COMPUTER TOMOGRAPHY AND IMAGE PROCESSING FOR ANISOTROPIC DAMAGE DETECTION ON FIBRE REINFORCED PLASTICS

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1. Introduction

Volume computer tomography (VCT) is an established non destructive testing method, which offers the possibility to capture internal structural damage three-dimensionally [1]. Thus, the complex failure mechanism of endless fibre reinforced plastics can be visualized and classified into the basis failure modes: fibre failure (FF) and inter fibre failure (IFF) taking different loading types into account: tension, compression and shear [2]. A new approach analyzes these VCT data in combination with image processing algorithms to identify the anisotropic damage parameters of pre-damaged CFRP tubes in dependence of the real arising failure modes. Thereby the kind, size and orientation of the detected failure will be estimated automatically. The software was developed on basis of the MATLAB environment and provides input data for a subsequently finite element analysis in ANSYS.

2. Methods

Materials and damage initiation

Tubular structures examined in this study were all manufactured using the filament winding process. The cylinders have an internal diameter of 32 mm and a wall thickness of 3.2 mm consisting of a $[\pm\omega]_{4S}$ stacking sequence lay-up. Samples for testing are 280 mm long and were damaged by using a pendulum impact test machine. The incident impact energy was controlled to low magnitude, so that the sample was not penetrated and only internal or barely visible damage occurred.

Computer tomography, data acquisition

The CT investigation was performed on pre-damaged CFRP tubes by using a cone-beam tomography consisting of a 225 kV microfocus X-ray source, an object slide and a 2048 x 2048 pixel flat panel detector. Due to the relationship of voxel resolution and object size the examined range was limited to a volume of about 36 mm x 36 mm x 28 mm (1600 projections per scan, scanning time ~72 min). So the reconstructed data has a resolution of 17.53 µm/voxel. The commercially available software (Volume Player Plus) has generated 2D-slices in x,y-plane with a series of 1579 images in z-direction (see Fig. 1).

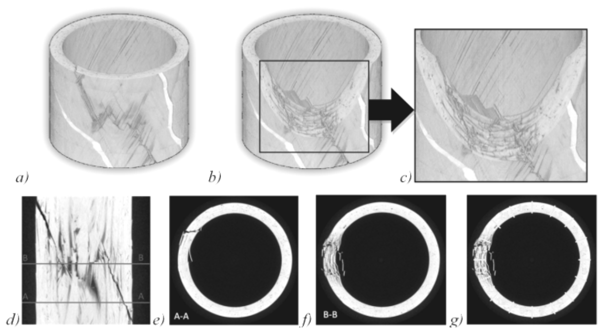

Fig. 1: a), b), c) 3D volume 3D-micro-CT reconstruction; d), e), f) cross sectional slice (2D reconstruction); g) slice with selected areas for manual analysis.

Automated analysis of CT-data

Most commercial software packages for CT data have limited capabilities for extracting quantitative data characterising the reconstructed structure [2]. To investigate localised damage it is important to extract information like distributions, size and orientation of the damaged structures. Because of noise and variations in intensity of 3D grey value data structure, the individual crack can't be easily identified from the whole CT-dataset. This paper presents a systematic approach to obtain this kind of information, using a special software tool created in the MATLAB environment. The algorithm of the program (Fig. 2) includes chosen Digital Image Processing operations and focuses on an analysis of a large number of slices of the inspected specimen by utilizing quick and effective techniques. The newly-developed CT-based Damage Analysis System (CT-DAS) uses a sequence of slices, which were extracted from VCT data in x,y-plane and 256 grey levels, as input images. According to the introduced algorithm CT-DAS finds, locates and classifies internal damage structure. The extracted information can be used for a finite element analysis.

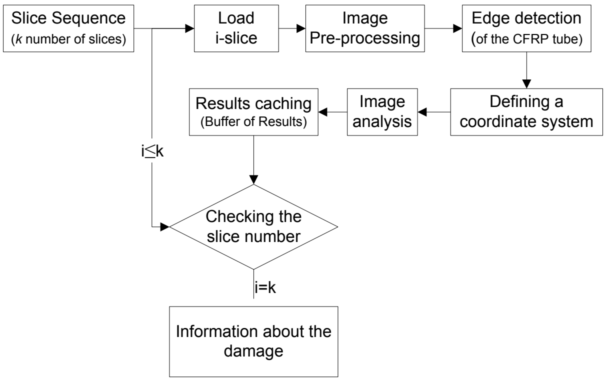

Fig. 2: Flowchart of the CT-based Damage Analysis System (CT-DAS) program algorithm.

3. Results and Discussion

Volume Computer Tomography (VCT) generates large data for the investigation of internal structure damages. The manual observation of these 3D data is time-consuming and leads to subjective results. Therefore a systematic approach to obtain an automated analysis method for large VCT data was developed on basis of 2D digital image processing. By processing the 2D images the extraction of damage distribution, size and orientation motivated by CUNTZE's fracture-mode-concept [2] was focused. With the acquired VCT data it is possible to classify three different fracture types corresponding to fibre reinforced materials: i) delamination or inter fibre fracture (IFF), ii) fibre fracture (FF) and iii) pores and local inhomogeneity (Fig. 3). The possibility to separate these kinds of damage opens new opportunities to investigate them and the interactions between them. This detailed description of the object structure leads to the prediction of damage parameters and can be mapped to a finite element mesh (Fig. 4).

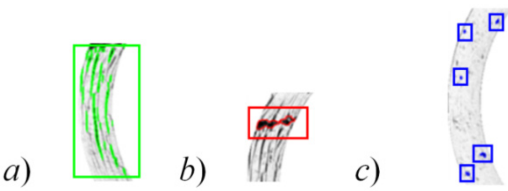

Fig. 3: Automated detection of three damage types a) delamination or inter fibre fracture (IFF), b) fibre fracture (FF) and c) pores and local inhomogeneity.

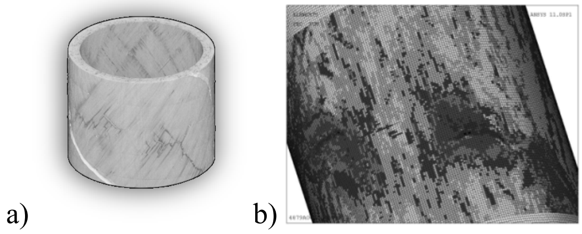

Fig. 4: a) VCT reconstruction of a damaged CFRP tube; b) Finite element mesh with damage distribution extracted from computer tomography reconstruction by an automated analysis.

For detection and classification of existing structure damage within FRP components a software was developed on the basis of image processing algorithms using the MATLAB environment. An evaluation of the local damage and thus the FRP degradation can be made by such an identification of the failure modes, which can flow into appropriate finite element models. With the following global FE-analysis in combination with the implemented failure-mode-based "degradation elements" the remaining mechanical behaviour of the composite structure can be determined concerning stiffness and strength.

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