Morphological study of defects in laminated joints of composite materials using microCT

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Abstract

Computed microtomography (microCT) has been used to inspect composite materials of the most varied types. From a volumetric analysis it is possible to characterize the phases (matrix and reinforcement) present in the materials, as well as to determine the percentage of defects that may exist. In laminated joints of pipe in polymeric composite material reinforced by fiberglass, delaminations and voids have been observed that may compromise the strength of these materials. A basic analysis with microCT allows to verify the presence of these occurrences, but to differentiate them a more accurate analysis is necessary. The objective of this study was to analyze computed microtomography of laminated composites. The results quantitative of the matrix and reinforcement were provided and a study of the sphericity of the defects was performed. The results demonstrated that more spherical defects tend to be small voids, whereas less spherical defects correspond to delaminations.

Keywords: Microtomography; Laminated Joint; Fiberglass.

1 Introduction

In order to reduce the exposure of steel pipes to corrosive environments, among others, the use of composite materials in the oil and gas industries has grown. Composite materials have good corrosion resistance, high strength in oriented directions and low weight [1, 2]. However, composite materials reinforced by fiber may exhibit critical defects, such as voids (porosities) and delaminations [3]. In particular, laminated joints of polymer composites may exhibit non-conformities due to manual processing [4].

Non-Destructive Testing (NDT) techniques are constantly advancing and offer the possibility of inspection during the manufacturing, construction, assembly, operation and maintenance phases. Several methods of NDT can be used for inspection of composite materials, such as ultrasonic tests, thermography, penetrating liquids, radiographs, tomography and microtomography, among others. The choice of technique to be used will depend on the objective to be analyzed [5-8].

Computed microtomography (microCT) can be used to reconstruct interior structural details of various materials with an interesting scale resolution for evaluation [9]. In terms of composites it is possible to obtain quantitative information about matrix and reinforcement and possible defects. The identification of nonconformities or defects is of extreme importance to ensure the quality of design admissible [10]. However, the information on the percentage of defects, alone, becomes insufficient. It is necessary to identify the types of defects (voids, delaminations or debonding) that could compromise the composite in question structurally. Dalen & Koster [11] performed microtomography analyzes and compared 2D and 3D methods to determine particle size of aerated emulsions. Plessis et al [12] analyzed the porosity of concrete inspected by computed tomography. Rique et al [13] inspected fiberglass-reinforced composites using Digital Radiography (DR) and microCT techniques to determine lack of adhesive and lack of adhesion. This work aims to analyze microCT images, performed in another study [14], of laminated pipe joints in polymeric composite material reinforced by fiberglass (GFRP) to determine the types of defects present in the samples.

2 Method

The images were obtained using a microCT system V|tome|x (GE). The details of the acquisitions of the images and the reconstructions can be found in a separate article. Important data for the understanding of this study will be described below. Four laminated joints (GFRP) with nominal diameters of 4 and 6 inches were inspected. According to the manufacturer, Joints 1 and 3 were free from defects and Joints 2 and 4 contained voids, delaminations and debonding of various sizes. The microtomographies were analyzed using the CTAn [15] software and segmented by the global method. The volumetric percentages of the defects were provided in a previous study and are summarized in table 1.
During the binarization process of the microCT images, the existing defects have an equivalent gray level. Therefore, with a basic analysis it becomes difficult to differentiate a delamination from a void. For this reason, we use 3D structural analysis tools within the CTAn itself. In this way it is possible to observe the equivalent diameter as a function of the thicknesses. To reinforce the results, the sphericity ($\pi \frac{(6V)^{\frac{2}{3}}}{A}$) of the defects was calculated through the Label Analysis tool of Avizo Fire [16] software. 3D images were made from CTVox [17] software.

### 3 Results

It can be observed in Figure 1 the relative volume of defects as a function of thickness (St.Th) for each case studied. A common fact among the four samples is that for the greater thicknesses a lower percentage of defects is found. For the Joint 1 half of the defects have a thickness less than 0.35 mm. For Joint 2 approximately half of the defects are below 0.60 mm. The Joint 3 had a greater distribution between the thicknesses, reaching the greater quantities below 1.2 mm of thickness. The Joint 4 obtained half the volume of defects at a thickness of not more than 0.66 mm. Considering that Joints 1 and 4, according to the manufacturer’s information, were not defective, microCT was still able to identify faults.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Total Volume (mm$^3$)</th>
<th>Defects (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint 1</td>
<td>$6.22 \times 10^3$</td>
<td>0.27</td>
</tr>
<tr>
<td>Joint 2</td>
<td>$4.86 \times 10^3$</td>
<td>0.60</td>
</tr>
<tr>
<td>Joint 3</td>
<td>$9.05 \times 10^3$</td>
<td>0.55</td>
</tr>
<tr>
<td>Joint 4</td>
<td>$9.54 \times 10^3$</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Figure 1: Structure thickness (St.Th) distribution of the Joints.
The data observed above can be better understood when we see, in Figure 2, the images of the defects and their respective scales. The graphs associated with the images give us an indication that the defects considered more serious, such as delamination or debonding, although in greater quantity, have a small thickness. However, the voids were thicker. Each image has its own color scale that corresponds to a thickness of the defective structure. Visually one can observe the characteristic in strip that a delamination or debonding present. This type of defect creates an empty space between the laminated layers. Already the voids configure a spherical geometry, with greater thickness.

One of the factors of great importance to be considered in determining the size of structures is what dimension of this structure is being measured. For spheres only, the size of a particle can be represented by its diameter. For structures with irregular shapes, other measurements are necessary to quantify their size. Since sphericity is a measure of how spherical an object is, a value equal to 1 represents a sphere. In this way, we can observe in Figure 3 that Joint 1 has ellipsoidal voids and other irregular defects that justify the large band seen in the reconstructed image. Let us consider irregular defects to be delamination or debonding. Joints 2 and 3 have spherical voids and many irregular defects. In relation to the Joint 4, a great concentration of ellipsoidal voids is observed.

Figure 2: 3D images of defects found in joints.
Conclusions

MicroCT presents very promising results in the NDT field. In particular, for inspection of composite materials due to the heterogeneous characteristics of the materials. In this study we used other 3D evaluation tools provided by the image analysis software. Although the characteristics of the defects in laminated samples are known, it is imperative that these defects are correctly identified in the tomographic images. The results express the significant presence of ellipsoidal voids distributed throughout the sample and clustered bands of delamination or debonding defects.

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References


