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# VISUALIZATION OF VOIDS IN ACTUAL C/C WOVEN COMPOSITE STRUCTURE

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## ABSTRACT

Void statistic is an important C/C composite parameter since the voids presence decreases the predicted properties. On the other hand minimum number of voids is needed for medical application. Void study supposes finding its exact 3D shape. Since the void distribution is statistic, many samples must be processed. Therefore automated methods are necessary. In the paper the set of plan-parallel structure images were scanned by optical microscopy. The void contours on 2D images were found automatically by the use of MATLAB procedures with the same accuracy as hand marking. The 3D void surface was created by small triangles from its plan-parallel cuts. The 3D void was studied by virtual reality that makes possible almost all ways of inspection.

## 1. INTRODUCTION

Measured parameters of textile composites have considerably lower values than those estimated from a lot of structure models changing from simple approach to rather sophisticated structure description and parameter modeling. Explanation is in the fact that almost all the models are based on ideal material structure that differs from the real one. There are two basic and the most important differences between real and ideal structure of textile composite:

1. Real yarns differ from ideal ones in longitudinal shape, relative positions, cross section, etc. These structure defects appear mainly in composite preparation before heat treatment. These defects can be termed long distance or volume (global) imperfections.
2. Real structure contains other defects as voids, cracks, etc. Their origin can be found in heat treatment (curing, pyrolysis, etc.) They can be termed as short distance or local imperfections.

Irrespective of the nature and size of the defects, their common feature is that they are random effects. Their type, position, shape and so on are different at different parts of the sample and also differs from sample to sample. The only method to study defects is to get acceptable structure images in three dimensions (3D), then to extract the object or defect shape from 3D images, determine its basic parameters, and, finally, to study the defect nature and effect. Each of the steps is very difficult and complicated. Furthermore, the statistic nature of defects requires a lot of samples to be processed. Therefore, the automation of a lot of routine operations is necessary.

The first step is therefore to get a high quality starting 2D structure image. Two basic methods are available today: Optical Microscopy (OM) and Computer Tomography (CT). Each method has its advantages and disadvantages that are discussed later. From the practical point of view we preferred the optical microscopy.

The second step, object recognition in general, requires a lot of routine work, because of a big number of objects and their complicated shape. Any automation increases the effectiveness of this step considerably. As soon as the object was defined, its classification and parameter determination (the last but one step) is a subject of creative work that can be automated efficiently.

In our department the real yarn geometry and structure defects were studied independently. In the past, efficient methods were made for the description of yarn real structure [1-3]. Therefore, now we focus to the study of local defects. Many experiences from previous study of yarn shape are applied.

In the paper we describe the method used for structure image getting, semi-automated method for defect boundary finding in plane images, 3D defect shape reconstruction from the partial planar images and basic defect parameter determination.

## **2. MATERIAL STRUCTURE SCANNING, STRUCTURE IMAGE PROCESSING AND DEFECT VISUALIZATION**

Woven C-C composite manufactured by standard technology was studied. Methods for material structure image acquisition are discussed. Then the semi-automated image recognition method is outlined. Quite general Virtual Reality Markup Language (VRML) was used for 3D object visualization.

### **2.1. Material Structure Images**

As it was mentioned in Introduction two basic general methods for material 3D structure visualization can be applied: Computer Tomography (CT) and Optical Microscopy (OM). Images of the set of plan-parallel cuts of material structure are the basic output of both the methods. However, the application possibilities and quality of results are different. CT is non-destructive, fully automated method, the positions and parallelism of cuts are precise, but the resolution is low and the application is limited by the type of material. Its application requires sophisticated expensive apparatus and complicated commercial SW. The sample scanning and result processing takes several hours.

On the other hand the optical microscopy exhibit very high resolution, it can be applied to arbitrary material, but it is a destructive method. Since only the surface can be scanned, the method requires removing of a very thin layer of material between subsequent scanning. This necessary procedure is the main disadvantage of OM method – the precision of cut positions and cut parallelism is low. Therefore the structure information is not uniform; in two dimensions we have a very detailed image, while in

the perpendicular dimension the information is very rough. Furthermore getting of 3D OM images requires a lot of routine hand work, only partial automation is possible.

Basic comparison of both the methods reveals that the CT should be preferred. It is really frequently used for the structure study of textile composites by commercial apparatus with spot size of approximately  $25\ \mu\text{m}$  [4], the spot diameter of  $12$  and  $6\ \mu\text{m}$  is also possible at more precise apparatus [5]. Unfortunately, the main application of X-ray CT is for composites of matrix and reinforcement made from different material, preferably with high atomic numbers. Then the contrast on CT images is acceptable. The studied C-C composite possesses the similar components of structure with a low atomic number. Experiment showed that the application of standard X-ray CT was not possible. Almost no contrast was on output CT images.

Another solution is the application of synchrotron CT [6]. Unfortunately, the scanned volume is low and the apparatus is unique. These limitations led to the use of OM method. The material cuts were prepared by standard metallographic method. The slice distance was approximately  $200\ \mu\text{m}$  with a big error of about  $50\ \mu\text{m}$ . The slice parallelism was also poor.

Structure image scanning and processing was realized by the use of standard equipment. Commercial image analyzer LUCIA was used for scanning of the surface of the sample cut. High resolution was possible. Only basic image processing was made by LUCIA SW, partial image composition, for example. Fig. 1 shows a typical partial image.

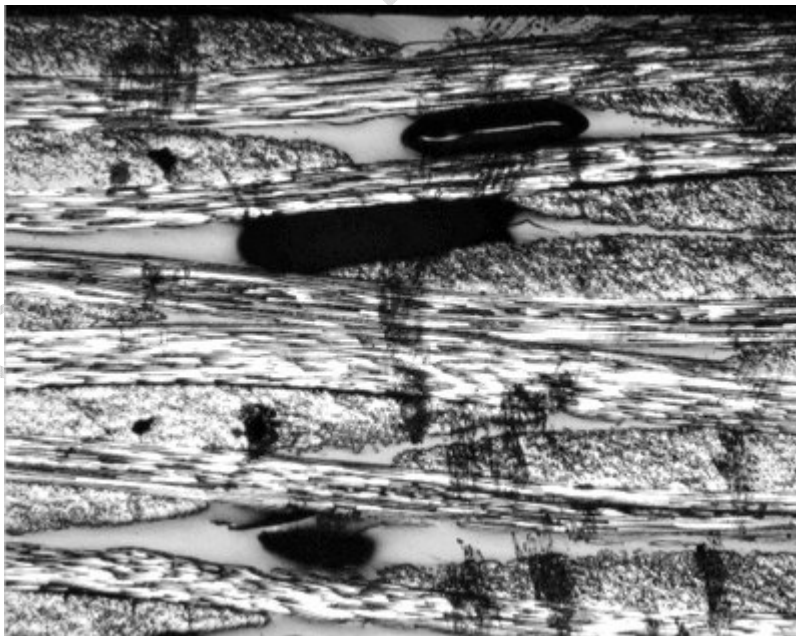


Figure 1. Typical partial image of scanned structure. Perpendicular and longitudinal yarns are well visible. Grey parts correspond to matrix and black areas represent voids.

## 2.2. Image Processing and Object Recognition

All the original image processing and void boundary recognition was made by our own SW based on MATLAB image processing procedures. The image pre-processing uses standard procedures to enhance image quality as histogram equalization, gamma correction etc. The resulting image is in Fig. 1.

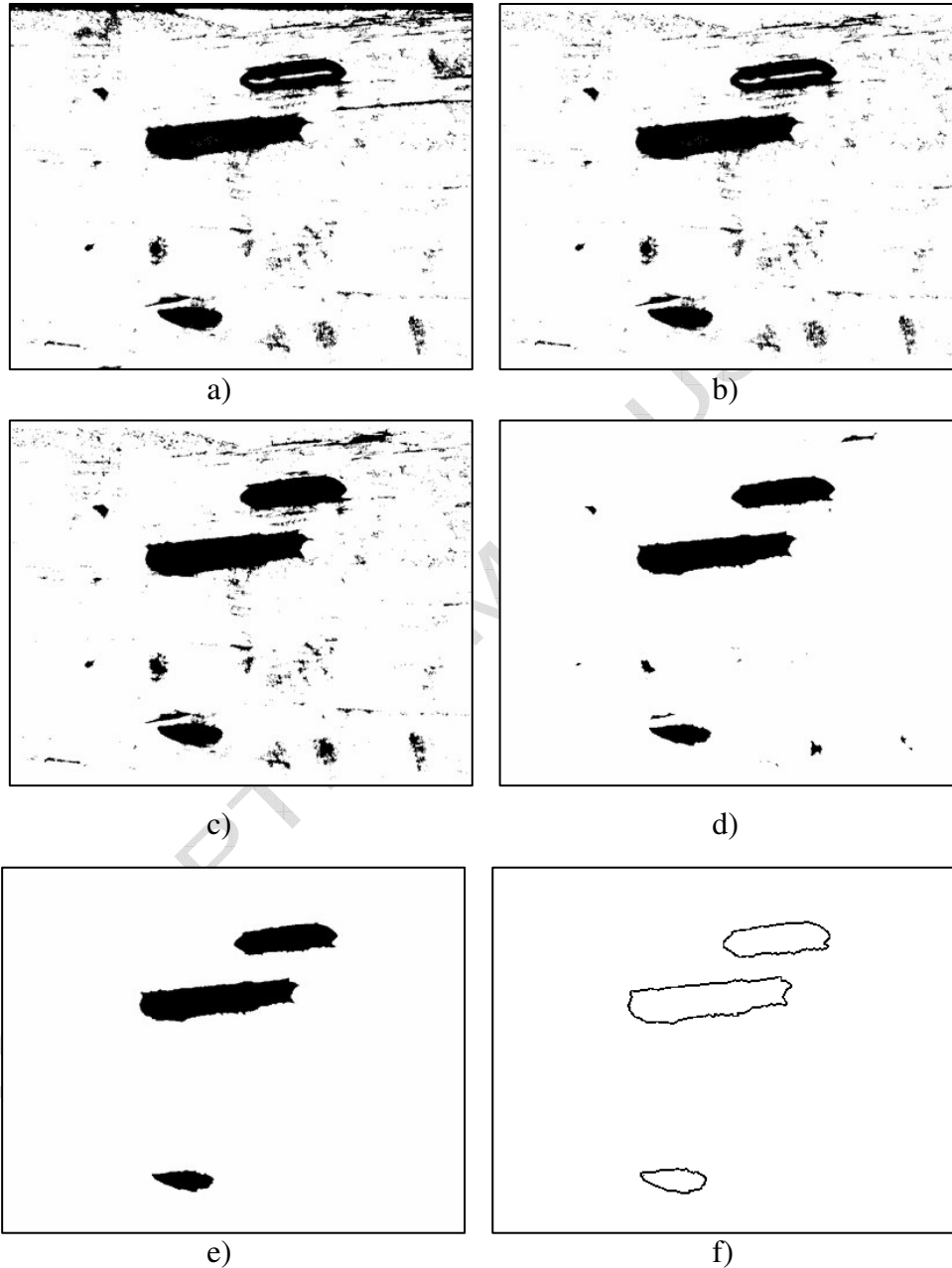


Figure 2. Object boundary recognition: a) Threshold application – key procedure. b) Removing objects near boundary. c) Closed area filling. d) Very small object removing by erosion procedure. e) Small object removing by size threshold. f) Boundary curve finding.

Standard MATLAB procedures were applied to object contour finding, see Fig. 2. The critical and key procedure is to select the correct threshold. The result shown in Fig 2a reveals that, besides searched objects, many other objects are found. The searched voids are three objects of largest area. Other found objects must be removed in following steps.

The first step removes objects close to the processed image boundary, since there is only part of useful objects. The result is in Fig. 2b. The most evident problem after this step is that area of some useful objects is not uniform, as the highest useful object in Fig. 2b. The standard MATLAB procedure makes the object area uniform, see Fig. 2c.

Many small false objects must be removed. The smallest ones are removed by the erosion procedure and the result is in Fig. 2d. Since the erosion affects boundary parts of all objects, irrespective if they are false or true ones, the method of dilatation must be applied to get approximately the origin size of remaining objects. Then the remaining objects are ordered by their size (in pixels) and by selecting the limit, undesired objects are removed. The result is in Fig. 2e. The last step is the finding of contours of true objects, Fig. 2f.

There are several key parameters that affect the success of automated contour marking. The first and the most important of them is the correct value of threshold in the first step. The second parameter is the level of erosion. The third value is the size of largest false object in pixels. Also the pixel definition of object contour is important.

### 2.3. Real Object Visualization

Automated void contour finding described in previous part allows getting of void contours at all its planar cuts. The resulting 2D curves are shown in Fig. 3a. The void surface can be reconstructed from these curves by the use of small triangles connected to subsequent contours as it is schematically demonstrated in Fig. 3b.

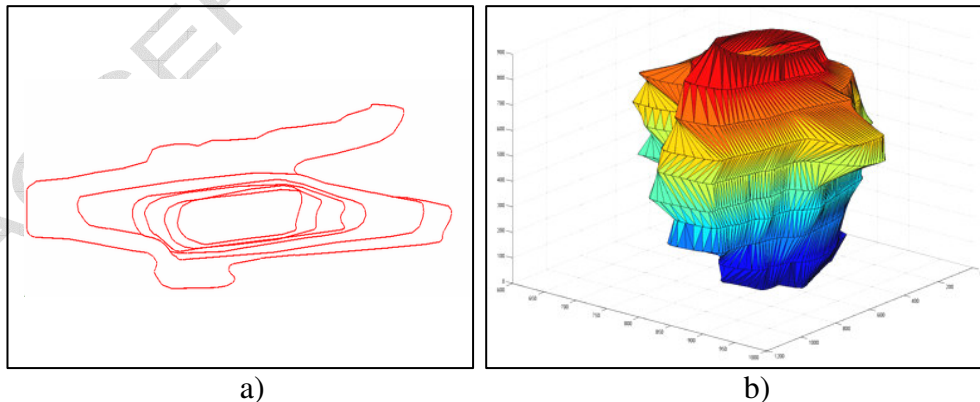


Figure 3. Visualization of the void in 3D space. a) The horizontal cuts of the void. b) Void surface reconstruction.

As it follows from Fig. 3b, the void surface is rough especially in the direction perpendicular to image area, since there is little information. The surface can be smoothed by the original method of Lissajouse figures. The details can be found elsewhere [7].

If the void surface is modeled by small triangles, their coordinates and other parameters can be stored in input text file of VRML system. The system makes possible very efficient 3D visualization of voids by moving them, rotating etc.

### 3. RESULTS AND DISCUSSION

The real void study consists of several steps. Typical steps are void contour finding in 2D images, 3D void visualization by the use of VRML system and finally the composite evaluation. Typical results of these steps are illustrated here.

In Fig. 4a there is the an original image with voids and Fig. 4b shows the void contours found by the automated procedure described in part 2.3. The precision of contour position is the same as if it has been made manually.

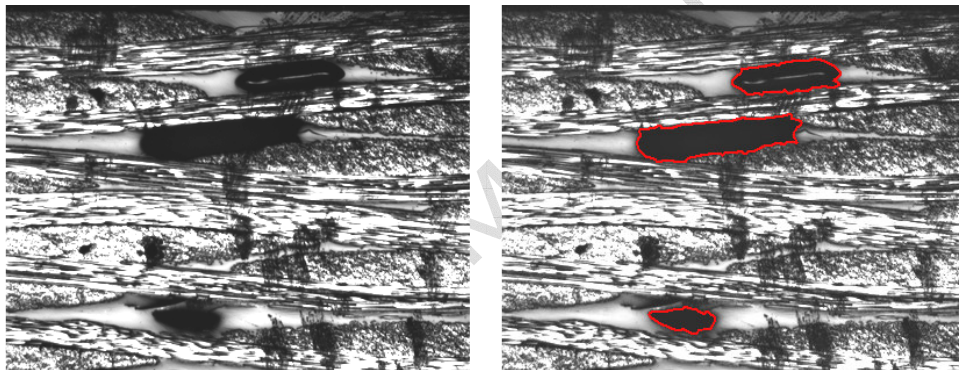


Figure 4. Contours of voids: a) Original image. b) Contour voids as a result of automated procedure.

Using the approach mentioned in part 2.3 and the virtual reality system (VRML) the 3D visualization of voids from their cross-section profiles is possible. As an example, there is in Fig. 5 the 3D image of a typical void in three main directions. Of course, the VRML inspection is not limited only to these three basic directions. Unlimited number of observer (Avatar) positions, distances and view angles are possible. The inspection can be hand driven or automatic, quasi-static or dynamic with very different path and velocity, etc. Referring to these few examples, we can conclude that the use of virtual reality reveals void details and makes possible the better understanding the actual 3D void shape.

Application of both the procedures to all the voids in the sample volume allows to obtain the complete 3D image of voids in a given volume, typical example is in Fig. 6. In reality, yarns and matrix are in the volume, but for the study of voidness the void extraction from the structure was carried

out. The advantages of virtual reality appear in this complex 3D image. Avatar can go through the composite, for example.

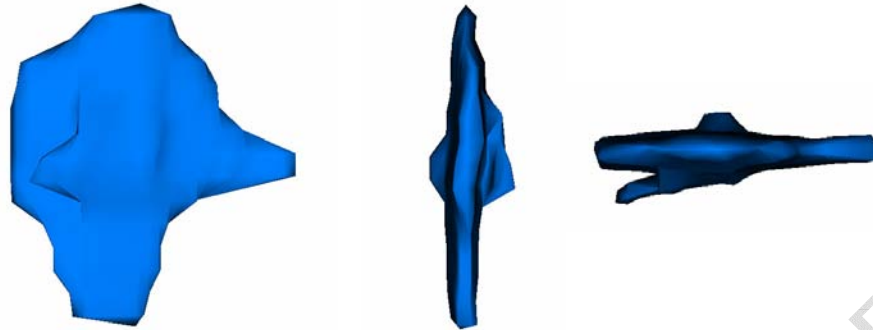


Figure 5. Typical void viewed by virtual reality in basic directions illustrates the insufficiency of voidness evaluation on 2D structure images

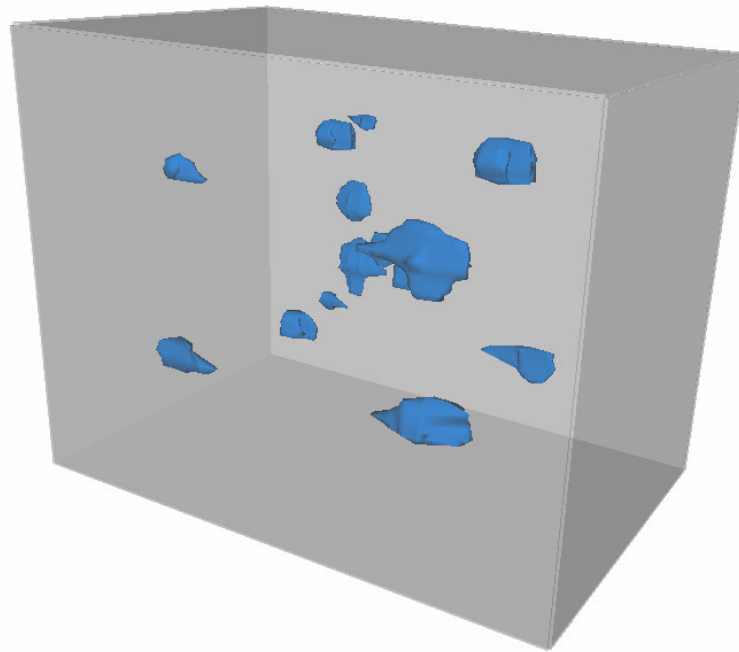


Figure 6. Real voids found in investigated composite volume. Only voids extracted from composite structure are considered.

In the paper we have shown that the composite structure imperfection can be effectively studied by a today standard HW and SW. Because of objective limitations we have used Optical Microscopy. However the Computer Tomography should be preferred, as it makes the HW sample processing more efficient. Standard SW can be used for both the object boundary detection and 3D visualization. Among many 3D visualization systems the VRML is preferred, since the image description is simple, the



system performs a lot of routine work and the image inspection has almost all possibilities.

In this paper we limited to the description of the method and illustration of typical and interesting results. Massive application of the method will make possible getting of void statistics among other things. The void statistics is important not only for modeling of composite properties, where the voids are undesired, but also for other application, for example medical one, where minimum pore concentration is needed.

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