MICRO-CT ANALYSIS OF GLASS KNITTED FABRIC STRUCTURE

Galina Harjkova[1], Marcin Barburski[2,3], Stepan V. Lomov[3], Olga Kononova[1]
[1]Riga Technical University, Institute of Mechanics, Latvia
[2]Technical University of Lodz, Institute of Architecture of Textile, Poland
[3]KU Leuven, Department MTM, Belgium
galina.harjkova@rtu.lv

Abstract. Micro-CT scanning (X-ray microtomography) is a non-destructive analysis technique that provides visualization of the internal structure of materials and it has been widely used in recent years for inspection of different types of materials. Unlike the traditional microstructure observation, X-ray microtomography does not require sample significant and time consuming pre-treatments as cutting and polishing. The objective of this study is to demonstrate the potential of the micro-CT technique for geometrical analysis of textiles. A technique for determining initial geometry of glass knitted fabric at a mesoscopic scale is presented. Geometrical parameters, namely the yarn positional information, shape and dimensions of cross-sections are determined using the X-ray microtomography experimental data. A structural model of the studied textiles is build. The obtained information can be used for further micromechanical modelling.

Keywords: knitted fabric reinforcement, textile, micro-CT, X-ray, glass fibres, microtomography.

Introduction

Knitted fabric reinforcement has unique properties compared with other fabric structures such as woven and braid, therefore this type of reinforcement has received great attention in the composite industry. Knitted fabric has a high degree of deformability and it is formable into the desired complex preform shapes for liquid moulding to produce the composite component [1].

The macroscopic properties of composites are strongly related to the fibre architecture [2; 3]. Thereby, it is important to have a reliable method for evaluating the geometry and to build the structure, point by point. The coordinates of these points could be taken using pictures of the structure, cross-sectional information from micro-cuts, or 3D pictures taken with microtomography analysis.

All the computational methods (finite element method, multi body dynamics, method of inclusions, etc.) are using some approximation 3D geometry of the fabrics as a starting point for further, more exact calculations [4]. At the same time the structure of real textiles differs from the geometry of the theoretical models. The geometry of fabrics in their unloaded state is highly variable due to the unconstrained nature of this state. In practice, significant geometric differences may exist between two cross-sections observed in two different unit cells of the same fabric [5]. Even for relatively simple (comparing with knitted fabric, where yarns are highly curved) woven fabrics complexity of the initial structure is observed, especially in case of laminates [6]. In knitted fabrics high variability of the cross-sections shape can be observed also within one unit cell.

Usually the observation of the real microstructure is made on the specimen surface using an optical or electronic microscope to obtain images in two dimensions. The measurable parameters in 2D are limited, therefore the internal structure hardly can be analyzed. Often the techniques are destructive and require pre-treatments (serial sectioning, polishing). These methods are time-consuming and tedious; furthermore, sample preparing procedures can distort the results.

Micro-computed tomography has been originally used for biomedical purposes [7]. It is a non-destructive method to obtain geometrical information about the internal microstructure of an object. X-ray microfocus computed tomography (also called X-ray microtomography or Micro-CT) usage in the material science field is very attractive, because this technique allows making 3D observation inside the sample that is not possible with the standard microscopy techniques. The vivid description of the actual structure positively affects the characterization of the structural parameters and numerical modelling of physical behaviour of true three-dimensional structure. X-ray microtomography appears to be an excellent tool for investigating and reconstructing the complex organization of fibrous materials such as highly looped yarns in knitted fabric.

The tomography scan provides a series of radiographs of the sample, post-processing of the scan raw data results in transaxial slices set, that are analyzed to describe the 3D structure. In this paper the scanning procedure and options are first shortly described, and then examples of the obtained data are shown and discussed.

Other non-destructive techniques based on laser ranging or ultrasonics are perhaps more appropriate than X-ray computed tomography (X-ray CT) for imaging damage, however X-ray CT appears to hold promise for imaging 3D yarn architecture [8]. To do X-ray microtomography measurements, it is not necessary to slice the samples and polish them that is a big gain of time.

The aim of this study is characterizing the actual textile architecture of weft knitted glass fabric using micro-CT scanning methods, further using that knowledge to develop 3D FE models and refining these models to predict the deformation response.

Materials and methods

To illustrate the capability of X-ray microtomography for 3D imaging two different types of glass knitted fabric (Fig. 1 and 2) were examined for this paper. The main properties of the investigated fabrics are generalized in Table 1. Single jersey glass knitted fabric (No. 1) has a relatively large course (C) and wale (W) number, thus it is loose and extremely flexible. Fabric No. 1 is manually produced on a flatbed type knitting machine using E-glass yarns supplied by the Latvian company JSC "Valmiera Glass Fibre" ("Valmieras stikla šķiedra"); fabric No. 2 is used as a mould cover in forming of automotive glass and it was supplied by the N.V. Bekaert S. A. from Belgium.

Table 1

Main parameters of investigated fabrics

Parameter, unit		No. 1	No. 2
Knitting pattern		Single Jersey	Jersey
Density, loops·cm^{-1}	wale	1.2±0.3	9.66±0.05
	course	1.8±0.3	8.33±0.05
Yarn linear density, tex		136 x 2[a]	42 x 2[a]
Fabric areal density, g·m^{-2}		156±8	950±5
Thickness, mm		1.3 ±0.1	1.11±0.07

[a] Numbers 136 and 42 are linear density (in tex) of one yarn; 2 – is a number of yarns twisted together.

To obtain the structure of these fabrics the X-ray microtomographic scanner used is a commercially available high-resolution system Skyscan 1172. The X-ray source and detector are stationary and the sample rotates while it is exposed to X-rays. The projections made are combined to generate a reconstruction of the volume of the specimen, which results in a high 3D resolution image of the sample. The principles of X-ray microtomography can be found in [3; 5], in this paper we will only shortly describe the scan settings. The samples are prepared – impregnated with glue to make them stiff and cut into possibly smallest pieces, but so that at least one full loop can be observed. Then the samples were positioned on a rotating object holder. The examination of the specimens is carried out at scanning resolution 4.87 µm for fabric No. 1 and with 3.13 µm for No. 2. Although the glass fibre diameter is about 9 µm, single fibres are not distinguishable. A set of projections is obtained after the scanning and reconstuction (NRecon) and 3-D volume representation of a sample can be obtained using volume rendering software (CTvox). The fabric architecture is well represented (Fig. 3a and 3c). The high resolution cross-section images are then analyzed with image processing software to obtain the geometrical properties. Within this study, the software ImageJ is used for measuring.

Threshold is used to binarize an image and to highlight the cross-section of interest. It is important to choose the right threshold level. If it is chosen too low the cross-sections contain too much noise and the results of the measurements are unreliable. Otherwise, if the threshold level is chosen too high then there will be no noise, but too much material will be gone, which means that the information about the structure is incorrect, therefore the results of the image analysis are also useless. The images are globally thresholded with a manually selected threshold value. An example of a processed cross-sectional image is presented in Fig. 1. Image processing is done manually, which limits the amount of analyses slices.

The X, Y, Z coordinates of the yarn middle line are obtained by tracing the cross-section of each yarn from 2D slices of the scanned volume. The fitting ellipse function was used to approximate the yarn cross-section shape and its dimensions (Fig. 1b). The fitted ellipse has the same area, orientation and centroid as the thresholded selection. The same fitting algorithm is used to measure the major and minor axis lengths and the angle between the major and horizontal axis, thereby the cross-section geometrical parameters are obtained.

a) b)

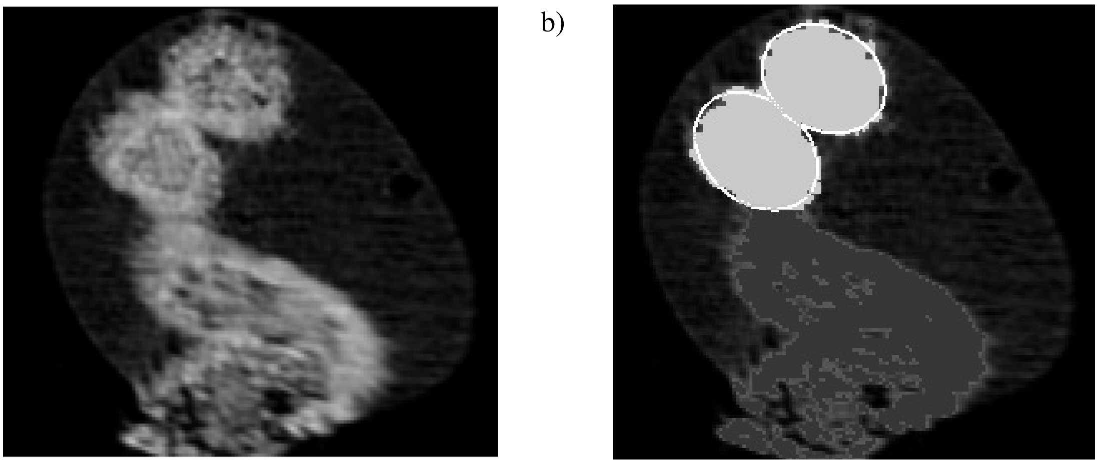


Fig. 1. **Projected cross-section of yarn in fabric No.2 (image obtained from micro-CT):** (a) initial cross-section, (b) thresholded cross-section and ellipses, fitted to thresholded areas

Results and discussion

In a result of the described procedure, the yarn paths (Fig. 2), areas of elliptical cross-sections and dimensions were obtained. To visualize the obtained results, a geometrical model was created using 3D modelling software SolidWorks (Fig. 3b and 3d). Since the cross-sections shape and size depend not only on the number and kinds of filaments but also on the loads imposed upon the structure [9], thus the geometrical model, based on X-ray microtomography data measurements, corresponds to the structure of the real weft-knitted fabric, where more elliptical cross-sections with smaller than in loop head and legs areas are observed in the two yarn contact zone.

a) b)

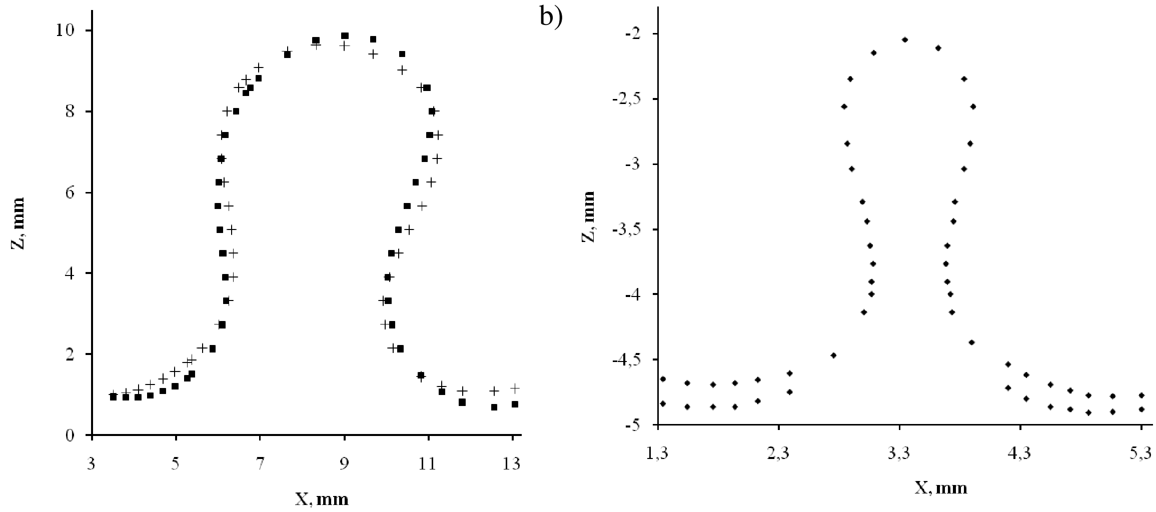
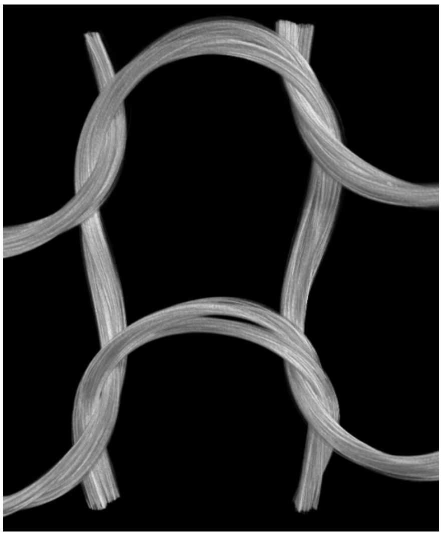


Fig. 2. **Yarn middle line coordinates:** a – fabric No. 1; b – fabric No. 2

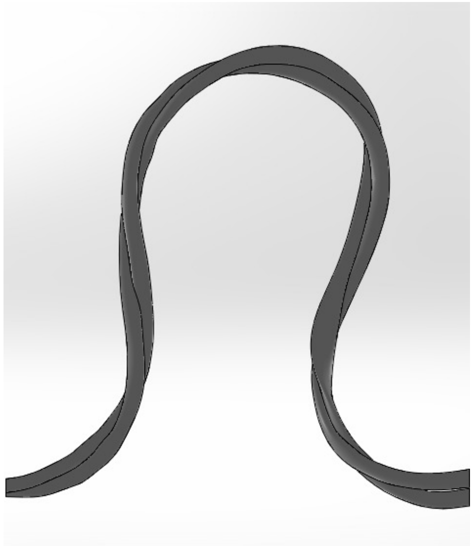
Once the geometrical information is obtained we can apply it to anything we want, for example, for FEM analysis.

A future step of this research can be detailed investigation of the thresholding level influence on the measurements and studies on suitable autothresholding algorithms.

a)

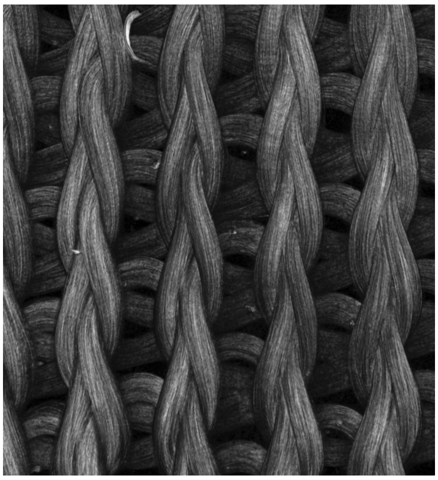


b)

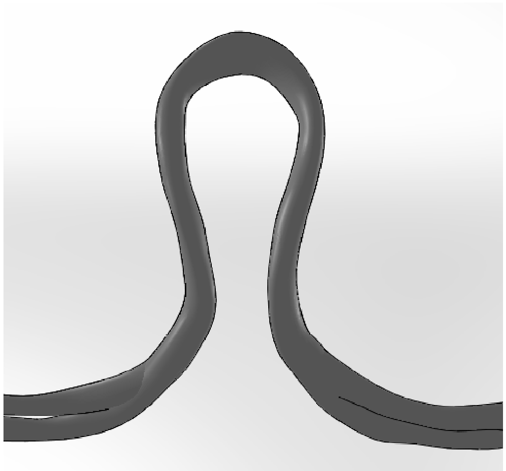


Fabric No. 1

c)



d)



Fabric No. 2

Fig. 3. **Weft knitted fabric:** a, c – reconstructed volume (CTvox software); b, d – geometrical model of one loop, based on the measured values

Conclusion

In this paper the yarn geometry in weft knitted glass fabric was characterized by using the X-ray microtomography technique. Comparing with the traditional techniques, used for microstructure observation, micro-CT is a non-destructive method that does not require significant pre-treatments, like serial sectioning and polishing, thereby X-ray microtomography usage can provide more detailed information inside the sample and more accurate measurements. Observations show that micro-CT analysis can be successfully used for recognition of a structure for different knitted fabric and the obtained results can be used for further micromechanical modelling. It should be mentioned, that in case of a fabric complicated structure micro-CT result data manual postprocessing can be difficult and time-consuming, therefore studies on data automatic processing and geometry recognition, as well as studies on data automated import to FEM programs have great potential.

References

1. Miravete A. (Ed.) 3-D Textile Reinforcements In Composite Materials. CRC Press and Woodhead Publishing Ltd, 1999, 180 p.

2. Pandita, S.D., Verpoest, I. Prediction of the tensile stiffness of weft knitted fabric composites based on X-ray tomography images. Composites Science and Technology, vol. 63, iss. 2, 2003, pp. 311–325.
3. Salvo L., Suéry M., Marmottant A., Limodin N., Bernard D. 3D imaging in material science: Application of X-ray tomography. Comptes Rendus Physique, vol. 11, iss. 9–10, 2010, pp. 641–649.
4. Renkens W., Kyosev Y. Geometry modelling of warp knitted fabrics with 3D form. Textile Research Journal, vol. 81 no. 4, 2011, pp. 437-443.
5. Boisse, P. (Ed.). Composite reinforcements for optimum performance. INSA Lyon, France, 2011, pp. 565-587
6. Badel, P., Vidal-Salle, E., Maire, E., Boisse, P. Simulation and tomography analysis of textile composite reinforcement deformation at the mesoscopic scale. Composites Science and Technology, vol. 68, iss. 12, 2008, pp. 2433–2440.
7. Müller R. The Zürich experience: one decade of three-dimensional high-resolution computed tomography, Topics in Magnetic Resonance Imaging, 13(5), 2002, pp. 307–322.
8. Desplentere F., Lomov S.V., Woerdeman D.L., Verpoest I., Wevers M., Bogdanovich A. Micro-CT characterization of variability in 3D textile architecture, Composites Science and Technology, vol. 65, iss. 13, 2005, pp. 1920–1930.
9. Keefe M. Solid Modeling Applied to Fibrous Assemblies. Part I: Twisted Yarns. Journal of The Textile Institute, vol. 85, no. 3, 1994, pp. 338-349.