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Observation of Inner Structure of Compressively Molded Wood

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The compressive molding process of wood with the high-pressure steam treatment has been developed in our laboratory. However, the best setting for the fabrication of desired products has determined by trial and error. Thus, we have been investigating a designed and manufactured aid-system for the process, we have been studying about the relationship between the steaming conditions and the changes of physical properties of treated wood. In this paper, square shaped woods were fabricated from logs by the compressive molding process with several steaming conditions. Next, the changes in the inner structure of before and after molded wood were observed by the CT without cutting. Comparison of annual rings distribution of processed woods, the wood fabricated with incomplete softening treatment was not enough softened and deformed. Three-dimensional models of before and after processed wood could be constructed and visualized from the CT images. By using this technique, inner structures of wood (inner branches, inner grain pattern) were observed on computer screen.
Keywords: CT image, Compressed wood, High-pressure steam

1. INTRODUCTION

The compressive molding process of wood with the high-pressure steam treatment has been developed and studied in our laboratory [1-2]. This process has been introduced by some facilities and researchers. They are examining multi-purpose and effective utilization of woody resources by the technique. However, the best setting for the fabrication of desired products was determined by trial and error. Additionally, the setting was varied by conditions of raw material (species, moisture contents, the state of branches...). Therefore, the fundamental knowledge of wood and well information for the technique is needed. Thus, we are investigating a designed and manufactured aid-system for the process [3]. We are studying about the relationship between the steaming conditions in fabricating process and the changes in structural properties by compressing. In this paper, the square shaped woods were fabricated from logs by compressive molding with several steaming conditions. The changes in the inner structures of before and after molded wood were observed by the Computer Tomography without cutting. The distribution of annual rings was numerically analyzed and the deformation and movement of inner branches were visualized.

2. MATERIAL AND METHODS

2.1 Compressive molding with high-pressure steam

The developed apparatus has an airtight autoclave with a pressing component. High-pressure steam is injected into the autoclave. The processes in this technique are briefly introduced in the following stages:

(1) Softening stage
High-pressure steam at 120-150 degree of Celsius is injected into the autoclave. The temperature and moisture contents of the material are increased so that the material becomes softened.

(2) Compressing stage
Softened material is compressed by the pressing component with molding blocks. The compressing stroke is controlled.

(3) Fixing stage
Deformed shape of compressed material is fixed by high-pressure steam at 160-200 degree of Celsius. The fixation is caused by the structural change of cellulose crystals and partial chemical degradation.

2.2 Preparation of compressively molded wood

The specimens for inner observation were Japanese cedar logs (20 old, R = 75~80 mm, L = 400 mm, moisture contents = 250%) . They were compressively molded by compressive apparatus (HISAKA H-10) with jigs, and the logs deformed squared shape block (106× 106 mm) . Table I shows parameters of the steaming conditions in compressive molding processes.

Table I. Treatment conditions of compressive molding process for each specimen

Specimen	Condition of raw material	Softening time at 120℃ (min)	Fixing time at 180℃ (min)	Vacuum Drying (hour)
A	Green	60	30	0
B	Green	10	30	0
C	Green	60	0	5

2.3 Observation of inner structure of wood by CT

It is reported that X-ray Computerized Tomography is good apparatus to observe the inner structure of wood in our previous works [1]. In this paper, the state of inner structure of wood before and after processing was observed by the CT (TOSCANER-20000AV). The scanning was 1028×1028 pixel (with scanning pitch : 4 mm) against the fiber-direction. The images were RGB segmented and inversed, thinning and coordinate conversion (Fig.1). In addition, the cross-sectional images of branches were extracted from the original images. Next, the three dimensional images of branches were constructed by the Micro AVS (Image to volume function).

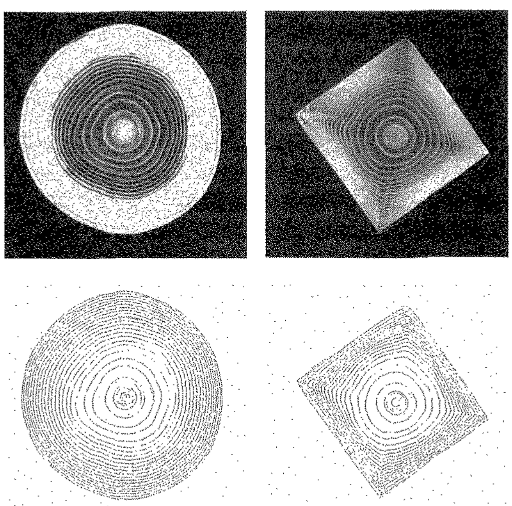


Fig.1 Typical example of scanned image and modified images for numerical analysis

Notes : Image size 1028×1028 pixel, scanned images were operated by Photoshop v4.0

2.4 Valuation of the changes in inner structure

The changes of inner structure of wood before and after moldings were observed for studying about the relationship between inner structure and the conditions for compressive molding processes. Scanned images at 40mm intervals (40, 80, 120, 160, 200, 240, 280, 320, 360 : 9 images) were discussed for the changes in the distribution of annual rings respect to fibrous section. Annual rings were numbered from 1 to 20 (21), and the cross-sectional area of wood was divided into four sections shown Figure 1. Divided four sections was named 0-5, 5-10, 10-15, 15-20.

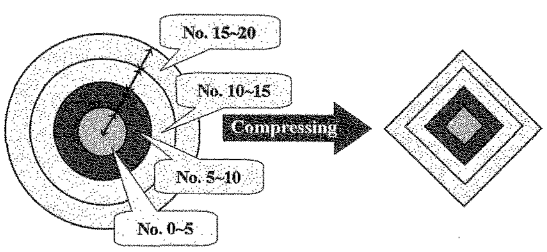


Fig.1. Division of cross-sectional area (0-5, 0-10, 0-15, 0-20) before and after processing

3. RESULTS AND DISCUSSION

3.1 The changes in distribution of annual rings

Table II shows the whole cross sectional areas of before and after molded wood (The average value of 9 images in fiber-direction). The value of area for after molded specimen C was 40.7 was higher than A and B. The specimen C was fabricated by compressive molding process without fixing treatment with drying-set treatment. So the deformed shape gradually recovered after preparation by moisture absorption. On the other hand, the specimen A and B were deformed to desired shape by compressive molding with fixing treatment, the shapes were permanently fixed its deformed shape. So the shapes are very stable if these are subjected to boiling, cyclic condition of drying and wetting. Additionally, the deformed shape of C can be approximately recovered by boiling.

Table II. The changes of whole cross-sectional areas of before and after processing

Specimen	Area ($\times 10^4$pixel) Before	Area ($\times 10^4$pixel) After	The change (%)
A	58.9	35.4	60.1
B	57.0	35.5	62.3
C	58.6	40.7	69.5

Figure 4 shows the multiple-bar graph of the cross sectional area of each section, Table III shows the changes in cross-sectional area of each section (Average value of 9 images in grain-direction). Comparison of the changes in section 0-5, A was 60.6% and was lower than B and C. This result indicates that inner layer of the specimen A was softened enough and compressed, fixed its deformed shape. The change in section 0-5 of the specimen B was 88.9% and the change in section 15-20 of B was 46.1%. It seemed that the specimen B was incompletely softened and the outer layers were mainly compressed. In the specimen C, the change in section 0-5 was 82.7%. The C was treated 60min softening at 120 degree of Celsius similarly to A. However, the section 0-5 in the C was not deformed compared with A in spite of C was enough softened. It was considered that the distribution of annual rings of C was likely A in the compressing stage and the inner layers were reformed in drying stage.

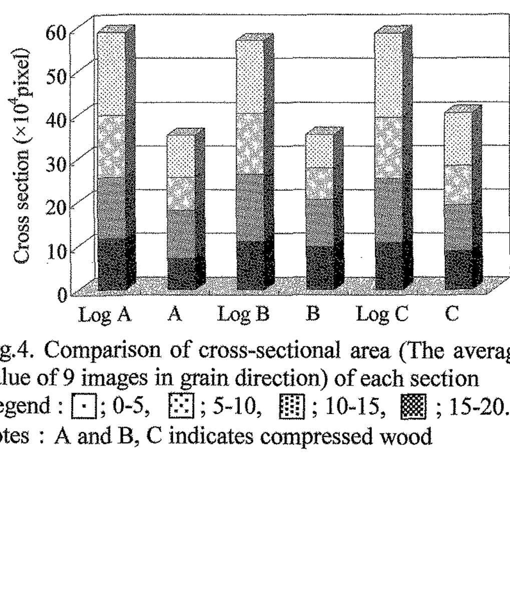


Fig.4. Comparison of cross-sectional area (The average value of 9 images in grain direction) of each section

Legend : □; 0-5, ▒; 5-10, ▦; 10-15, ▩; 15-20.

notes : A and B, C indicates compressed wood

Table III. The areal changes of each section

Sample	Changes of area in each section (%)			
	0-5	5-10	10-15	15-20
A	60.6	78.1	53.5	51.2
B	88.9	70.1	52.3	46.1
C	82.7	70.8	64.0	63.7

In drying set treatment, the recovery stress against the compressive loading was temporarily relaxed by removing thermal energy and water in compressed wood. The drying is processed wood surface. So the relaxations of the recovery stresses were gradually processed from outer to inner. However, high-pressure steam treatment (steaming at 180 degree of Celsius) can quickly relax the inner recovery stress. The specimen C was not given fixing treatment, so the inner and outer layers were recovered.

Figure 3 shows the variation in cross sectional area of each section as a function of scanning position in fiber-direction. The areas become bigger through the fiber from the top-end (scanning position at 400 mm) to the bottom-end (0 mm). The areal distribution of each section of the raw specimens was near, therefore, it is assumed that the inner structure of pre-preparations can be identified.

Figure 4 shows the variation of each section area as a function of the scanning position in fiber-direction. In the specimen A, upper lines of 5-10 and 10-15 are built around the scanning position at 80 mm. It is more than probable that the effect of existence of inner brunches. In the specimen B, both end in fiber-direction (scanning position at around 40 to 80, 320 to 360) were relatively compressed as compared with the other parts. This result indicates that the softening treatment for specimen B was incomplete, so the surfaces of wood (outer layer, top-end, bottom-end) were more softened than the center position. The softened parts were relatively compressed and fixed its deformed shape. Consequently, the high-pressure steam injected gradually to the end of lumber and the softening treatment 10 min for the log (R 150 mm L 400mm) are not enough. In the specimen C, build-up curves can be observed at scanning position around 240 mm as is the case with A. The C was softened sufficiently, so the noteworthy changes against the fiber-direction were not observed.

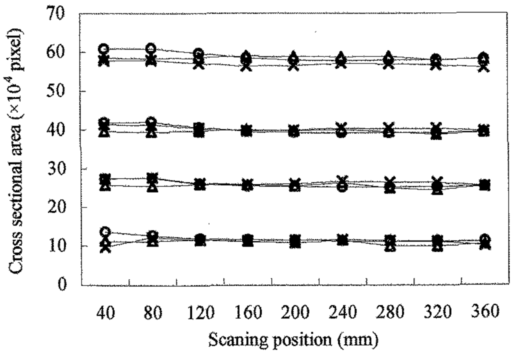
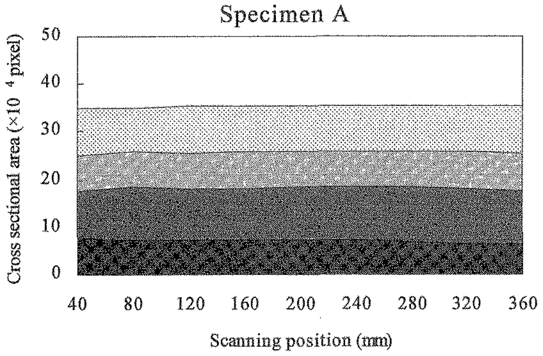
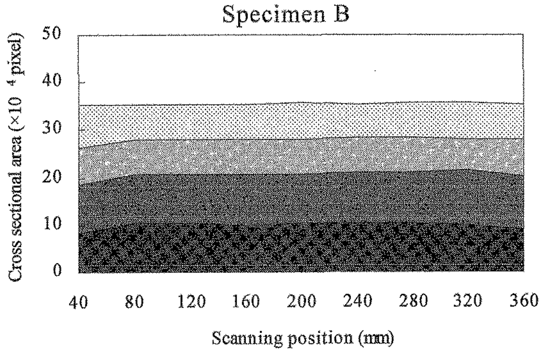


Fig.3. Changes of distribution of each section in fiber-direction (before processed specimen)
Legend : ○; specimenA, ×; B, △; C.





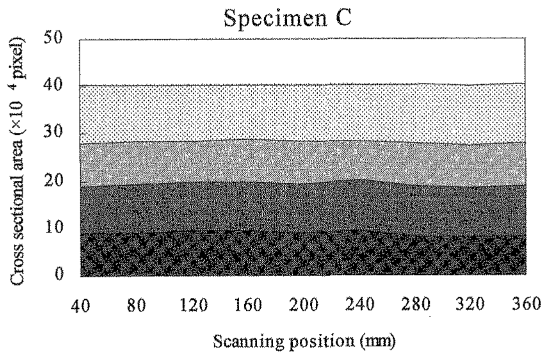


Fig.4. Variation of each section area as a function of scanning position in fiber-direction
Legend: ; 0-5, ; 5-10, ; 10-15, ; 15-20.
Notes: After molded specimen

3.2 Three-dimensional models of wood

This section deals with the observation of the inner structure of wood. Three-dimensional models were constructed and visualized from CT images by using Micro AVS with a computer.

Figure 7 shows the example for three-dimensional models of inner branches in wood (a) before and (b) after compressive moldings. The branches in wood were moved and deformed by compressing. However, the volumes of the branches were not down significantly. Branches are hard to compare with heartwood and sapwood in general. It seemed that the stress concentrations generated around the branches. So it is possible that the cracking, exfoliation, and other faults occur by branches movement. However, these faults could not be found by the observation of 3D models constructed from CT images.

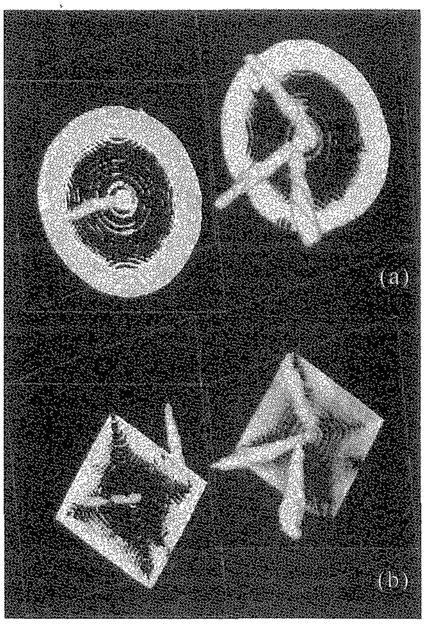


Fig.7. 3D models of inner branches of (a) before and (b) after compressively molded wood
Notes: Specimen A

Figure 6 shows virtually cut model of (a) before processed log and (b) after processed squire shaped wood on computer screen. The position of inner branches and grain pattern are observed without cutting. By using CT images with this application, desired and beautiful grain pattern can be got without sawing. This application can be used for the production of woody craft article [4]. In addition, the color contrast of CT images indicates the difference in density. Density distribution and moisture map of wood can be expressed by using this application technique.

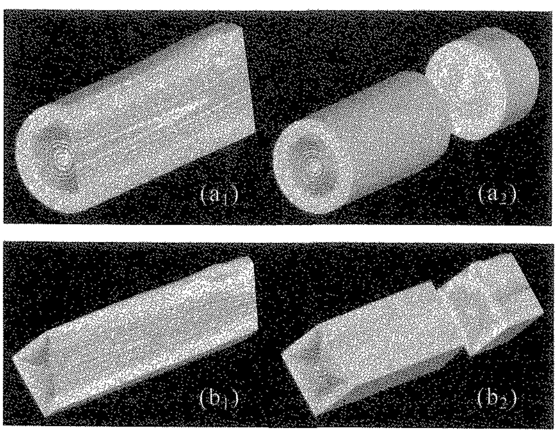


Fig.6. 3D models constructed from CT images
(a_1) logwood cut in the fiver-direction
(a_2) in the grain direction
(b_1) molded wood cut in the fiver-direction
(b_2) in the grain direction
Notes: Specimen A

4. CONCLUSION

This paper discussed about the relationship between steaming conditions and the change in structural properties of before and after compressively molded wood. Distribution of annual rings and the changes in the inner branches in before and after processed wood were observed by the CT without cutting. By the observation of inner structure of the square shaped wood which was fabricated by several steaming conditions, we could analyze the relationship between the steaming conditions and the distribution of annual rings. The compressively molded wood fabricated by compressive molding with incomplete softening, the inner layers of the wood were not enough compressed.

We could construct and visualize a three-dimensional model from CT images of before and after processed wood. Deformation and movement of the inner branches by compressing were observed. In addition, the inner grain patterns of wood could be checked on PC screen without cutting.

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