Acquisition and Observation Methods of Three-dimensional Leather Structure Based on Micro-CT

HUAYONG ZHANG[1]*, TIANDUO LI[2], YULING WEI[1] and JINYONG CHENG[2]

[1] State Key Laboratory of Biobased Material and Green Papermaking, Qilu University of Technology, Shandong Academy of Sciences, Jinan, China 250353.

[2] Shandong Provincial Key Laboratory of Molecular Engineering, School of Chemistry and Pharmaceutical Engineering, Qilu University of Technology (Shandong Academy of Sciences), Jinan, China 250353

Abstract

Components and working principle, parameters and data acquisition steps of micro-CT are introduced in detail. Taking the chrome-tanned leather for example, the images of each stage of the experiment are presented and the 3D digital models of leather structure with 1.5μm resolution have been obtained by micro-CT. It lays a good foundation for the study of leather structure by micro-CT.

INTRODUCTION

Leather is formed by the tight weaving of collagen fibre bundles. The three-dimensional (3D) woven network of collagen fibres is the structural basis of the physical and mechanical properties of leather. Recognizing and studying this three-dimensional woven network of collagen fibres can facilitate researches on structure-performance relationships of leathers effectively and can promote improvement and development of leather production techniques.[1] There are many methods to acquire the 3D woven structure of leather, including microtomy, the layered polishing method of metallographic sample preparation, magnetic resonance imaging (MRI) imaging method and the micro-CT method.[2-5] Among them, the first two methods are time and labour-consuming ones. Although MRI imaging method won't cause damage to samples, it has low resolution and high cost. In this study, the micro-CT method which causes no damage to samples and has high resolution was applied.

CT is the short for computed tomography. Micro-CT generally refers to CT with the spatial resolution reaching lμm~10μm. It is a non-invasive and non-destructive imaging technique and scans samples by X-ray to acquire internal structural information of samples, without damaging samples.[6] Later, it composes 3D structural images of samples based on analysis and processing, thus producing thorough three-dimensional structural information of samples. Micro-CT is widely applied in many research fields, such as medicine, materials, biology, archaeology, electronic engineering and geology.[7-10]

The small size of leather fibre bundles and the complicated weaving structure proposed high requirements on performance and parameter setting of instruments. So far, there are few studies on three-dimensional structure of leather based on micro-CT. In 2014, E. Bittrich *et al.* studied structure of leather by micro-CT and acquired the 3D structure of vegetable-tanned leather under the resolution of 3.3μm. However, they failed to get clear structure images of chrome-tanned leather, which were attributed to influences of the tanning metal.[5]

In this study, scanning steps and imaging observation method of high-resolution micro-CT to chrome tanned leather were explored and introduced systematically. Research conclusions can provide certain assistance and references to further study the 3D structure of leather.

EXPERIMENTAL MATERIALS AND INSTRUMENTS

Dried pieces of blue stock of chrome-tanned cattle hide was chosen for this work and were provided by the Qilu University of Technology Leather Laboratory.

The micro-CT Equipped with CCD detector and analysis software was a Bruker SkyScan2211, Belgium.

EXPERIMENTAL METHODS

1. Composition and principle of micro-CT

The major component of micro-CT is composed of an X-ray source, rotating sample platform and high-resolution detector (Fig.1). In addition, it covers the control system and computer processor *etc*. Structure of micro-CT is shown in Fig. 1.

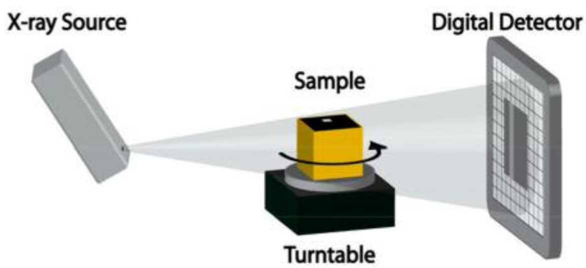


Figure 1. Schematic diagram of micro-CT system.

* Corresponding author: E-mail: headingzhy@126.com

The X-ray emission source and detector were fixed, while the samples rotated between X-ray source and detector. Besides, samples could move vertically and horizontally. The conical X-ray beam which is produced continuously by X-ray sources penetrate samples and images of the sample was aimed at the X-ray detector. Since the penetrability of X-ray in different substances differs, light intensity at different positions of the detector varies. Accordingly the source intensity produced a grey image[11] and the projected image of sample from this perspective is acquired. The X-ray projection images of the sample from different perspectives are gained by rotating it at certain angles. After a series of projection images are acquired, the data of these projection images were processed by a mathematical algorithm, thus getting three-dimensional information of the sample. X-ray sources mostly have a tungsten anode with micro-focus ability. Micro-focus technology uses the geometrically amplified X-ray system which reduces marginal fuzziness and can acquire X-ray images from different perspectives around the object. The detector has a plate detector and CCD detector. Processing and analysis of data formed by micro-CT scanning requires the use of special three-dimensional analysis software.

2. Projection images Acquisition by micro-CT

2.1 Preparation of sample

According to the target resolution, the leather sample was processed into a certain size of sample blocks (cylindrical is the best, but other shapes can also be used). Then, sample was fixed vertically onto the sample holder of micro-CT by light wax and then put into the instrument.

2.2 Scanning steps and parameters

(1) Determine voltage and current of the X-ray source according to penetration extent of X-ray into sample.
(2) Adjust sample at the centre of the view (screen) and keep it at this position in subsequent steps.
(3) Adjust resolution to target resolution from low to high.
(4) Sample was removed out of the view and the exposure time was adjusted until the mean transmittance was about 60%. Meanwhile, CCD flat fields (bright and dark fields) were corrected.
(5) Sample was moved back to the original position and X-ray focusing was carried out by adjusting the focusing current.
(6) Set scanning step length and scan times in each step.
(7) Select the scanning range (180° or 360°).
(8) Set the save path and begin to scan to get series projection images of the sample.

2.3 Image processing

(1) Adjust relevant parameters and reconstruct the series projection images into a series two-dimensional (2D) section image.
(2) Observe and produce 2D section images along different directions
(3) Produce and process 3D images by using series 2D section images.

RESULTS AND DISCUSSIONS

1. Determination of scanning parameters

In this experiment, resolution was set at 1.5μm/pixel and the leather sample size was about 5.4mm x 3.9mm x 8mm. Depending on the structural properties of the leather, image qualities under different parameters were observed and compared. Having comprehensive consideration of the efficiency and quality, CCD detector was chosen. Scanning parameters were set: voltage and current of the light tube were 50KV and 320μA, respectively. The exposure time was 1000ms and the focusing current was 620.9mA. The scanning step length was 0.2° and each step had 8 scans. The scanning angle was 180°. The scan took a total of 3 hours and 38 minutes, getting 970 projection images.

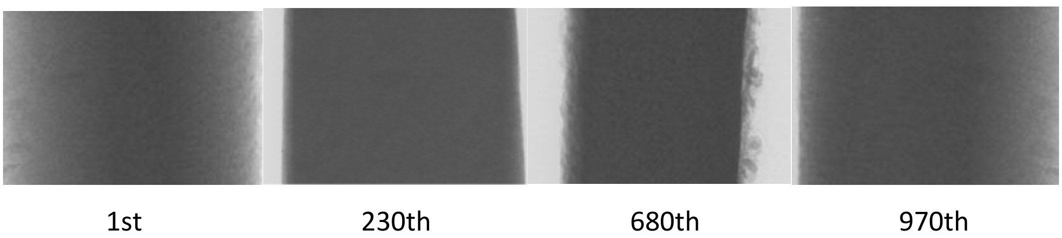


Figure 2. Leather projection images acquired by micro-CT. Numbers refer to image number.

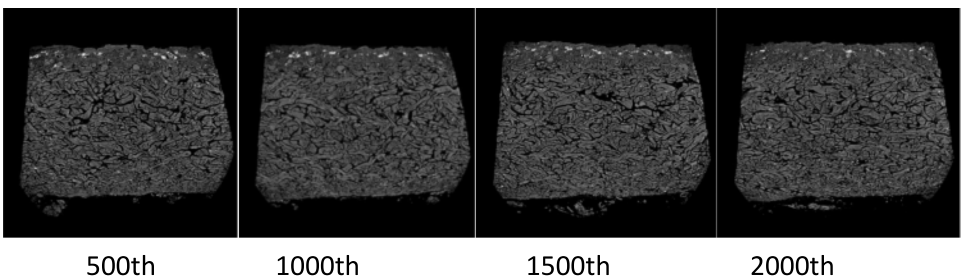


Figure 3. Leather section images reconstructed from the series CT projection images.

The image pixel size was 4032 x 2688 (bmp format, 10.3M). Four images are shown in Fig. 2. Since the projection image was gained after X-rays penetrated through the whole sample, it superposed multiple layers of sample information and couldn't reflect the leather's structure intuitively.

2. Reconstruction and observation of 2D section images

Section images of leather were reconstructed from the series of projection images by the NRecon software (NRecon is a high-speed volumetric reconstruction software, which can be optionally accelerated by a GPU-cluster, which contains eight NVIDIA Tesla cards. It uses cone-beam volumetric algorithms. Reconstruction includes beam-hardening correction, alignment optimisation, ring artifact correction, reconstruction in a restricted volume of interest, reconstruction of objects larger than the field of view, interactive density window selection and many other options). Firstly, the series projection images were aligned (Misalignment = 12) and eliminated negative influences of ring artifact (Ring Artifact Correction = 14) and beam hardening (Beam Hardening Correction = 90%), accompanied with appropriate smoothing (Smoothing = 3). Next, 2D sections were reconstructed and 2357 series images of 2D section (x-y) were produced. Pixel size of each section image was 4032 x 4032 (bmp format, 15.5M) and the interlayer distance was 1 pixel (1.5μm). Four section images are shown in Fig. 3. It can be seen from Fig. 3 that the grain surface and reticular layer of this leather sample were obviously distinguished. In the grain layer, fibre bundles are thin and woven tightly. In the reticular layer, fibre bundles of the middle portion are thick and woven loosely, showing big spaces between fibre bundles. Some fibre bundles close to the grain layer and dermal layer are thin and woven slightly tightly. The many white bright spots in Fig. 3 are high-density crystals which are not processed cleanly. There are many large white bright spots in the grain layer, but there are few small spots on the reticular layer.

Three orthogonal section images centred at any point of the reconstructed space were displayed by the DataViewer software (DataViewer has two viewing modes: 2D and 3D. The 2D case is quite straightforward. In 3D viewing mode, three orthogonal views, namely, coronal or x-z view, sagittal or z-x view, and transaxial or x-y view, are extracted from image volume at the point indicated by a cross-hair and displayed next to each other). Pixels were expressed in different colours according to the grey value. For example, in Fig. 4, three orthogonal section images which passed through one point were clear. The same structure could be observed from different perspectives to reflect fibre bundles and pores intuitively. In addition, all structures can maintain the original shape completely by using the digital slicing method, without deformation and collapsing.

3. Reconstruction and observation of 3D images

A series of 2D section images were reconstructed into 3D images by the volume rendering software CTVOX (CTvox displays a set of reconstructed section images as a realistic 3D objects with intuitive navigation and manipulation of both object and camera, a flexible clipping tool to produce cut-away views, background selection including custom scenery and an interactive transfer function control to adjust colors and transparency. Imaging possibilities include lighting, shadows and stereo viewing). By setting the transparency of pixel points with different grey values, the three-dimensional structure of overall structure or one substructure was reflected intuitively (Fig. 5a). Then certain colour and material properties could be given. In Fig. 5b, blue colour, surface lighting and shadows were given to the pixel points and the emission and diffuse nature of pixel points were adjusted to make the 3D structure clearer. Such as the trichopores, fiber and pore cross sections were much clearer than those in Fig. 5a. Moreover, random digital cutting could be carried out and one part of the result was displayed and processed. For example, the 3D digital model of the selected part position is shown in Fig. 6. In Fig. 6, obviously, the part surface of grain layer was cut off, which exposed the pores or veins clearly. The high-density white crystals were exposed (Fig. 6a). To distinguish fibre bundles and pores more clearly, the fibre bundles were expressed in deep blue and pores were expressed in red (Fig. 6b). Then, fibre bundles and high-density crystals were set transparency, the 3D connection of the pores were brought out (Fig. 6c). Later, fibre bundles and pores were set transparency, so 3D distribution of high-density crystals was observed (Fig. 6d).

CONCLUSIONS

A method to acquire and observe the 3D woven structure of leather through micro-CT was introduced. The composition and principle, parameter settings and data acquisition steps of micro-CT were introduced thoroughly. Images were processed by the corresponding software accordingly, thus getting the series 2D and 3D images of chrome-tanned leather. The 3D digital structure gained has the following purposes and significance: it is not only beneficial to further study the morphology of the 3D structure of leather accurately and thoroughly, but also to explore the relationship between structure and performance of leather. Assisted by the corresponding image processing tool, any slices or internal structure of 3D volume can be analysed deeply through a series of cutting, enhancing and measurement functions, such as measuring morphological parameters of leather fibre bundles and pores (*e.g.* diameter, length, specific surface and volume), studying distribution pattern of fibre bundles, observing connectivity of spaces among fibre bundles, and calculating physical parameters (*e.g.* porosity, volume density and fractal dimension) of leather. Further studies on these aspects will be carried out in future.

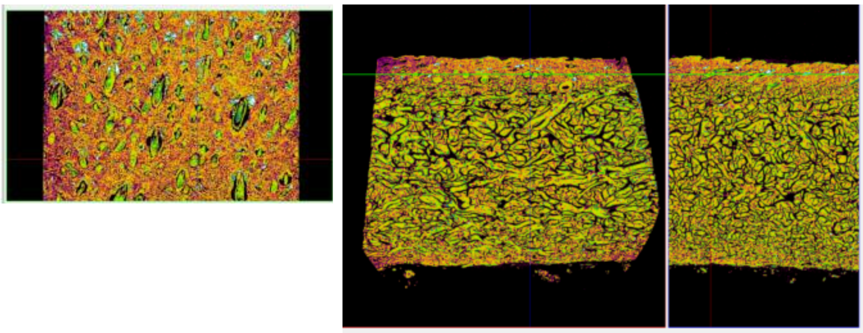
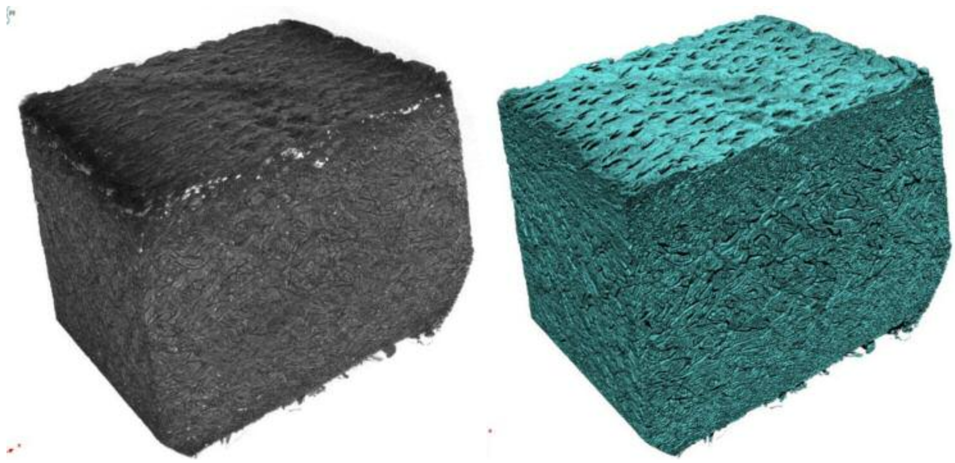


Figure 4. Three orthogonal section images of leather.

(**a**)



(**b**)

Figure 5. 3D volume rendering reconstruction images of leather (5.4mm × 3.5mm× 3.9mm).
(**a**) Original gray (**b**) Certain colour and material properties given.

(**a**) (**b**)

(**c**) (**d**)

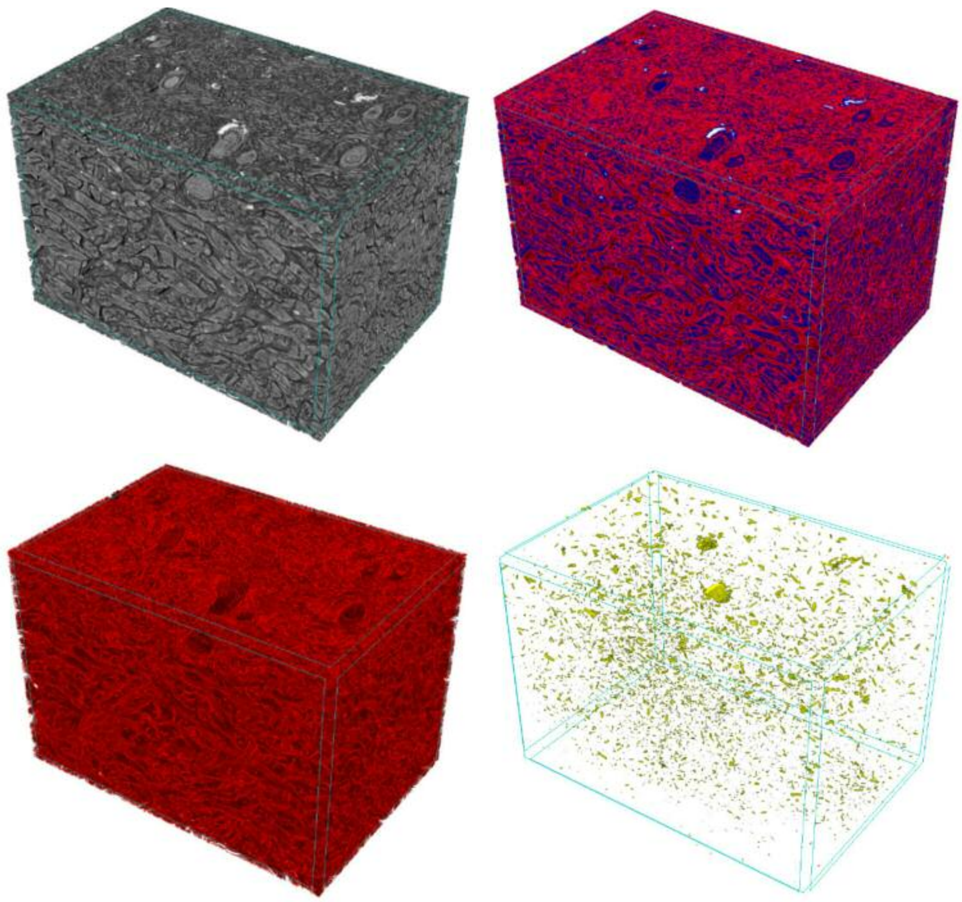


Figure 6. Selected part position of 3D digital model (3mm × 1.5mm × 2mm).

ACKNOWLEDGEMENTS

This work is supported by the Project of Natural Science Foundation of Shandong Province (No. ZR2017LB024) and the National Natural Science Funds of China (No. 211776143), China.

(Received 2019)

in association with
China Leather

References

1. Yuan, J. J., *Leather Sci. and Eng.,* 2011, **21**, 19.
2. Luo, L. S., *Materials Rev.,* 2010, **24**(09), 1.
3. Zhang, H. Y., *J. Amer. Leather Chem. Ass.,* 2014, **109**, 1.
3. Zhang, H. Y., *J. Amer. Leather Chem. Ass.,* 2018, **113**, 248
4. Zhang, H. Y., *J. Soc. Leather Technol. Chem.*, 2015, **99**, 23.
5. Bittrich, E., *J. Amer. Leather Chem. Ass.,* 2014, **109**, 367
6. Moreno-Atanasio, R., *Particuology,* 2010 (8), 81.
7. Kariem, H., *J. Materials Sci.,* 2018, 1.
8. Zhou, M., *Energies*, 2018, **11**(6), 1409.
9. Heyndrickx, M., *Mater. Charact.,* 2018, **139**, 259.
10. Zauer, M., *Wood Sci. Technol.,* 2014, **48**(6), 1229.
11. Sukop, M. C., *Phys. Rev. E.,* 2008, **77**, 026710.