Note

Classified Characters of Wood Quality in the Junvenile Stage of Cultivars of Japanese Cedar*

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Abstract——Nine wood quality indicators are compared with three groups of growth rates and three types of load-deflection curves in bending on 36 cultivars of juvenile Japanese cedar (*Cryptomeria japonica* D. Don). The fast-grown trees have shorter tracheids. In the load-deflection type having the large plastic region, tracheid length is shorter and fibrils lie more flatly and bending modulus of elasticity is lower on the same specific gravity as in other two load-deflection types. The trees in this type, therefore, seem to be more juvenile. Moreover, much proportion of the trees in this type belongs to the fast-grown group. Then, by all meams, the precise information of wood quality is necessary for the utilization of fast-grown cultivars.

1. Introduction

Japanese cedar (*Cryptomeria japonica* D. Don) is the most important conifer for reforestation in Japan. There are, however, many cultivars in it and their wood qualities, such as the mechanical properties required to wood construction and the growth rate, are considerablly different.

Recently we measured wood quality indicators in each one timber from thinning operation of 36 cultivars of Japanese cedar, which had been gathered from various regions of Japan, mainly Kyushu Island, and had been planting on a strand of Kumamoto Perfecture in the center of Kyushu Island for 20 years.

These detail data were already published on " Wood Research and Technical Notes " written by Japanese[1,2]. In this report, these 36 cultivars are classified by growth rates and load-deflection types in bending, and then the characters are discussed on these classified groups or types.

2. Wood quality indicators

Nine wood quality indicators, that are specific gravity, annual ring width, latewood percentage, tracheid length, fibril angle, static modulus of elasticity in bending, con-

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sumed energy to static bending fracture, bending strength and shear strength, are chosen.

The annual ring width and the latewood percentage are measured from the first ring to the outermost ring (6th-13th ring from pith) and their values are averaged. The other seven indicators are measured at/near 7th (or 6th) annual ring from pith. The small and clear specimens are used on 4 mechanical indicators, such as modulus of elasticity and strength, complied with Japanese Industrial Standards. The tracheid length are measured by a microscope after chemical maceration. The photographs of X-ray diffraction patterns are used to decide the fibril angle in respect to the tracheid axis. The deatiled measuring methods of these indicators are also shown in the previous reports[1,2].

3. Classification of cultivars

In consideration of wood quality, it is better that the 36 cultivars are classified by some factors and the characters are compared with the classified groups, because only one timber can be just used to measure wood quality in each cultivar.

As fast-grown cultivars may become to be more important, growth rate is chosen for one factor. Thirty-six cultivars are divided into 3 groups of same size in order of the mean annual ring width, that are (1) slow-grown, (2) intermediate-grown and (3) fast-grown groups. See Fig. 2.

The other factor is the type of load-deflection curves in bending. It offers the informations on elasticity and plasticity and is useful to the mechanical utilization of wood. The load-deflection curves are classified by 3 types, having (I) high elasticity and small plastic region, (II) intermediate elasticity and plastic region and (III) low elasticity and large plastic region, as shown in Fig. 1 and the previous report[1].

4. Classified characters and discussions

4.1 Groups of growth rates

The wood quality indicators and numbers of cultivars in each group are summarized in Table 1. The significant difference can not be found on almost all indicators, except mean annual ring width and tracheid length. So, the fast-grown cultivars appear to be profitable to use, but it will be discussed in detail in the following sections. The relation of tracheid length to mean annual ring width is shown in Fig. 2. It is clear that much proportion of the fast-grown trees has shorter tracheids.

4.2 Types of load-deflection curves

Table 2 shows the wood qualtiy indicators and numbers of cultivars in each type. The type III, having large plastic region, is very peculiar. In this type, the fibrils lie more flatly and the tracheid length is shorter and then the modulus of elasticity in

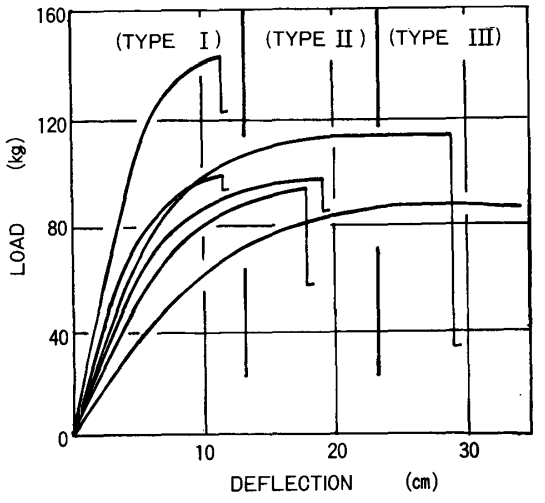

Fig. 1. Classification of load-deflection curves in bending[1].

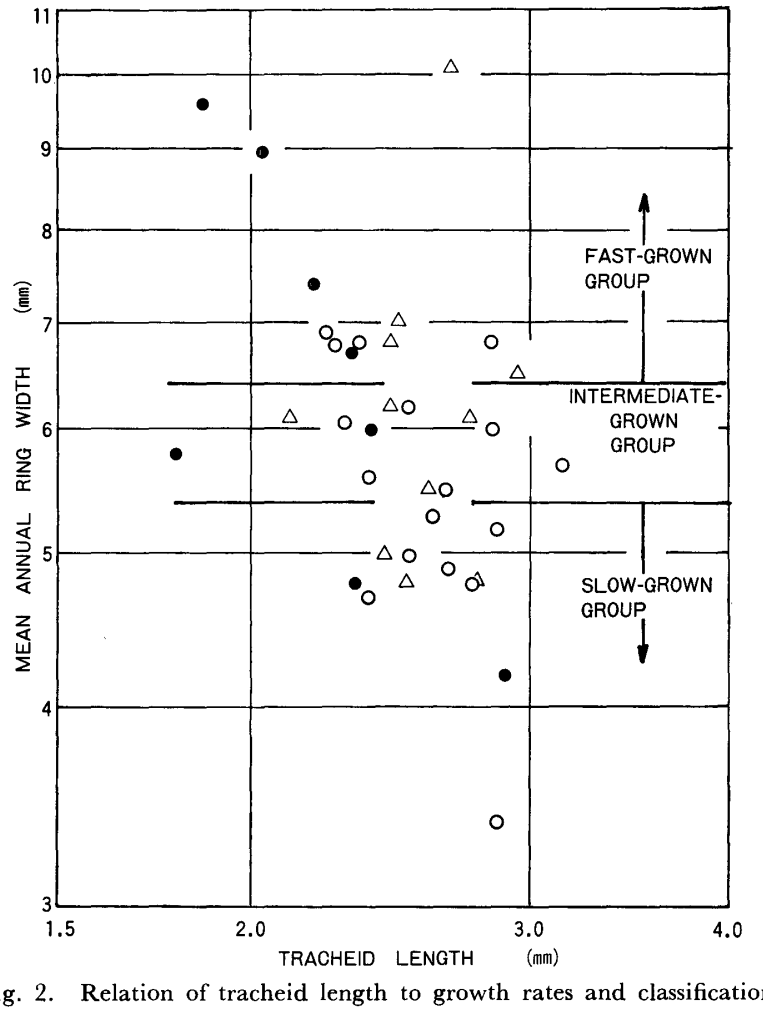

Fig. 2. Relation of tracheid length to growth rates and classification growth rates. Symbols in figure: ○ Type I, △ Type II, ● Type III in load-deflection curves.

Table 1. Wood quality indicators in three groups of growth rate

Group	Number of cultivars	Specific gravity	Mean annual ring width (mm)	Latewood percentage (%)	Tracheid length (mm)	Fibril angle (°)	Modulus of elasticity in bending ($\times 10^3$ kg/cm^2)	Consumed energy to bending fracture (kg·cm^2)	Bending strength (kg/cm^2)	Shear strength (kg/cm^2)
Slow-grown	12	0.390±0.044	4.74±0.50	11.2±2.9	2.62±0.21	40.9± 8.2	56.7± 8.9	2.17±0.68	501±57	64.7± 7.7
Intermediate-grown	12	0.400±0.048	5.90±0.27**	11.9±3.0	2.49±0.35	42.6± 8.5	56.7±10.5	2.44±0.63	522±73	60.6±10.6
Fast-grown	12	0.393±0.042	7.57±1.25**	10.2±3.1	2.37±0.29*	41.8±10.3	48.6±13.9	2.41±0.47	499±69	67.7± 8.6

The groups are classified as shown in Fig. 2.
Values=Mean±Standard deviation.
*: Significant to any other group(s) at 5% level.
**: Significant to any other group(s) at 1% level.

Table 2. Wood quality indicators in three types of load-deflectin curves

Type	Number of cultivars	Specific gravity	Mean annual ring width (mm)	Latewood percentage (%)	Tracheid length (mm)	Fibril angle (°)	Modulus of elasticity in bending ($\times 10^3$ kg/cm^2)	Consumed energy to bending fracture (kg·cm^2)	Bending strength (kg/cm^2)	Shear strength (kg/cm^2)
High elasticity, I	17	0.398±0.040	5.63±0.94	11.8±2.9	2.59±0.27	38.5±9.5	62.4±8.1	2.10±0.51	532±76	65.9± 7.8
Intermediate, II	11	0.365±0.020	6.26±1.49	9.8±2.9	2.54±0.20	43.5±8.8	51.3±4.9*	2.19±0.41	479±39	62.1± 4.2
Large plasticity, III	8	0.427±0.045**	6.74±1.91	11.3±3.4	2.22±0.35**	46.4±5.9*	40.1±9.4**	3.05±0.43**	494±55	72.4±10.1**

The type are classified as shown in Fig. 1.
Values=Mean±Standard variation.
*: Significant to any other type(s) at 5% level.
**: Significant to any other type(s) at 1% level.

bending is lower, although specific gravity is larger. On the other hand, the consumed energy to bending fracture and shear strength are larger.

The relationship between specific gravity and modulus of elasticity is of the deepest interest. The relationship between them is theoretically formulated in the longitudinal direction as follows[3]:

$$\log E = \text{constant} + \log \rho,$$

where E is modulus of elasticity and ρ is specific gravity. Fig. 3 shows their relations in our results. It was also shown in the previous report[1]. This theoretical relation appears to hold in the types I and II, with two exceptions in type II. And all trees in type III are apart on a large scale from this theoretical relation. They are in a dashed circle in Fig. 3. In other words, bending modulus of elasticity in type III is lower on the same specific gravity as in other two types.

The relation of fibril angle to tracheid length is shown in Fig. 4. The arrows in this figure show the cultivars that are apart from the theoretical relation in Fig. 3. The great potion of them has the flatter fibril angle and/or the shorter tracheid length.

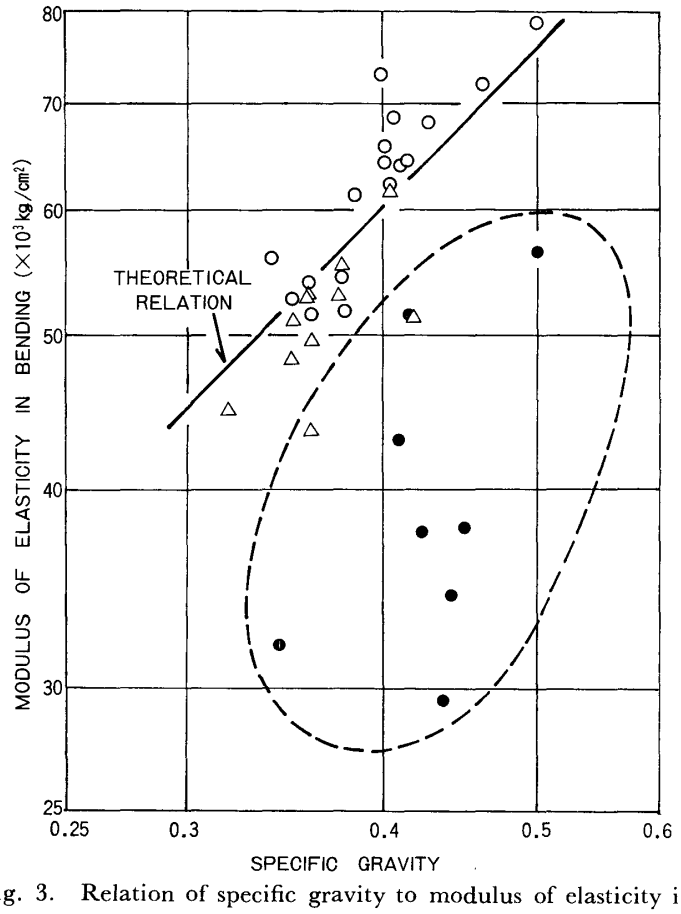

Fig. 3. Relation of specific gravity to modulus of elasticity in bending[1]. Symbols in figure are the same in Fig. 2. See the text for the theoretical relation.

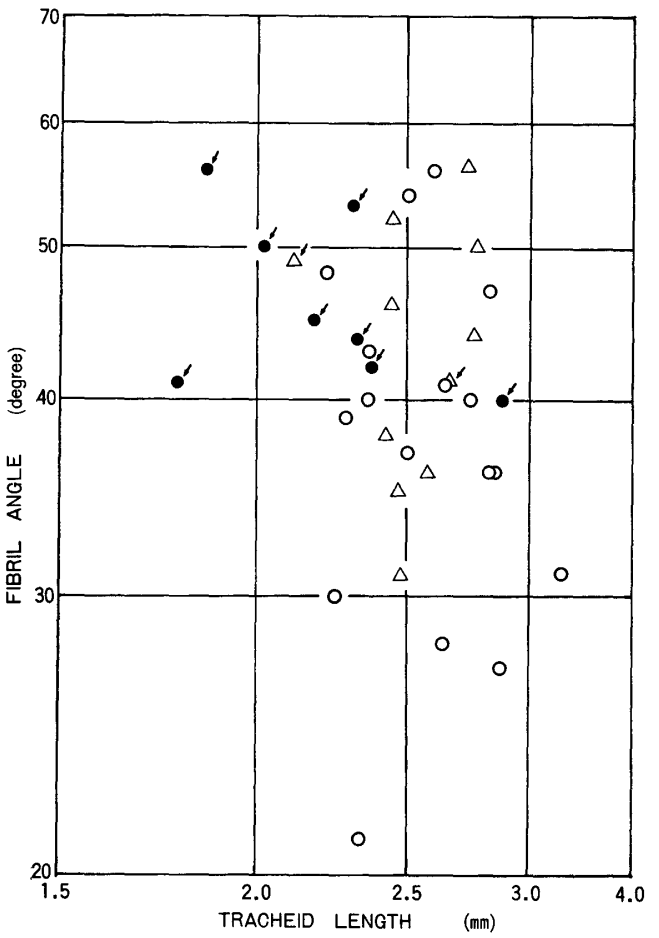

Fig. 4. Relation of tracheid length to fibril angle. Symbols in figure are the same in Fig. 2. The arrows show the cultivars that are in the dashed circle in Fig. 3.

It is the reason why they are apart from the theoretical relation and thus they might be further in the deeper juvenile stage than others[4].

As described in the previous report[1], bending and shear strengths are linearly proportional to spectific gravity over all load-deflection types. And consumed energy to bending fracture is roughly proportional to the third power of specific gravity independently of the load-deflection types as shown in Fig. 5.

It seems to be curious that the dependences of elastic modulus on specific gravity are different between type III and other two types, which have different microscopic structures that are fibril angle and tracheid length, while the characters related with fracture depend only on a macroscopic quality or specific gravity. Because it has been generally confirmed that elasticity is insensitive for structure but fracture is very sensitive. Then our results could be interpreted in the followings: The 36 cultivars would have too much variations of microscopic structures to influence elasticity. On the other hand, fracture would be affected by more variations of macroscopic factors

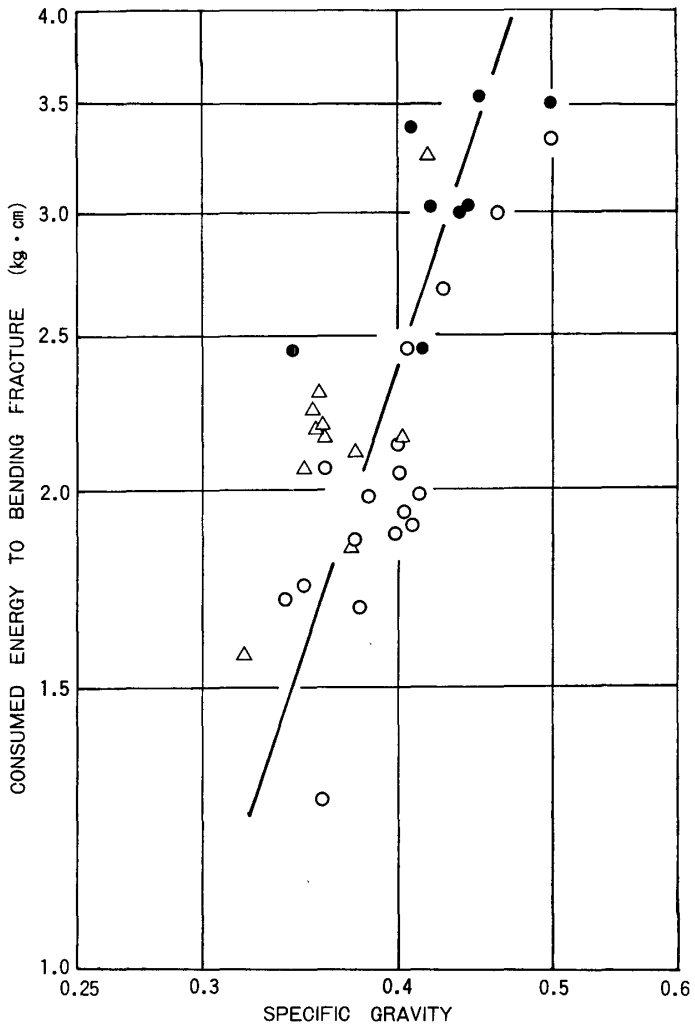

Fig. 5. Relation of specific gravity to consumed energy to bending fracture. Symbols in figure are the same in Fig. 2.

than microscopic structures.

4.3 General descussions

The percentage of each type of load-deflection curves in each group of growth rates are summarized in Table 3. See also Fig. 2. It is shown that about a half of the type I, having high elasticity and small plastic region, and a half of the type III, having

Table 3. Percentage of types of load-deflection curves in groups of growth rates

	% in		
	Slow-grown group	Intermedite-grown group	Fast-grown group
Type of high elasticity, I	47.1	29.4	23.5
Type of intermediate, II	27.3	36.4	36.4
Type of large plasticity, III	12.5	37.5	50.0

low elasticity and large plastic region, belong to the slow-grown and the fast-grown group, respectively. Therefore, when we are going to use the fast-grown trees, we should know their wood quality and use them in their right places.

The types of load-deflection curves obtained here from one timber might be generarized on each cultivar. S. MIO[5] measured some wood quality indicators, such as specific gravity, tracheid length, modulus of elasticity etc., in 6 cultivars which are also contained in our experiments except one cultiver. Their types of load-deflection curves exactly conicided with our types. Moreover, in his experiments, two cultivars belonging to our type III had slightly shorter tracheids and modulus of elasticity in them was lower in spite of higher specific gravity than in other types. These result are also coincident with our results. Boka-sugi is a typical fast-grown cultivar in Japan and is included in the type III of our experiments. It seems to belong to the same type, even when it is planted in the place of original forestation[6] or in other area[7]. In Yoshino-[8], Yaku-sugi[9] in type I and Yanase-sugi[10] in type II that are planted in the original forestation, their elastic properties seem to be resemble to our results. These facts would show that the characters in elastic properties should be genetic.

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