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COMPUTED MICROTOMOGRAPHY IN THE ANALYSIS OF FIBER MIGRATION IN YARN

Marta Toda, Katarzyna Ewa Grabowska

The Technical University of Lodz, The Institute of Architecture of Textiles,
Zeromskiego street 116, 90-543 Lodz, Poland
E-mail: marta.toda@p.lodz.pl katarzyna.grabowska@p.lodz.pl

Abstract:

This study is a short analysis of the use of computer microphotography in fiber migration testing as a modern non-destructive testing method. Microtomography operates similarly to X-ray computed tomography systems used in medicine, but with much better resolution owing to the use of a smaller radiation spot. The internal structure is reconstructed as a series of two-dimensional cross-sections that are then used to create 2D and 3D morphological objects. This process is non-destructive and does not require special preparation of a testing material.

Keywords:

Computed tomography, Microtomography, Yarn structure

Introduction

X-ray computed tomography (CT) is a medical imaging method using computer processing of obtained images (scans). Digital processing of geometry is used to create three-dimensional (3D) image inside the object from large series of two-dimensional x-ray images taken around one axis. Although the computed tomography is most often used in medicine, it is also more and more often used for testing in materials engineering. Another example is the use of CT in archaeology for imaging of sarcophagus content or e.g. DigiMorph project of the University of Texas at Austin that uses a CT scanner to study biological and paleontological specimens. X-ray tomography offers a powerful tool that enables internal structure of textiles to be explored before and after deformation and provides information on their geometry.

Computed Tomography

Using a high resolution CT scanner is a non-destructive technique that may be used to obtain internal images of materials. Schematic operation principle is presented in Figure 1. An X-ray beam passing through a rotating sample gives a two-dimensional projection that is recorded by the CCD detector. The purpose of the detector scintillator (for example monocrystal of cadmium) is to convert the x-ray energy into visible light to protect CCD matrix against radiation. In classical tomography, 2D projection is made up of attenuation coefficients of each stage of object scanning. Data collected are then used for numerical volume reconstruction by using an algorithm filtering out rear projection. As a final result, 3D model is obtained [1].

Industrial CT

Industrial computed tomography is a process that uses X-ray equipment to produce a 3D model of components both in outer and internal structure. Industrial CT has already been used in many areas of industry to monitor internal components.

The conversion of CT data into CAD models by using tools available on market is still quite difficult, and therefore this area offers large potential of development. In future, 3D-CAD rendering of data series from 3D tomography for simulation and analysis with the finite element method will be even more important. The reason for this is the fact that 3D model instead of theoretical model will be used as a basis for calculations for geometry of objects [2].

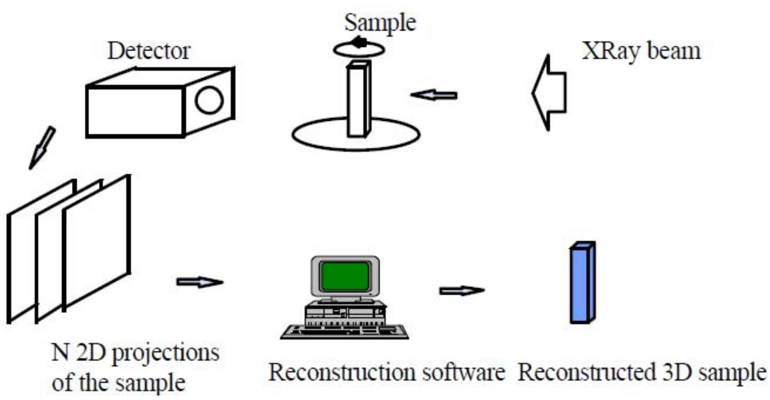

Figure 1. Principle of X-Ray Tomography

CT in textiles

Toshihiro Shinohara [3] proposed to extract the positional information of its yarns from a 3D image obtained from its X-ray CT images. For extracting the yarn positional information, filament directions are first estimated by correlating the 3D image with a filament model. Then, by averaging the estimated filament directions in a calculating region, the yarn direction is estimated.

Knowledge on the micro-structure of composites is important to investigate their mechanical properties such as the tensile stiffness. X-ray computer tomography, Pandita S.D., is used to characterize the micro-structure of rib weft knitted fabrics. This tomography technique provides three-dimensional images of rib weft knitted fabrics [4]. CT allows analyzing the spatial distribution of fibers, for example in textiles. The high resolution images for plain weave give interesting information in terms of spatial fiber distribution for both deformed and undeformed configurations [5].

Fiber migration

The existing strength analyses of twisted yarns showed a significant impact of fiber movement phenomenon, fiber migration. The last research shows that yarns are not ideally twisted in a helical structure and it is believed that fibers in yarn have stochastic distribution with variable distance of a fiber trajectory from the yarn axis. This phenomenon is closely related to tension of component fibers in the yarn twisting process.

In a yarn drawing process, there are some phenomena that must be taken into consideration in theoretical analysis, that is:

- Sliding the fibers apart and their breaking during drawing;
- Fiber migration in the process of twisting them into yarn;
- Compression of fibers and yarn;
- Unevenness of yarn.

The yarn structure is described by three main parameters: twist, fiber density, and fiber migration. The yarn structure may be divided into areas with larger or smaller radial coordinate. Packing density of fibers across the yarn cross-section is different. Its significant reduction occurs rather on the outer surface and in the core than between those areas. So far, the idealized helical yarn geometry according to Hearle J.W.S. theory (Figure 2a) has been taken in theoretical assumptions. In this theoretical model, it is assumed that yarn is of circular section and fibers form helical trajectories around the concentric cylinders with constant radius. Each fiber has a helical trajectory with constant pitch h and radius r, and helix angle increasing from 0 for $r=0$ to α for $r=R$. In reality, fiber trajectories in yarn are of very complicated shapes; one of such trajectories indicated with thick line is shown in Figure 2b. Therefore, a fiber trajectory is often questionable [6,7]

Materials and methods

Tests of five samples of multiple threads with a length of 5 mm were performed. Measurements of thread microtomography were taken with the best possible resolution of 2.5 μm. X-ray computed tomography is a non-destructive testing method of materials that makes it possible to obtain flat or spatial distribution of the selected physical quantity. It utilizes object projections taken from different directions to produce 2D sectional images or 3D spatial images. As a result of measurements, precise images of internal details of an object tested are obtained. Image scanning was performed by using SkyScan 1174 micro-CT scanner. An example 3D model of the sample D5 (1100 twists/m) is presented in Figure 3.

Results

As a result of imaging with CT, a set of images (scans) of the yarn cross-sections was obtained for each yarn sample as a bitmap that was then assembled into 3D model. Figures 4 - 8 present yarn in a longitudinal section for seven different distances from the yarn axis.

Discussions

As a result of CT scanning analysis of cotton yarn, it was found that the regularity of fiber distribution in section increases with increasing the number of yarn twists. Packing density of fibers across the yarn cross-section is different. Reduction occurs on the outer surface. Considering the helical arrangement of fibers in yarn, it was found that fibers, in the core area, are in a straightened form or twisted one with a small helix radius. The fibers, located further from the yarn axis, increase helix radius r and relocate toward the outer surface.

As a result of scanning analysis of the samples of obtained yarns made of staple fibers, it was found that the regularity of fiber distribution in section increases with increasing the number of yarn twists. Packing density of fibers in the yarn longitudinal sections is different depending on the distance of section from the yarn axis. Considering the helical arrangement

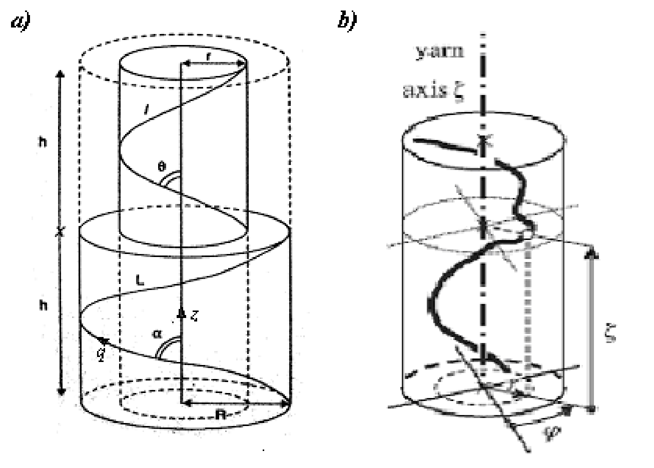

Figure 2. a) Idealized twisted yarn geometry [7]; b) fiber trajectory in yarn [6]

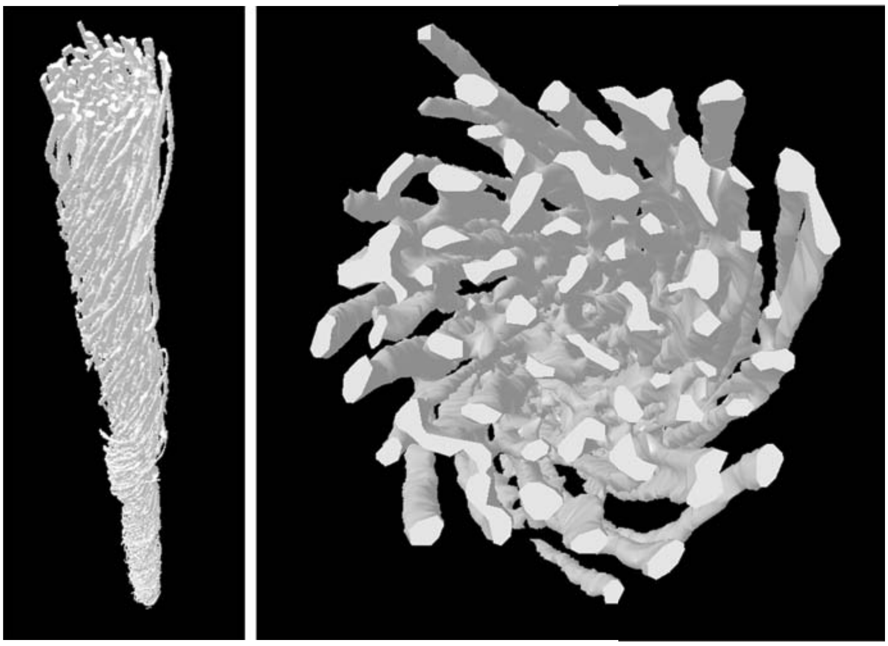

Figure 3. An example of a three-dimensional model of the sample D5 – 1100 twist/m

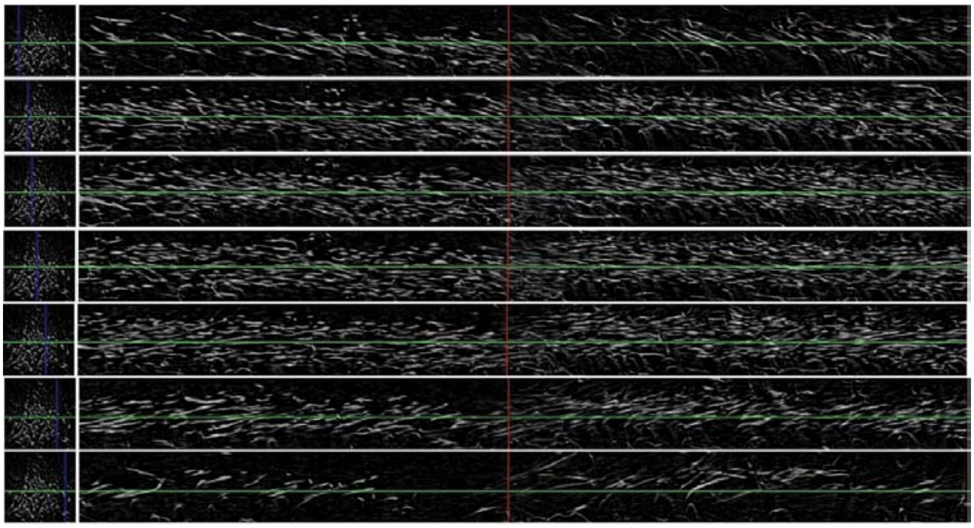

Figure 4. The longitudinal section yarn in seven different distances from the axis of the yarn - cotton yarn 25tex, 700 twist/m

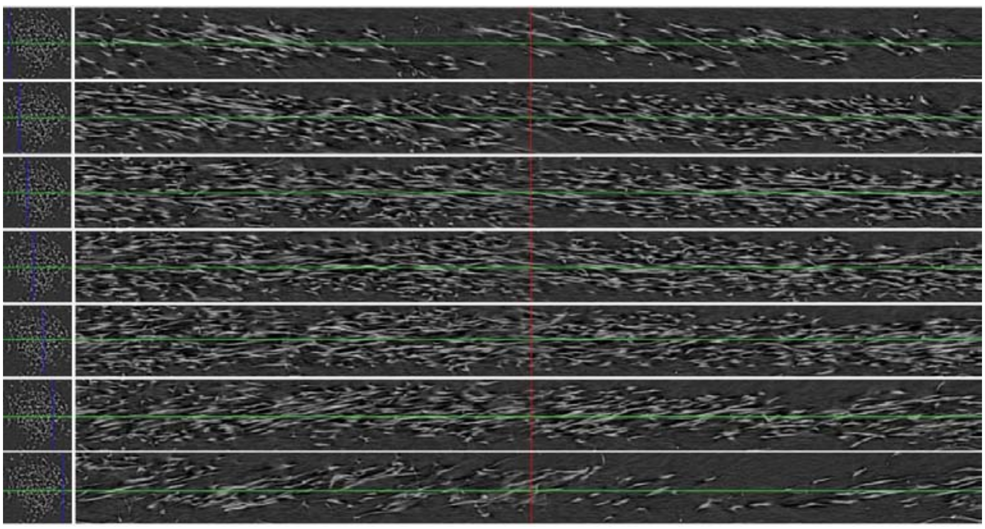

Figure 5. The longitudinal section yarn in seven different distances from the axis of the yarn - cotton yarn 25tex, 800 twist/m

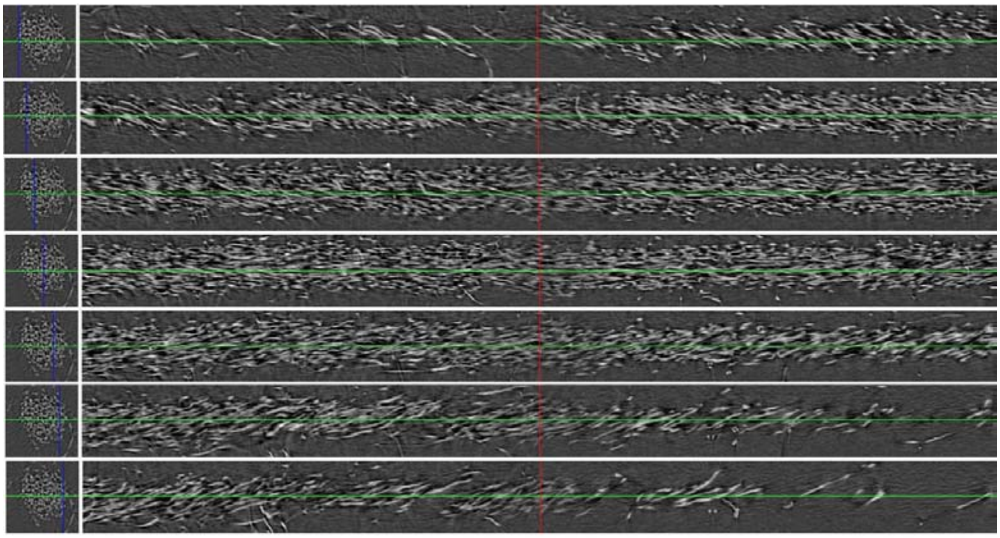

Figure 6. The longitudinal section yarn in seven different distances from the axis of the yarn - cotton yarn 25tex, 900 twist/m

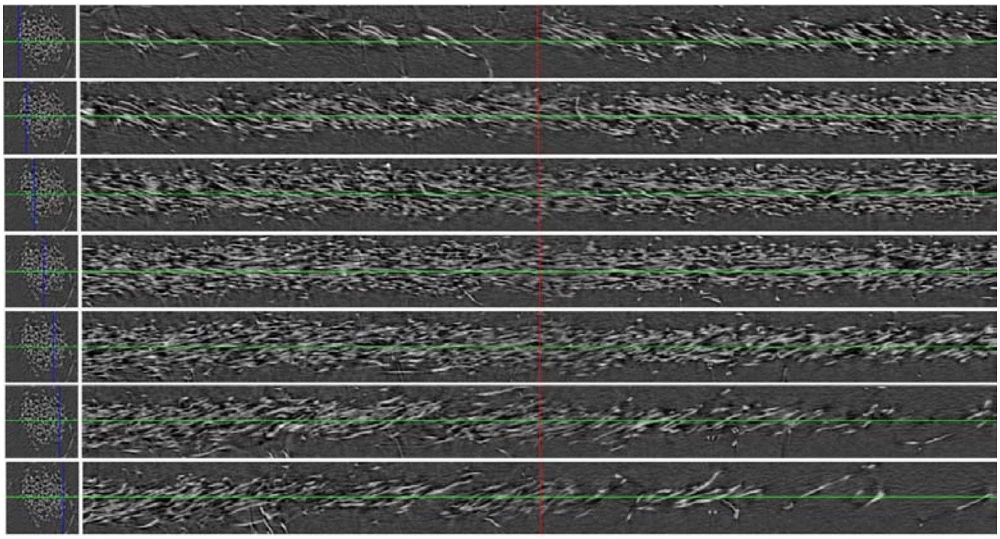

Figure 7. The longitudinal section yarn in seven different distances from the axis of the yarn - cotton yarn 25tex, 1000 twist/m

Figure 8. The longitudinal section yarn in seven different distances from the axis of the yarn - cotton yarn 25tex, 1100 twist/m

of fibers in yarn, it was found that fibers, in the core area, are in a straightened form and/or twisted one with a small helix radius and their uniform distribution. The fibers, located further from the yarn axis, increase their helix radius and are pushed toward the outer surface of the yarn.

Conclusion

There are many advantages to using CT scanning over traditional. The main points include:

- A non-destructive test for inspection and metrology;
- Design requirements for both internal and external components are validated quickly and accurately. Development costs are reduced in creating the first CAD model;
- Product quality is improved to reduce the risk of recalls;
- Internal complex features can be precisely measured without destructive testing;
- Parts are scanned in a free state environment with no fixtureing applying stresses which could damage delicate part or display warping that is not present in the part;
- For the first time rapid prototyping of the internal components can be completed without the daunting task of creating the CAD file from scratch.

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