Fracture Mode and Tensile Strength on Latewood in Japanese Wood

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***Abstract*-Tensile test of latewood taken from Japanese cedar including moisture content of 9 % was conducted at quasi-static loading rate of 1.0 mm/min by means of universal testing machine. In order to measure tensile elongation, two different strain measuring method were adopted; strain gage and non-contact extensometer. Two curves of tensile mechanical response were observed with two modes of fracture in the latewood specimen; principal fracture and shear fracture. Average elastic modulus of principal fracture and shear fracture were 16.5 GPa and 12.1GPa, respectively. It was suggested that mechanical properties of latewood has relation to fracture mode in latewood from Japanese cedar.**

I. INTRODUCTION

Wood has a benefit feature of absorbing carbon dioxide (CO_2) for own photosynthesis, and the CO_2 includes inside of wood even if it's after they burnt up [1]. Wood applications have been considered to be developed to the new productions which woods have not been applied on. For creating demand and effectively utilizing of Japanese wood, a detailed investigation on the wood property is requested in the future [2]. Cedar (Cryptomeria japonica) is a species endemic to Japan. It is cultivated the most in the Japanese country and its use is expected to expand. Wood is a natural composite of complex hierarchical structure [3]. Characteristics of wood are dramatically different along its principal anatomical directions and just on the mezzo–scale of its anatomical structure, remarkable differences exist between heartwood and sapwood, earlywood and latewood. As the tree grows up, it develops two growth rings in the tree; an earlywood and a latewood as shown in Fig.1. The inner portion of the growth ring is called the earlywood (another name; spring wood), which is formed during the early part of the growing season. The earlywood is less dense than the latewood and has wider vessels to transport nutrients. The outer portion of the growth ring is called the latewood (another name; summer wood), which is formed later in the growing season each year. The latewood has higher dense than the earlywood and makes narrow vessels. In previous study [4-7] on the tensile test of the wood, however, elastic modulus and tensile property of the earlywood and the latewood of Japanese cedar are not clear yet. In this study, tensile experiment on the latewood of a Japanese cedar is carried out to evaluate tensile property as the first step research [8-10]. In addition, fracture mode on the latewood is observed after the tensile experiment in this study.

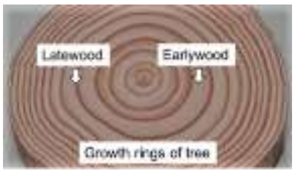


Fig.1 . Growth structure of wood rings

II. EXPERIMENTS

A. Wood

Latewood was used from a Japanese cedar called Obi-Sugi cedar in an even-aged 40-years old forest stand from Nichinan city, Miyazaki prefecture in Japan. The wood was specific gravity of 0.37 and 9 % moisture content (MC) after equilibrium with the relative humidity of the air atmosphere. Fig.2 shows cross section and orientation of the longitudinal latewood sample taken from the Obi-Sugi.

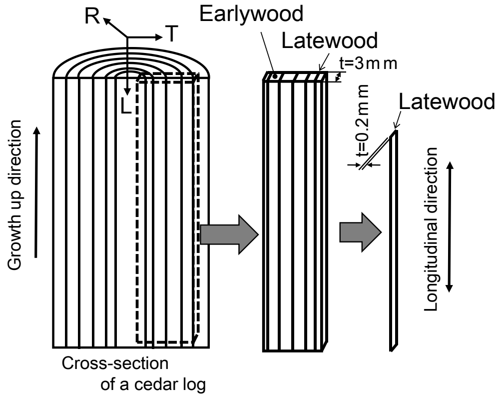


Fig.2 . Schematic showing the cross section and orientation for the latewood sample

B. *Test Sample*

The latewood sample with thickness (radial) of 0.2 ± 0.05 mm, width (tangential) of 3.0 ± 0.5 mm and length (longitudinal) of 130 mm was cut out, and then the sample was immersed in the water for 24 hours for purpose of removing residual cutting strain into sample. After immersion procedure, the sample dried in atmosphere for 72 hours. Fig.3 shows configuration and dimensions of the tensile specimen. Gage length is 70 mm for tensile elongation measurement.

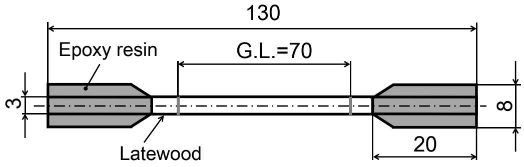


Fig.3 . Tensile specimen of the latewood in this study

C. *Tensile Test*

Tensile experiment in accordance with Japanese Industrial Standards (JIS) was performed at initial loading rate of 1.0 mm/min. Fig.4 shows a tensile testing system (EZ-SX, Shimadzu) in this study, tensile load is measured by one load cell with capacity of 500 N, and displacement is measured by non-contact extensometer (DVE-101/201, Shimadzu). Fig.5 shows the latewood specimen attached one strain gage (FLK-1-11, gage length of 1.0 mm, gage width of 0.7 mm, Heatproof temperature of 393 K (120 °C), Tokyo Sokki Kenkyujo Co.) [8]. The latewood sample was glued on the pasteboard with thickness of 0.2 mm. Twenty tensile specimens of each Fig.3 and Fig.5 were prepared in this study. The tensile strength and elastic modulus for individual specimens were calculated using the mean value of three measured cross section area. Elastic modulus was determined as a slope of a straight-line fitted to the stress-strain curve between 10 to 30 MPa. Two failure strain data were calculated using the strain value from the extensometer and attached strain gage, respectively.

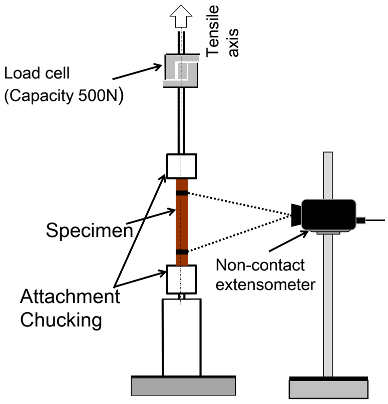


Fig.4 . Tensile testing system using non-contact extensometer in this study

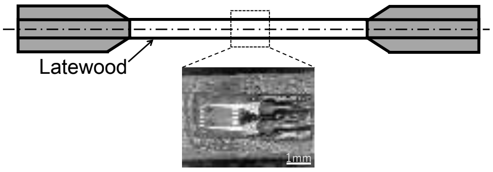


Fig.5 . Tensile specimen attached a strain gage for longitudinal strain measurement during tensile test

D. *Fracture Mode Observation*

After tensile test, the both of specimen of the latewood which treated a gold sputtering was observed for understand the failure mode of the latewood.

III. RESULTS AND DISCUSSION

Fig.6 shows stress-strain curve of the latewood when two different strain measuring methods; strain gage and non-contact extensometer are used. In all specimens, when the applied load peaked, the specimens was quickly fractured.

By comparing the measurement results of the strain gage and the extensometer, an initial strain stage was almost the same, and after that, as the tensile stress was continuously increasing, a large different occurred between data of the strain gage and the extensometer. Overall, the specimen with strain gage failure earlier than that with extensometer regardless of fracture pattern. Fig.7 shows crack path along the edge on the strain gage. Thus, influence on stress concentration of the strain gage confirmed due to coating of adhesive agent. Therefore, it is concluded that the strain gauge is effective for the measurement of Young's modulus, but it is ineligible for the measurement of mechanical properties such as strength and fracture strain.

In addition, two curves of fracture patterns; (a) principal stress fracture and (b) shear fracture were observed in Fig.6. Average elastic modulus of (a) and (b) were 16.5 GPa and 12.1 GPa, respectively. Due to different fracture pattern and elastic modulus, it is suggested that the microstructure, density and defect concentration in both specimen (a) and (b) may differ even for latewood taken from the same site.

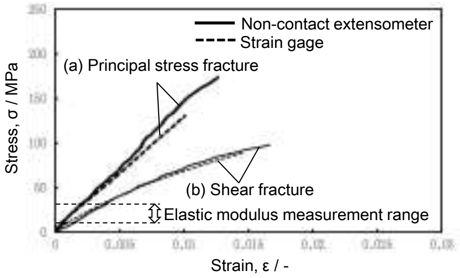


Fig.6 . Tensile stress-strain curve of the latewood

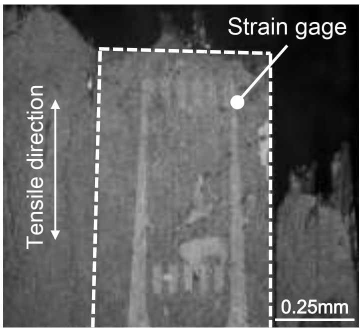


Fig.7 . Fractured latewood specimen along the edge of attached strain gage

Fig.8 shows all plots of tensile strength and failure strain, which are all tensile experimental results. The appearance of the fracture pattern of principal stress fracture was 9 out of 20 pieces and correlation coefficient was R=0.85. On the other hand, R value of shear fracture was 0.36.

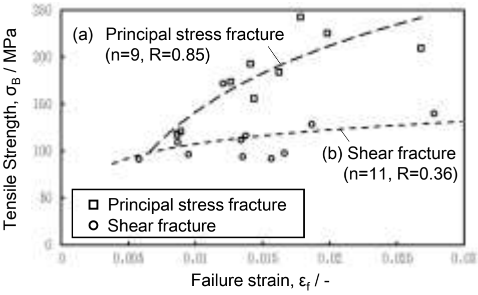
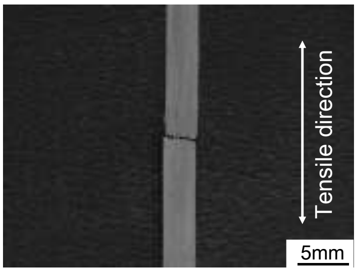
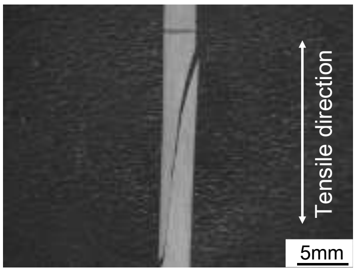


Fig.8 . Plots of tensile strength and failure strain in all tensile experimental results



(a) Principal stress fracture



(b) Shear fracture

Fig.9 . Fracture mode of the latewood specimen tested with non-contact extensometer

Fig.9 shows two fracture mode; (a) principal stress fracture, (b) shear fracture observed after tensile experiment with non-contact extensometer. Both fracture showed caused instantaneous separation behavior when peak stress was reached under tensile deformation. Longitudinal fracture modes of the latewood specimen is shown in Fig.9 (a) (principal stress fracture) and 9 (b) (shear fracture) corresponding with (a) and (b) in Fig.6 and 7, respectively. In Fig.9 (a), principal stress fracture formed, which crack path surface is a perpendicular cross section to the tensile direction. Factor of initiation of the principal stress fracture in latewood is not clear yet. Because of that, closer experiment of fracture surface observation is required in future. On the other hand, in Fig.9 (b), shear fracture occurs at angle of 15 to 20 degrees to the tensile direction. It is known that microfibrils with spiral structure in middle secondary layer (S2 layer) forming angle of 5 to 30 degrees contribute to strong of longitudinal cell-wall axis in wood [11]. Moreover, ray tissue exists in wood structure. Wood rays are seen as narrow stripes or line that extend across the growth rings in the radial direction from the skin bark to the center of the tree. Fig.10 shows the ray tissue distribution and arrangement in the wood [12]. Fig 11 shows the microphotograph of the fracture surface when shear fracture morphology is occurred. It is conformed that fractured ray region is observed on the fracture surface. As for the factor of the occurrence of shear fracture in latewood, it is suggested that ray tissue is greatly related.

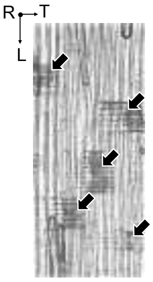


Fig.10 . Distribution of the ray tissue in wood [12]

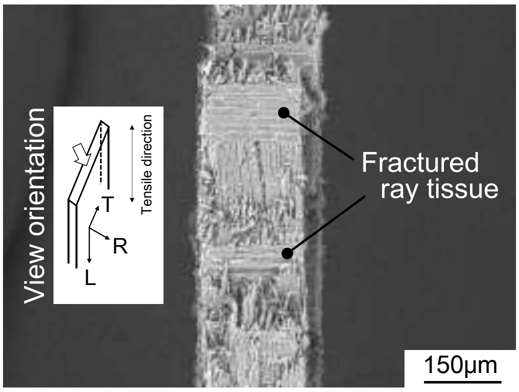
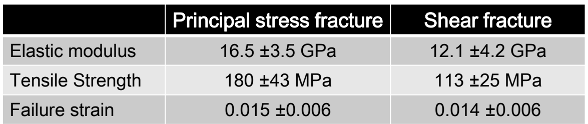


Fig.11 Microphotograph of the fracture surface in specimen showing shear fracture

Table 1 shows tensile properties of the latewood tested in this study. By various researchers [14, 15], mechanical properties of Japanese cedar (i.e. complex earlywood and latewood) have been investigated, it is found that elastic modulus is 6 to 7 GPa and strength is 34 MPa (MC=15 %). From these results, it is apparent that the latewood performs the function of mechanical support against the load applied.

Table.1 Mechanical property of the latewood



	Principal stress fracture	Shear fracture
Elastic modulus	16.5 ±3.5 GPa	12.1 ±4.2 GPa
Tensile Strength	180 ±43 MPa	113 ±25 MPa
Failure strain	0.015 ±0.006	0.014 ±0.006

IV. CONCLUSION

Tensile test of the latewood with 9 % MC in Japanese cedar was conducted to determine elastic modulus and tensile property. The strain gage and the non-contact extensometer were used to measure initial tensile strain data. The findings of this study were summarized as follows:

1. Strain gauge is effective for the measurement of Young's modulus, however it is ineligible for the measurement of mechanical properties such as strength and fracture strain.
2. Two fracture modes: principal stress fracture and shear fracture were observed in latewood specimen under tensile stress.

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