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Yarn Structure Investigation with Micro CT and Image Processing Techniques

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Abstract

A new technique based on a combination of micro computerized tomography (CT) and digital image processing was used to investigate ring yarn structure. Two yarn specimens were scanned through a micro CT system and three image processing algorithms were developed to extract the structural information of the yarns. A comparison was made between structures of both yarns and their effects on yarn quality were analyzed. The results indicate the combined techniques can successfully characterize the structure of ring spun yarns, which facilitates improved understanding of the structure-property relationships of yarns made from staple fibres such as fine wool and cotton.

Introduction

The arrangements of fibres within a textile yarn have significant influence on its quality parameters [1]. Although extensive research has been conducted on yarn quality improvement, there is still a lack of knowledge on yarn structure [2]. This lack of understanding of yarn structure can be attributed to an absence of appropriate techniques to characterize complicated yarn structures. The tracer fibre technique and cross sectional microtomic method have been used in practice for decades to study fibre arrangement inside yarns but they only provide partial information of yarn structure. The tracer fibre technique exposes the trajectory of a very limited number of single fibres out of stack of tens or even hundreds of fibres twisted inside a yarn [3]. The cross sectional microtomic method only reveals the fibre arrangement at a certain section along yarn length [4]. Both of these techniques are invasive in operation, hence they cannot be applied together on a single yarn specimen. The complete characterization of yarn structure requires information on cross sectional as well as longitudinal arrangements of the fibres, which cannot be achieved together through these two techniques.

The idea of applying micro computerized tomography (CT) has recently emerged to study the yarn structure [5,6]. Micro CT scanning is a non-invasive technique that works quite similarly to medical CT scanning except that it uses a high resolution X-ray detector (up to the sub-micron level) [7]. In the scan the yarn specimen is slowly rotated under continuous exposure to the X-ray beam, which penetrates it continuously around its circumference. The resulting X-ray projections at each angle are recorded by a detector. Once the scanning cycle is complete, the projections are merged together to form a three dimensional model of the yarn, which is can then be sliced along the cross sectional plane. The resulting sequence of cross sectional slices achieved through micro CT scanning contains information of internal yarn structure both in terms of cross sectional as well as longitudinal arrangements of fibres. However, this information is only useful if the fibre elements can be extracted with reasonable accuracy and quantified into meaningful yarn structure parameters. Previous studies on micro CT scanning of yarns have not shown a method for translating the results into a useable form [5,6].

In this study, a combination of micro CT scanning and digital image processing has been used to address this problem. The CT images of yarns were acquired through high resolution CT scanning and processed through image processing algorithms to calculate various yarn structural parameters. The potential application of this combined technique to investigate complete yarn structure has been evaluated by applying it to two yarn specimens that were produced by controlled variations in spinning triangle geometry. The differences in the quality of yarns have been assessed in the context of their structural differences.

Materials and methods

Yarn spinning

Two yarn specimens, i.e., yarn A and B both of 12 tex linear density were produced from 100% Australian cotton (upper half mean length 31.5 mm, 4.5 Micronaire) on a Zinser 350 (Saurer, Switzerland) ring frame. The linear density and twist level of the roving were 724 tex and 42 TPM (turns per meter) respectively. The spindle speed was set up at 10,600 rpm. An air suction based compact spinning attachment was mounted over the ring frame to compact the fibrous strand at two vacuum pressure settings i.e. low pressure and high pressure compacting. The temperature and relative humidity in the spinning shed were 25°C and 55% respectively. The yarns were produced by controlled variations in yarn twist (Z direction), fibre compacting level and diagonal offset direction [8]. Yarn A was produced with 1108 TPM, high compacting pressure and left diagonal offset while Yarn B was produced with 1032 TPM, low compacting pressure and no diagonal offset. Yarn tensile properties were evaluated through Uster Tensorapid 4 (Uster Technologies, Switzerland) while yarn evenness and hairiness was measured on Uster Tester 4 (Uster Technologies, Switzerland).

Micro CT scanning

Both yarn specimens were scanned through a helical type micro CT scanner that was built in-house at the Australian National University (Canberra, Australia). The yarns were mounted inside a carbon fibre tube of 3 mm diameter and 50 mm length. The ends of the yarns were taped with the tube keeping the specimen under slight pre tension to avoid unnecessary movement during the scan. The scanning resolution (i.e. voxel size) of the CT system was 1.33 microns while its magnification was 110.68 times. The X-ray energy was set at 60 keV. The exposure time per projection was 1.8 seconds and a total of 26,782 projections were collected. The resulting projections were merged together in a 3D volumetric model that was sliced along the yarn's cross sectional plane to produce a sequence of CT images.

Image processing

Three algorithms were developed using image processing toolbox of Matlab R2016b (MathWorks, USA) to process and quantify the yarn CT data, which comprised of a sequence of 12,240 CT images per specimen. The first image-processing algorithm enhanced the original images through noise removal, image smoothing, edge enhancement and background subtraction, preparing them for further analysis. The second image-processing algorithm performed various morphological operations on the pre-processed images such as erosion and dilation to determine total fibre and yarn areas. The third image-processing algorithm segmented the individual fibres in each image based on their movements in succeeding CT image by motion segmentation and region growth techniques. Image J 1.46r (National Institutes of Health, USA) was used for visualization of the yarn volumetric model.

Results and discussion

The quality parameters of both yarn specimens are given in Table 1. Yarn A showed superior quality than yarn B over most of the parameters measured. The broader contrast between the yarn quality parameter was the yarn strength, as yarn A was 3.7 cN/tex (i.e. 28-29%) stronger than yarn B. It is quite logical to think that the strength in a yarn comes either from the fibre strength or their arrangement inside yarn structure. As both yarns were produced from the same roving, the effect of material variation can be eliminated. Thus, the arrangement of the fibres in each yarn was analyzed using micro CT scanning and then investigated.

Table 1: Quality parameters of yarn specimen

Sample ID	Yarn strength [cN/tex]	Yarn elongation [%]	Yarn hairiness [H index]	Yarn evenness [CVm %]
Yarn A	16.6 ± 1.5	6.49 ± 0.46	3.36 ± 0.2	16.23 ± 0.15
Yarn B	12.9 ± 2.01	4.99 ± 0.68	3.58 ± 0.1	17.14 ± 0.31

Fig. 1 shows the typical cross sectional images of yarn A and yarn B as acquired through micro CT scanning. It is difficult to identify any differences in both images by mere visual comparison. However, these images can be processed through digital image processing techniques to calculate various yarn structural parameters to compare their structures.

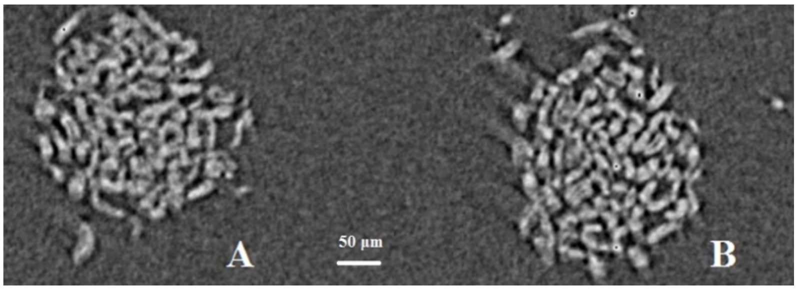

Fig. 1: Typical CT cross sectional images of yarn A and yarn B

In order to characterize the yarn structure, two sets of parameters need to be calculated. First set includes those parameters which are related to fibre distribution within yarn cross section such as fibre packing density. The second set of parameters is related to the longitudinal arrangement of fibres such as fibre migration intensity as described by Hearle and his associates [1]. The information related to the set of cross sectional parameters lies within each individual CT image while the information related to the set of longitudinal parameters is spread across various CT images. Hence, three different image processing algorithms were applied to process the CT dataset and to extract the information of interest in terms of meaningful parameters and their outcomes are shown in Fig. 2 (a-c) representing image enhancement, cross sectional analysis and individual fibre segmentation respectively.

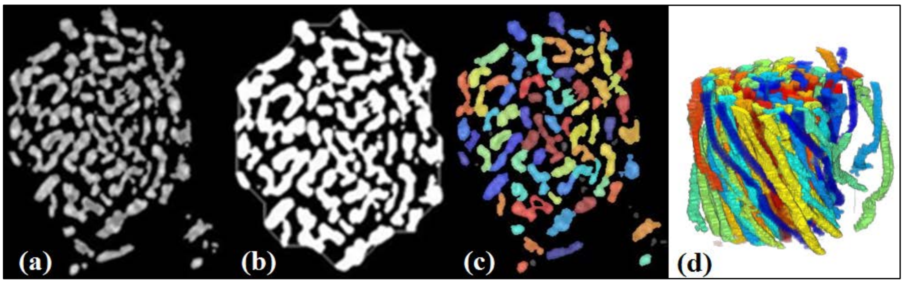

Fig. 2: Images processed through three image processing algorithms a) enhanced image b) characterization of yarn cross section related parameters c) Individual fibre segmentation and d) volumetric representation of individual fibre tracking along yarn length

The cross sectional analysis resulted in total fibre and yarn areas allowing measurement of fibre packing density and yarn diameter. A 3D volumetric model of the yarn is shown in Fig. 2 (d), which is produced by stacking final processed images together where each fibre is represented in a different color. This indicates the ability of the technique to track the positions of all fibres within the yarn. The spatial coordinates of the tracked fibres allowed characterization of fibre migration in terms of its amplitude and intensity [1].

The averaged values of structural parameters measured through image analysis of the CT dataset are given in Table 2. The diameter of yarn A was slightly smaller and its packing density was slightly higher than yarn B, suggesting a slightly more compact structure. However, these differences were minor and within the standard deviation of the measurements. The amplitude and the intensity of the fibre migration were higher in yarn A compared to yarn B. The higher standard deviations in both migration parameters for yarn A represent broader differences in migration behaviour of fibres in this yarn. This comparison suggests that the higher extent of fibre migration resulted in a more integrated structure of yarn A enabling it to withstand comparatively higher tensile stress than yarn B.

Table 2: Yarn structural parameters calculated through image analysis of yarn CT dataset

Sample ID	Yarn diameter [microns]	Packing density	Amplitude of migration	Mean migration intensity
Yarn A	230.67 ± 8.6	0.499 ± 0.02	0.25 ± 0.2	1.61 ± 0.05
Yarn B	236.04 ± 6.24	0.494 ± 0.02	0.21 ± 0.1	1.36 ± 0.02

Conclusion

A technique based on a combination of micro CT and image processing was used to investigate and compare the structure of two cotton ring yarns. The ability of the combined techniques to track the arrangement of all fibres within a yarn is established. The comparison of structures of two yarns suggest that higher fibre migration in Yarn A is likely to be the cause of superior tensile strength in one of the yarns. The proposed technique will be applied on a variety of yarns in future to study yarn structure-property relationships and to improve yarn quality.

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