. This paper focuses on CT setting optimization for imaging CFRP test samples with induced impact damage and on using CT outcomes to validate thermography-based data.

Keywords: computed tomography, composite materials, thermography, impact damage detection

1 Introduction
The economic feasibility of carbon fibre reinforced plastics (CFRP) products must be assured throughout the whole product life cycle. In particular, a long term operational reliability and economic repair processes must be assured. The established concepts from aircraft and aerospace industry, where in general damaged parts are replaced, are not applicable for mass production of e.g. automobiles, since the effort and the amount of required resources are not economically feasible and ecologically justifiable.

Impact damages are the most likely damages that occur in automobiles. In particular, impacts of small objects, such as stones or hail can cause severe damages that sometimes are optically invisible, but need to be repaired to assure the safety of the automobile. The non-destructive detection of those invisible damages is a challenge. Therefore, non-destructive, reliable, efficient and automated measurement technology is required to fit the component (e.g. material, part size) and repair work shop specific requirements (e.g. portability, price).

One promising approach is the active lock-in thermography. Thermography systems are portable, safe, easy to use, and cover large components in a single image. The active thermography technique is non-tactile, reliable and capable to detect impact damages with their respective failure characteristics e.g. delaminations, debondings, air locks, porosity and fibre fracture [1].

The disadvantage of thermography is that it does not easily reveal the 3D defect geometry. Efforts have been made to address this matter by other authors [1-3] and also under the Brazilian-German Collaborative Research Initiative on Manufacturing Technology (BRAGECRIM) research project, which supports this work.

Computed Tomography (CT) has been identified in this research project as the proper technique for validating thermography as an alternative method for characterizing quantitatively impact damages in CFRP test samples. The focus of this paper remains in the CT setting optimization for imaging CFRP test samples and in contrasting thermography and CT measurement results.

2 Experimental background
CT is a holistic method capable of detecting most of the occurring impact damages in CFRP samples. The main outcome of a CT imaging process is a 3D voxel matrix that represents the local distribution of the reconstructed absorption coefficient in form of small gray scale coded cubes, which are arranged in a 3D grid. The voxel matrix is the base for all subsequent analyses, which enables CT to gain information about the defect and its exact position on the test sample. However, the measuring envelope of industrial CT systems is not sufficient and the data capturing is very time consuming, making it inappropriate for automotive mass production.

CT is therefore the right (reference) technique for validating 3D impact damage geometry properties obtained from a stack of active lock-in thermography images. The excitation frequency dependent analysis of phase images enables a 3D illustration of internal damages. In order to determine the setting parameters calibrated blind bore holes are used as reference geometry. The procedure is adopted and adjusted for impacted samples.
Test samples have been manufactured for parameter setting such as the CFRP sample shown in figure 1 using 10 layers of Hexply M49/600T2x2 with five blind holes for each diameter (5 mm, 8 mm, 12 mm, 15 mm) and four blind holes with 20 mm diameter. The wall thickness to the top surface is 0.5 mm, 1 mm, 1.5 mm and 2 mm for the 20 mm. The test sample is designed to investigate the resolution of the defect area in determined depth layers.

Experiments have been performed on a METROTOM 1500 CT system manufactured by Carl Zeiss, which is equipped with a 225 kV micro-focus tube with directional target and a 2048 pixel by 2048 pixel detector. Considering also the source-detector distance, the CT system is able to measure CFRP samples that fit to a virtual cylinder of (Ø300 x 350) mm. The cone beam CT system can reach focal spot sizes below 5 µm and detail recognition below 3 µm. CT projections have been reconstructed by a filtered-back projection Feldkamp algorithm and the reconstructed volume, processed and visualised with the commercial software VGStudio MAX 2.2. For active lock-in thermography, the Edevis OTVis 5000 system has been used, which is equipped with two 2.5 kW halogen light sources and a Flir Systems SC5650 infrared (IR) camera.

3 Final remarks
Knowledge about the 3D position and type of defects in a CFRP test sample is essential for a reliable evaluation of damaged components and the consequent repair process in the workshop environment. CT enables capturing the component’s geometry holistically and thus establishing correlation between the results of other non-destructive testing methods more suitable for the workshop environment. In addition to the blind bore hole test sample illustrated in figure 1, representative impacted test samples have been devised and evaluated with CT and thermography techniques, which will be described, analysed and discussed in the final manuscript.

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References