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RAPID COMMUNICATION

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Deformation behavior of wood under stress relaxation in a radial direction as a laminated annual-ring structure

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Key words Stress relaxation · Annual ring · Radial compression · Image analysis · Compressive strain

Introduction

When compressive load is applied to wood in a transverse direction, the wood has high deformation capacity (low stiffness) and a superior ability to absorb the elastic energy. These characteristics of the wood subjected to transverse compression are important when wood is used as a construction material.

Those characteristics seem to be mainly due to the elaborate geometrical arrangements of various macrostructural and microstructural units that constitute wood. Some anatomical approaches to dealing with the mechanism for deformation under transverse compression have been made.[1–5] They suggested that the deformation of the cross section in compression related to the irregular cellular arrangements, the earlywood–latewood structure, or the change in the shape of cells. However, no studies have examined the relations between the laminated annual-ring structure and the deformation behavior of wood under transverse compression. It is clear that many mechanical features of wood are influenced by the structure of annual rings, that is, the repeatedly laminated tissues of the earlywood and latewood.

In this study, we analyzed the deformation behavior of coniferous wood during stress relaxation under radial compression, to clarify the relations between the deformation behavior and the laminated annual-ring structure of wood.

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Materials and methods

Hinoki (*Chamaecyparis obtusa* Endl.) with an average annual ring-width of 1.4 mm was used as specimen material. The external dimensions were 12 (R) × 8(T) × 8 (L) mm. The direction of compression was the radial direction. The machine for material tests (WET-SEM servopulser, Shimadzu) was incorporated into a scanning electron microscope (SEM) to carry out the compression test within the SEM chamber. We could continuously observe under low vacuum conditions (0.8 ± 0.2 Torr, 20°C). The accelerating voltage was 15 kV.

The section of the specimen to be observed (cross section) was finished with a microtome, and the moisture content was conditioned to attain a value that kept the weight of the specimen constant before and after the compression test, which was carried out in a SEM chamber. We also confirmed that the strain measured by a strain gauge was maintained at zero under nonloading for 24 h. The average density and moisture content of the specimens were 410 kg/m^3 and 0.7%, respectively.

The strain gauge (gauge length: 5 mm, KFG-5-120-C1-5, Kyowa) was attached in a radial direction. The compressive force was continuously applied to the specimens at a constant strain (1%), which was measured and monitored by the strain gauge.

The process of deformation during stress relaxation was continuously observed on a monitor and recorded with a videocassette recorder (HV-MX1, Aiwa). High-resolution photos were also taken during stress relaxation. The photo images were input into a personal computer (Power Macintosh G3, Apple Japan), and image analyses were carried out in order to measure the changes in the length of the various macrostructural and microstructural units that constitute wood. In this report, the macrostructure and microstructure correspond to the laminated annual-rings and a single annual-ring, respectively.

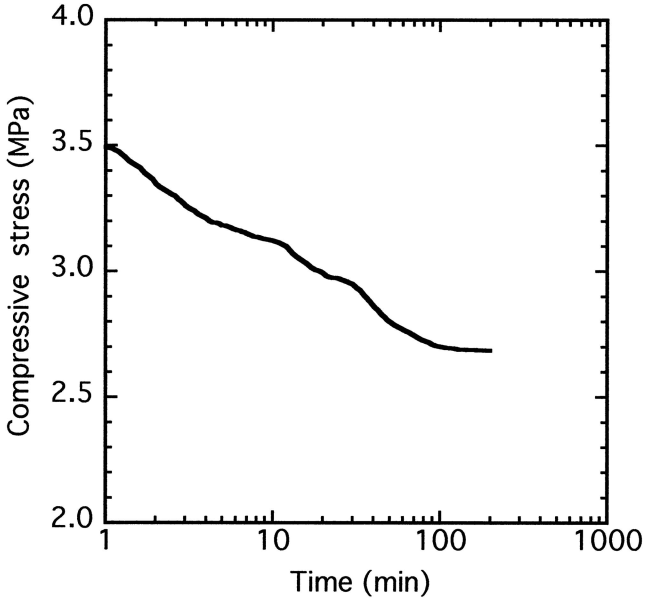

Fig. 1. The stress relaxation curve obtained in a radial compression test

Results and discussion

The stress relaxation curve obtained in the radial compression test is shown in Fig. 1. The stress decreased monotonously with the logarithms of time.

Figure 2 shows a SEM image of the center area on the cross section of the specimen. The number of full annual rings in the specimen was seven.

We obtained compressive strains in a level of annual ring using image analysis of SEM images. The strain (ε_i) is given by:

$$\varepsilon_i = \frac{l_0 - l_i}{l_0} \quad (1)$$

where l_0 is the width of an annual ring before loading and l_i is the width of an annual ring after loading. Figure 3 shows the compressive strain in levels of annual ring versus time during stress relaxation in a radial direction. The measurement was started after 3 min. Before 3 min, we could not measure the strains because of violent variations. Letters in Fig. 3 (*L1*, *L2*, *L3*, and *L*) correspond to those of the annual rings in Fig. 2. The strain of *L* was obtained by measuring the change in the total widths of three annual rings (L1, L2, and L3). It should be noted that the strain of *L* was almost constant during stress relaxation.

In the early stage, the strains of *L2* and *L3* increased with time, while the strain of *L1* decreased abruptly. In the subsequent stage, although the strain of *L2* increased continuously, the strains of *L1* and *L3* gradually decreased with time. This result suggests that every annual ring is deformed individually and that when the strain of one annual ring becomes large, the strains of the others are recovered. These behaviors are considered to be due to the viscoelasticity of wood and to be outstanding features of wood as a laminated annual-ring structure. In our next report, we will examine these phenomena theoretically.

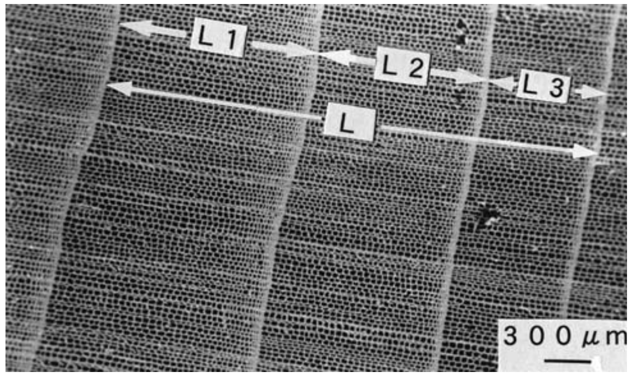

Fig. 2. A scanning electron microscope (SEM) image of the specimen cross section. Letters (L1, L2, L3, and L) correspond to those in Fig. 3. *Bar* 300 µm

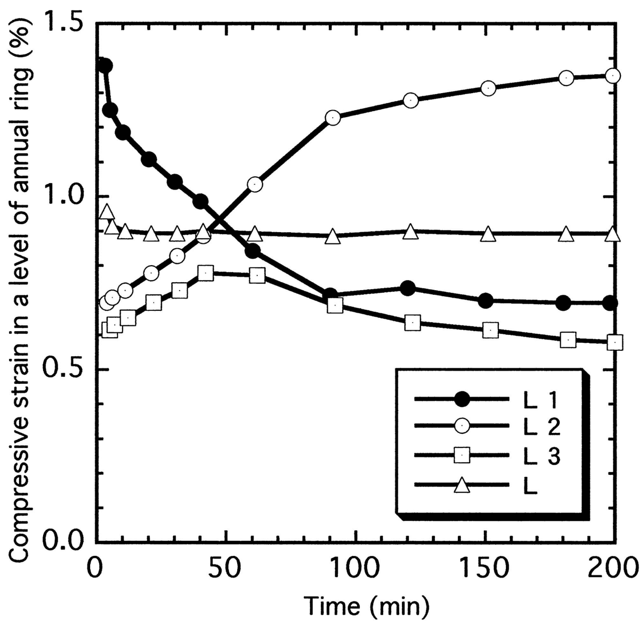

Fig. 3. The compressive strain in the levels of annual ring versus time during stress relaxation in the radial direction. The strain was obtained from Eq. 1 using image analysis of SEM images. Letters (*L1*, *L2*, *L3*, and *L*) correspond to those of the annual rings in Fig. 2

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