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Determination method of the elastic modulus and yield stress of wood

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Abstract

In this paper, we formulated the stress-strain and stress-plastic strain relationships, and examined the determination method of the Young's modulus and the yield stress which dominate the stress-strain property.

Agathis (*Agathis* sp.) and katsura (*Cercidiphyllum japonicum* Sieb. and Zucc.) with various grain orientations were used for the specimens. These specimens were uniaxially compressed, and the stress-strain relationship was formulated by Ramberg-Osgood's power function. Then, the strain component was separated into the elastic and the plastic parts, and the stress-plastic strain relationship was formulated by Ludwik's power function. The yield stress was obtained by extrapolating the plastic strain to zero. The obtained Young's moduli and the yield stresses were compared with those determined visually, and the validity of our proposal was examined.

From the experimental results, we concluded that the Young's modulus and the yield stress were determined properly by the formulation process proposed here.

1. Introduction

In our previous paper, we proposed a determination method of yield stress from the results of several uniaxial-compression testing data.[1] In this proposal, the strain component was separated into elastic and plastic parts, and the yield stress was determined by formulating the stress-plastic strain relationship into an empirical stress-strain equation. In separating process, we decided the elastic modulus by drawing a straight line on the initial linear part of the stress-strain diagram because the elastic modulus can be determined more easily than the yield stress. By this determination method, however, the measurement error cannot be reduced entirely.

In this paper, hence, we determined the elastic modulus as well as the yield stress by a formulating method stated later, and tried to reduce the arbitrariness in the determination procedure of the elastic modulus and yield stress.

2. Theories

In the previous paper, we determined the yield stress by formulating the stress-plastic strain relationship. From the stress-strain diagram, the plastic strain, ε^p, was obtained from the

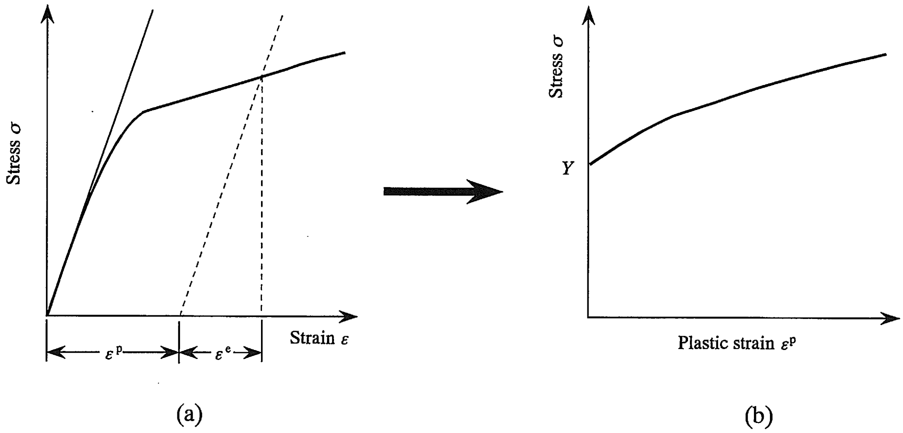

Fig. 1. Transformation of stress-strain relationship into stress-plastic strain relationship.
Note: (a): Stress-strain relationship, (b): Stress-plastic strain relationship.

following equation:[2)]

$$\varepsilon^{p}=\varepsilon-\varepsilon^{e}=\varepsilon-\frac{\sigma}{E}, \tag{1}$$

where σ is the stress, and E is the elastic modulus. In obtaining the plastic strain, the elastic modulus is usually determined by drawing the straight line over the initial linear part of stress-strain diagram. Generally, the value of elastic modulus is evaluated more precisely than that of yield stress, and is determined visually by an observer. By this method, however, it is difficult to evaluate the elastic modulus when the stress-strain diagram has a large curvature in the initial part. Thus, we think that it is reasonable to determine the elastic modulus objectively as well as the determination of the yield stress.

The stress-strain relationship was conventionally expressed by several formulas cited in an Osgood's paper.[3)] Among these formulas, Ramberg-Osgood's power formula, which is represented as follows, is most popular one:

$$\varepsilon=\frac{\sigma}{E}+K\left(\frac{\sigma}{E}\right)^{n}, \tag{2}$$

where K and n are the parameters determined for a good fit of stress-strain diagram. The elastic modulus E is determined by the method of least squares as well as the determination of those parameters.

Using the value of the elastic modulus, the strain component is separated into the elastic and the plastic part as Eq. (1), and the stress-plastic strain relationship is obtained. This stress-plastic strain relationship is regressed into an equation. In our previous paper, we recommended to use the Ludwik's power function which is represented as follows:

$$\varepsilon^p = K' \left(\frac{\sigma - Y}{Y}\right)^{n'}, \tag{3}$$

where K', and n' are parameters determined for the good fit of stress-plastic strain relationship, and Y is the yield stress obtained by the same procedure for the determination of K', and n'.

3. Experiment

3.1 Materials

Agathis (*Agathis* sp.) and katsura (*Cercidiphyllum japonicum* Sieb. and Zucc.) were used for the testing materials. Specimens were conditioned at 20°C and 65% relative humidity before and during the tests.

3.2 Compression tests

Compression-test specimens were cut with the dimensions of 40 × 20 × 20 mm. These specimens had the angles of 0 to 90 degrees at intervals of 15 degrees between the grain directions and long axes in the LR-(longitudinal-radial) planes.

Uniaxial strain gages (gage length = 2 mm, KFC-5-C1-11, Kyowa Dengyo Co., Ltd.) were bonded on the centers of the LR-planes, and a load was applied along the long axis of the specimen at the crosshead speed of 1 mm/min. Five compression tests were made for each test condition.

Firstly, the stress-strain diagram was regressed to Eq. (2), and the Young's modulus E was determined. Using this Young's modulus, the plastic strain component was separated by Eq. (1), and then the stress-plastic strain relationship was regressed to Eq. (3). The yield stress was determined by extrapolating the plastic strain ε^p of Eq. (3) to zero.

On the other hand, the straight line was drawn on the initial segment of stress-strain diagram, and the Young's modulus and the yield stress were determined visually. The Young's modulus was determined by the inclination of the straight line, whereas the yield stress was determined as the branching point of the elastic line and the stress-strain curve. These values were compared with those obtained by the formulations.

4. Results and discussion

Fig. 2 and 3 show the comparisons of the Young's moduli and yield stresses determined by formulation and observation, respectively. From these figures, both mechanical properties can be determined properly by the formulation method proposed here.

We should note that the proper function should be adopted in formulating the stress-strain and stress-plastic strain relationships. As shown in the previous paper, the value of yield stress was estimated as a smaller one when the stress-plastic strain relationship was formulated by Swift's power function represented as follows.[1)]

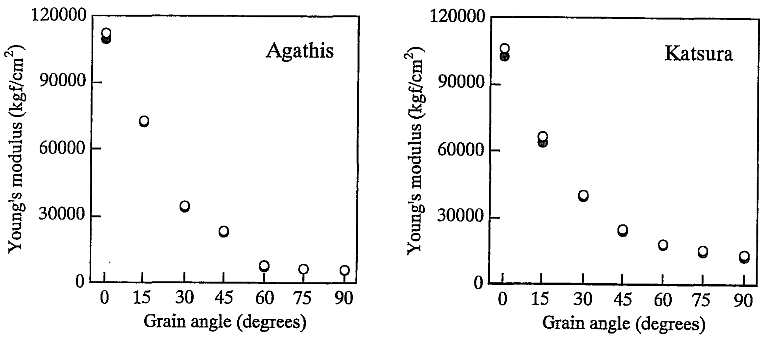

Fig. 2. Young's modulus corresponding to the grain angles.
Legend: White and black dotts represent the means of data obtained from the formulation and observation, respectively.

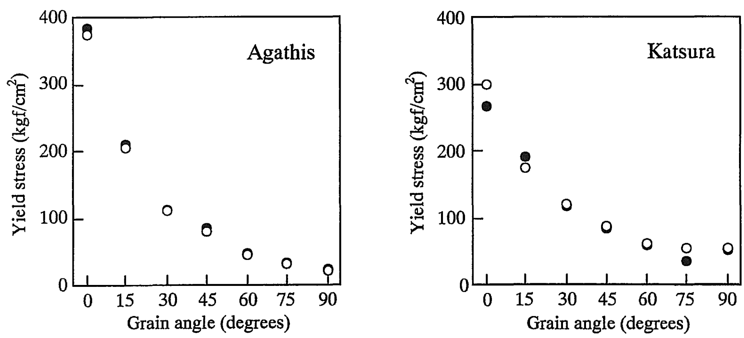

Fig. 3. Yield stress corresponding to the grain angles.
Legend: Same as in Fig. 2.

$$\sigma = Y_S \left(\frac{\varepsilon^p + b}{b} \right)^m, \tag{4}$$

where Y_s is the yield stress and b and m are the material parameters. However, we think that the Young's modulus and the yield stress can be determined properly when the Ramberg-Osgood's and Ludwik's functions are applied to the stress-strain and stress-plastic strain relationships, respectively.

Another parameter dominating the stress-strain property is the failure point of stress-strain diagram. We think that it is easy to determine the failure point because this point coincides the peak of stress-strain diagram. With the Young's modulus, the yield stress (strain), and the failure stress (strain), the stress-strain relationship can be approximately obtained. Therefore, we think that it is reasonable to determine the Young's modulus and the yield stress without arbitrariness.

5. Conclusion

We proposed a determining method of the elastic modulus and yield stress of wood by formulating the stress-strain and stress-plastic strain relationships, and examined this method by the uniaxial-compression tests of the specimens with various grain orientations.

From the testing results, we concluded that the elastic modulus and yield stress can be determined without arbitrariness by our proposal.

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