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The Use of X-ray Computed Tomography in Bio-Composite Research

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Abstract

X-ray computed tomography (CT), which was introduced in the medical field in the early 1970s, is also a powerful tool for the non-destructive measurement of dynamic processes in wood. For more than 20 years, medical CT has been used in wood research at Luleå University of Technology. The uniqueness of the CT equipment allows processes such as drying, modification; water absorption; internal and external cracking; and material deformation to be studied in temperature- and humidity-controlled environments. The data recorded by the CT scanner during the process is converted into two or three dimensional images that, for instance, can show dynamic moisture behaviour in wood drying and crack formation.

This paper provides an overview of the possibilities of using CT in bio-composite research, and shows examples of applications and results that can be particularly difficult to achieve using other methods. A specific focus is on studies on wood products that use combinations with materials such as metal and especially about how to deal with the difficulties that this entails.

The practical application of the result is that CT scanning, combined with image processing, can be used for non-destructive and non-contact three-dimensional studies of exterior construction elements during water sorption and desorption, to study parameters such as swelling and shrinking behaviour; delamination phenomena; and crack development.

Keywords: Computed tomography, wood-composites, Gibbs phenomenon.

Introduction

Computed Tomography (CT) has been used for wood research since the early 1980s [1, 2]. This study focused on the use of medical CT scanners for wood research for its convenience in terms of sample size, versatility, and ease of operation. The working principle of CT is that X-rays are attenuated differently when passing through different materials. A detector collects the X-ray radiation emitted from a source on the opposite side of the object in different positions around one plane. The attenuation of the X-ray radiation is dependent on the attenuation coefficient of each material according to Lambert-Beer’s law. The data collected by the detectors is processed with a filtered back-projection (or convolution) algorithm, which is a technique based on Fourier transform, and converted into a two dimensional grey-scale image. This image is formed by pixels that carry the information of the so-called CT number or Hunsfield number, which is the normalization of the X-ray attenuation coefficient to the corresponding absorption coefficient for water. The CT number for air is around -1000 and for wood it is around -500 (there is a large variation depending on the density of the wood species, type of wood, and its moisture content). High-density materials appear from light grey to white in a CT image and low-density areas are darker grey to black. Usually a water phantom is scanned together with the specimen so that the CT image can be calibrated in a way that air appears black and water appears white. The result is an image with a grey scale that is proportional to the density, which allows further studies such as moisture content measurements and capillary flow in wood based materials.

In a medical CT scanner, the sample remains still while the X-ray source and detectors rotate on opposite sides, which is an advantage when working with large samples. The use of medical CT for bio-composite elements is limited by the fact that materials that are found above aluminium in the periodic system block all the X-ray radiation and are thus unsuitable to be scanned. Another limitation is the Gibbs phenomenon, which shows the borders between materials with large difference in CT numbers as a blurry transition because the Fourier transform cannot reconstruct a step function correctly and overshoots where there is a sharp discontinuity [3]. These two problems are addressed in this article with two projects studying a combination of wood and aluminium. The first is the testing of a glulam beam with a metallic connector and the second is the study of different reconstruction algorithms to study wood-aluminium transitions.

Materials and Methods

A Norway spruce (*Picea abies* Karst. (L.)) glulam beam (115 x 315 x 400 mm^3) with a metallic connector was used for CT scanning. The parts of the metallic connector, formed by a 5 mm thick plate and 100 mm long dowels of 10 mm in diameter, were replaced by aluminium (**Figure 1**).

Figure 1: Glulam beam with the connector parts replaced by aluminium.

Luleå University of Technology in Skellefteå has established a CT centre that uses the advantages of medical CT to perform unique tests for the non-destructive monitoring of dynamic processes such as drying, modification, tracking, and material deformation.

Eventually, the CT scanner is combined with a specially designed drying chamber that allows reproducing industrial drying schedules or thermal modification processes and scanning the material as it is being subjected to the process.

The scanning was performed in a Siemens Somatom Emotion Duo medical CT scanner, which has an energy range from 80 to 130 kV and a scanning depth ranging from 1 to 10 mm. The field of view is 500 x 500 mm^2 divided into 512 x 512 pixels, providing a resolution of 1.024 pixels per mm. Applying different reconstruction algorithms built into the scanner's software, it can generate images with higher resolution. In order to study the effects of these algorithms in the reconstruction of the border between materials, a combination of aluminium and wood was scanned. **Figure 2** shows the scanned object: two pieces of Scots pine (*Pinus sylvestris* L.) with a 3 mm aluminium plate in between them. The object was scanned with no reconstruction (spatial resolution of 1.024 pixels per mm) and with six different reconstruction algorithms reducing the field of view in half (spatial resolution of 2.048 pixels per mm).

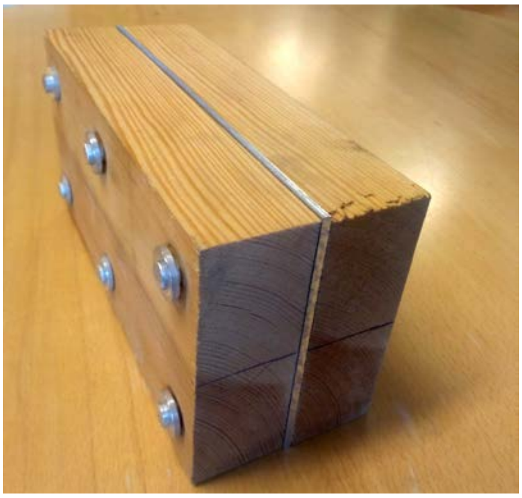

Figure 2: Two pieces of Scots pine attached to a 3 mm thick aluminium plate.

Results and Discussion

Figure 3 shows a CT image of the glulam beam with aluminium replacing the original metal connectors. The lower dowel is sealed with silicone sealant. It is clearly possible to scan wooden elements with aluminium parts and inspect the interactions of both materials. This means that it is possible to study metal-wood composites as long as the metallic parts are replaced with aluminium or any other suitable material like resins or plastics.

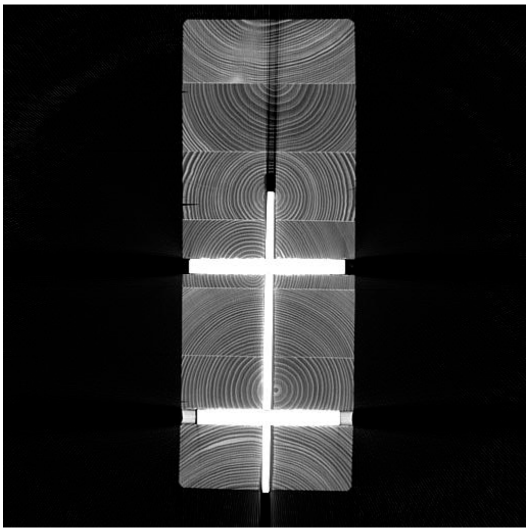

Figure 3: Cross-sectional view of a glulam beam of Norway spruce with an aluminium plate anchored with two aluminium dowels. The lower dowel is sealed with a silicone sealant. The grey scale of the image indicates density: high density materials, like aluminium, are white, whereas low density (air) is represented by black pixels.

The precision can, however, be lowered in areas near the transition of materials due to the Gibbs phenomenon. **Figure 4** shows the values of the CT number for the object presented in **Figure 2** in a profile perpendicular to the aluminium plate from the different reconstruction algorithms that were tested. These different algorithms show different sharpness in the transition between wood and aluminium, but none of them is able to capture the sharp border. The transition zone in the reconstructed images is between about 3 and 7 pixels in width depending on the reconstruction algorithm.

Figure 5 shows a CT image of the cross section of the object with no reconstruction (a raw image from the CT scanner) and with two different reconstruction algorithms. Even though **Figure 5** shows an improvement in image resolution with increasing sharpness of the algorithm, it is also known that this increases the noise and therefore produces a less accurate picture.

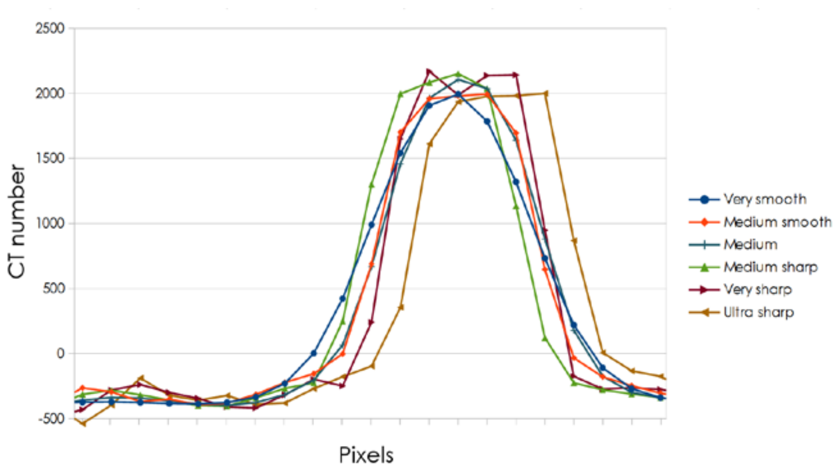

Figure 4: CT number corresponding to the transition wood-aluminum-wood as represented by six different reconstruction algorithms.

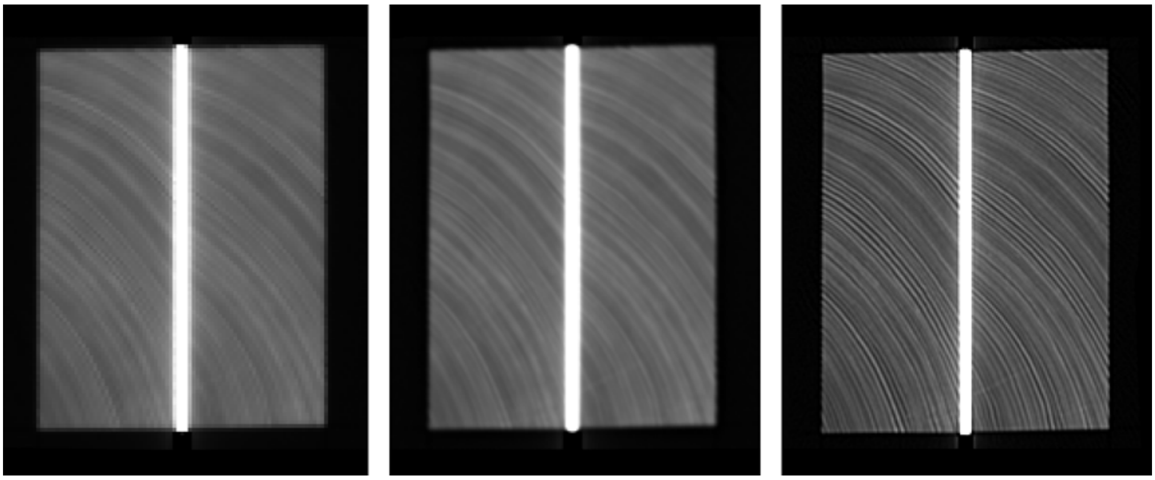

Figure 5: CT image of two Scots pine wood pieces attached to a 3 mm thick aluminium plate with no reconstruction (left), medium-smooth reconstruction algorithm (center), and very sharp reconstruction algorithm (right).

The application of medical CT-scanning can be used for non-destructive and non-contact three-dimensional studies of different wood composite elements during water sorption and desorption, to study parameters such as swelling-shrinking, delamination phenomena, and crack development.

Conclusion

The division of Wood Science and Engineering at Luleå University of Technology has one of the few CT facilities in the world specifically adapted for material studies in large scale. Furthermore, the CT scanner can be combined with a specifically designed drying chamber.

It has been shown that medical CT is a powerful tool for the study of composites that combine wood and aluminium. A high accuracy can be achieved by selecting the appropriate reconstruction algorithm, and the response of the specimen to dynamic processes can be measured: cracks, deformation, interactions with water, etc.

The practical examples given in this paper provide an overview of possibilities and limits of the CT scanning technique for testing different timber engineering elements in which wood, metal, and moisture interact and strongly influence the performance.

References

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