TOLERANCE ANALYSIS OF THIN-WALL CFRP STRUCTURAL ELEMENTS USING TOMOGRAPHIC IMAGING

E. Casarejos1(*)1, P. Aguiar2, J.D. Barreiro3, P. Izquierdo1, A. Segade1, J.A. Vilán1, P. Yañez1, A. Iglesias1
1Department of Mechanical Engineering, University of Vigo, E-36310 Vigo, Spain
2Fundación Ramón Domínguez, CHUS, E-15706 Santiago de Compostela, Spain
3HVU Rof Codina, Dpto. C. Clínicas Veterinarias, Univ. de Santiago de Compostela, E-27002 Lugo, Spain
(*)Email: e.casarejos@uvigo.es

ABSTRACT

This paper describes a methodology to perform dimensional characterization of non-rigid structural elements made of Carbon Fiber Reinforced Plastics (CFRP) using Computed Tomography (CT). Basic measurements used for quality control and design verification of production samples are described.

Keywords: Non-destructive techniques, X-ray, computed tomography (CT), carbon fibre reinforced plastic, CFRP, non-contact measuring method.

INTRODUCTION

Dimensional characterization of non-rigid components is difficult, costly and time consuming by using traditional tools like coordinate measuring machines (CMM) or laser scanning systems. A measurement technique based on CT imaging technology allows geometric interrogation of complex structures and characterization of inaccessible features without touching the part, and can provide a cost effective path for design verification or reverse engineering.

A lightweight self-supporting CFRP alveolar structure is been developed by our group to support the heavy-loaded detector barrel of the CALIFA calorimeter at the experiment R3B at the international facility FAIR (Facility for Anti-proton and Ion Research) [Casarejos, 2014]. The CFRP pieces are pocket-like truncated pyramids, made of CFRP pre-preg fabrics, cured under a temperature-pressure cycle, handcrafted one-by-one with male-female molds, and glued together in bundles to conform the CF-structure. Metrology is key to control the production quality and guaranty the required geometrical accuracy of the system.

MATERIALS AND METHODS

Different samples of the CFRP structure building pieces have been scanned using a medical CT (HITACHI ECLOS Helicoidal Multi-slice CT [ECLOS]), at the Veterinary Hospital Rof Codina of Lugo (Galicia, Spain). This CT system allowed obtaining 0.25 mm resolution images of 0.6 mm thick slices along a 50 cm diameter field of view (FOV).

We have developed a simple procedure to use the CT information for production quality control and design verification based on a set of features of main interest: wall radio-density and thicknesses inhomogeneity, distance between reference points at edges and angles between edges.
The obtained CT-scan data series were exported from the CT acquisition system in standard format DICOM [DICOM], and visualized, equalized and analysed using visualization and analysis software tools MRIcro [MRIcro] and Amide [Amide].

The digital treatment of the data of the CT-scan as images enables the use of conventional image analysis programs. Using MRicro (a commonly used free software designed for brain image visualization), the DICOM file set is converted to a single file in standard image visualization format Analyze [Analyze]. This file containing the full CT image stack (3D array of voxel-based volume) was visualized using conventional image analysis software Amide, where different visualization planes can be defined by the user, enabling a complete visualization of the internal structure of the inspected parts.

The short range of radio-density values required establishing particular contrast windows, focusing the view on a specific radio-density interval, enhancing visualization of specific structures and features. The visualization software Amide involves several radio-density predefined scales (grey or colour scales). The “hot-metal” colour scale was used, allowing a direct colour identification of density values of the object structure.

Measurements were performed on the 2D images of three different cross-sectional planes of the CT scans: transverse (transaxial plane), coronal (frontal plane) and sagittal (anterior-posterior plane) cuts. Measurement uncertainty was determined by performing multiple independent measurements.

The following overview shows the steps followed for CT imaging and dimensional characterization of CFRP structure samples:

1. CT-scan data acquisition of a piece.
2. A set of files corresponding to the acquired tomographic axial cuts is exported in standard format DICOM.
3. The DICOM file set is converted to a single file in standard image visualization format Analyze, using MRicro tomographic visualization software.
4. The full CT image stack (3D array of voxels) is visualized using conventional (easy to use) image analysis software Amide, where different visualization cuts can be defined.
   - Image visualization choosing a predefined colour scale (colour map “hot-metal”).
   - Visualization is optimized to enhance details (edges, defects,...) in the radio-density range of interest by adjusting the contrast window (defined by thresholds).
   - Visual inspection of multiple CT image planes allowing qualitative analysis.
   - Basic quantitative analysis is performed using simple measurement tools: distances between points, relative angles of profile lines,...

Figure 1 and figure 2 illustrate the CT image visualization and measurement procedure.
Fig. 1 - Upper-left panel: A collection of CF pieces produced with different sizes, fabrics, procedures, etc. Upper-right panel: Analysis based in a finite elements models for composites. Lower-left panel: CT image visualization of a coronal cut of a CF structure made of 8 pieces glued together. Lower-right panel: The 3D CT images are converted into engineering CAD information to quantitatively compare with the designs.

Fig. 2 - The tomographic 3D images can be analyzed visualizing cuts in any plane to study every detail of the actual structure.

RESULTS

1) Sample piece of CFRP truncated pyramid

A sample CFRP truncated pyramid piece, with outer dimensions of 98 mm x 53 mm x 232 mm, was scanned resulting in a CT image set study with voxel size of 0.235 mm x 0.235 mm x 1.25 mm.

Figure 3 shows an example of visualization different views of the CT-scan of the CF piece sample using Amide image analysis software.

Table 1 shows a comparison between CAD design specified and CT measured values of different angles defining the truncated irregular quadrangular pyramid geometry of a sample part. A good agreement was found between the values specified in the CAD design and the values obtained from measurements based on the CT images.
Fig. 3 - CT image visualization of transverse (transaxial plane), coronal (frontal plane) and sagittal (anterior - posterior plane) cuts of a truncated irregular pyramid CF piece.

Table 1 - CT based measurements of different angles between the edges of truncated irregular pyramid CF piece samples, compared to their values defined at the CAD design.

<table>
<thead>
<tr>
<th>Geometrical parameter</th>
<th>CAD design</th>
<th>CT metrology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle measured on transaxial plane (transverse view) cut at height =10mm</td>
<td>7.56º</td>
<td>7.5 º (±0.2)</td>
</tr>
<tr>
<td>Angle measured on transaxial plane (transverse view) cut at height =100mm</td>
<td>7.56º</td>
<td>7.8 º (±0.2)</td>
</tr>
<tr>
<td>Angle measured on transaxial plane (transverse view) cut at height =200mm</td>
<td>7.56º</td>
<td>7.6 º (±0.2)</td>
</tr>
<tr>
<td>Angle measured on coronal view of longitudinal cut (internal, near edges) at front face</td>
<td>7.97º</td>
<td>8.0 º (±0.2)</td>
</tr>
<tr>
<td>Angle measured on coronal view of longitudinal cut (internal, near edges) at back face (wider face)</td>
<td>8.63º</td>
<td>8.7 º (±0.2)</td>
</tr>
<tr>
<td>Angle measured on sagittal view (defined by anterior-posterior faces) of longitudinal cut (internal, near edges)</td>
<td>5.0º</td>
<td>5.0 º (±0.2)</td>
</tr>
</tbody>
</table>

2) CFRP structure of 8x2 pieces

A sample CFRP structure made of 8x2 pieces, with outer dimensions of about 200 mm x 250 mm x 450 mm, was scanned resulting in a CT image set study with voxel size of 0.939 mm x 0.939 mm x 1.25 mm. A total number of 360 CT slices, with a spacing of 1.25 mm, were acquired.

Different views of the CT-scan of the CF structure are shown in figure 5, corresponding to the piece shown in figure 4.
Table 2 shows a comparison between CAD design specified and CT measured values of different angles defining the geometry of the CF structure made of 16 pocket-like CF pieces in a 8x2 arrangement.

![Fig. 4 - Pictures of a CF structure made of 8x2 pieces ready for the CT scan procedure (left), made of 16 individual CF pieces precisely glued together (right).](image)

![Fig. 5 - CT image visualization of transverse (transaxial plane), coronal (frontal plane) and sagittal (anterior-posterior plane or lateral plane) cuts of a CF structure made of 8x2 pieces glued together.](image)

Table 2 - CT based measurements of different angles between the external edges of a CF structure made of 8x2 individual pieces, compared to their values defined at the CAD design.

<table>
<thead>
<tr>
<th>Geometrical parameter</th>
<th>CAD design</th>
<th>CT metrology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle measured on a transaxial plane cut (transverse view), at midpoint of the structure. Defined by external faces of the 2 piece-pair rows of the structure.</td>
<td>CAD: 10°</td>
<td>10.2° (±0.2)</td>
</tr>
<tr>
<td>Angle measured on a coronal view, at midpoint of the structure. Defined by external faces of a 2 piece-pair.</td>
<td>CAD: 20.48°</td>
<td>20.4° (±0.2)</td>
</tr>
<tr>
<td>Angle measured on an anterior-posterior plane cut (sagittal view), at midpoint of the structure. Defined by the external faces of the 8-piece stack of the structure.</td>
<td>CAD: 39.99°</td>
<td>39.8° (±0.2)</td>
</tr>
</tbody>
</table>
A good agreement has been found between the values specified in the CAD design and the values obtained from measurements based on the CT images.

CONCLUSIONS
We have developed a simple procedure to perform dimensional characterization of non-rigid carbon fibre reinforced plastic pieces based on tomographic imaging, using a medical CT and conventional image analysis software.

Good agreement was found between the values of representative angles defined in the CAD design of the inspected structures and the corresponding values obtained from measurements on the CT images of the resulting production samples.

These preliminary results show that the proposed methodology can be useful for design verification of non-rigid components and structures.

ACKNOWLEDGEMENTS
This work was partially supported by funding of the Spanish Ministry (FPA2013-47831-C2-2-P) and Xunta de Galicia (EM2012/140).

REFERENCES


[3]-{DICOM} Digital Imaging and Communications in Medicine, DICOM, http://dicom.nema.org/.


[6]-{Analyze} Analyze file format http://analyzedirect.com/.