論　文

Multiple Regression Analysis of the MOE of Sugi Wood using Cambial Age and Ring Width as Predictor Variables

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形成層年令および年輪幅を説明変数とするスギ弾性係数の重回帰分析

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要　旨　木材の機械的性質をあらわす指標として，最も有効とおもわれるものは弾性係数であるが，この弾性係数を，簡単に測定しうる量をもって推定することができれば，実用上便利であると考えられる。この研究では，そのような量として，形成層年令（髄からの年輪数）および年輪幅をえらび，それらが弾性係数と有意的に相関関係をもつことを確認した後，この２ツの因子を説明変数として，重回帰分析を行い，以下の重回帰式を得た。

$$Y = 73.97 + 2.48X_1 - 3.59X_2$$

ここに，　Y：弾性係数（$\times 10^3$kg/cm²），　X_1：形成層年令(年)，　X_2：年輪幅（mm）

この式は，形成層年令32年まで，年輪幅 1.3mm～11.3mmの範囲でよく適合することが認められた。

Summary: The modulus of elasticity (MOE) is thousht to be the most effective index representing the mechanical properties of wood, and if the MOE can be estimated by any simply measurable measures, convenience in the practical use is expected.

In this study, the cambial age (ring number from the pith) and the ring width were chosen.

After confirmation that the ring width and the cambial age significantly correlated with the MOE, a multiple regression analysis was performed using them as the predictor variables.

The multiple regression equation obtained was as follows,

$$Y = 73.97 + 2.48X_1 - 3.59X_2$$

where, Y = MOE ($\times 10^3$kg/cm²), X_1 = cambial age (years), X_2 = ring width (mm)

It was recognized that the formula fit well into the observed data of the MOE within the cambial-age

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limitation of 32 years and in the ring width range of from 1.3mm to 11.3mm.

1 . Introduction

The modulus of elasticity (MOE) of wood is the most suitable measure for predicting the mechanical properties of wood, because there is a close relationship between the MOE and the strength in wood, and the MOE can be measured by a non-destructive method.

Many researchers have found the MOE of wood has close relationships with specific gravity, moisture content and microfibrillar orientation in the S_2 layer, so that these measures can be considered predicting factors for the MOE of wood.[1][2]

These measures described above, however, can be obtained by time-consuming and troublesome ways or by using a special apparatus, so that they are not considered to be satisfactory in respect of convenience. If there are any measures which can be obtained by simple counting or by a simple apparatus such as a scale or callipers, and if these measures have close relationships with the MOE of wood, they seem to be effective in predicting the MOE of wood in practical use.

From this point of view, two predicting factors, the cambial age and the ring width, were chosen, and a multiple regression analysis was tested using these two factors as predictor variables.

The reasons why the cambial age and the ring width were chosen as predictor variables are, 1) as R. D.Preston[3] pointed out, the tracheid length correlates negatively with the fibrillar orientation in the S_2 layer of the cell wall, and the tracheid length is short near the pith and becomes longer toward the bark, so the MOE is expected to vary similarly to the trend of tracheid length variation from pith to bark, and 2) the ring width correlates negatively with the specific gravity, and a close and positive relationship exists between the specific gravity and the MOE of wood.

As Sugi (*Cryptomeria japonica* D.Don) is one of the most important planting species in Japan, it was used as a testing species in this study.

2 . Materiais and Methods

2-1 *Preparation of test pieces and determination of the cambial age and the ring width*

Table 1 shows the outline of Sugi trees used in this study.

From the boles of trees listed in Table 1, disks of 3cm thick were removed, and the removal location of the disks was from 2m to 6m in height from the ground.

From each disk, test pieces sized 2cm(T)× (0.5cm~2.0cm) (R) × 3 cm (L) were cut off successively along a diameter. The scheme of the procedure is illustrated in Fig.1.

The number of rings involved on the cross section of each test piece was set at one to three, when the ring width was very narrow, however, five rings were permitted.

Table 1 . Characteristics of Trees tested

Test tree	Source	Age	DBH (cm)	Height (m)
A	Ehime Univ. Forest	25	23	15.8
B	ibd.	25	12	13.0
C	ibd.	25	23	17.8
D	Kuma Ehime Pref.	37	25	19.2
E	Omogo Ehime Pref.	13	24	10.2
F	Ehime Univ. Forest	43	26	20.0

The cambial age of the ring near the center of the cross section of each piece was assumed to be the representing cambial age of the piece.

The ring widths on the cross section of each test piece were averaged and this average ring width was assumed to be representative of the piece.

2-2 *Measurement of specific gravity and MOE*

The specific gravity in air dry of each test piece was determined by weighing and measuring the dimensions. Two strain gages were pasted on the tangential surfaces of each piece facing each other. The MOE was determined by measuring the strain through a strain indicator under a compressive load paallel to the grain, and the load was within the elastic limit for the species tested.

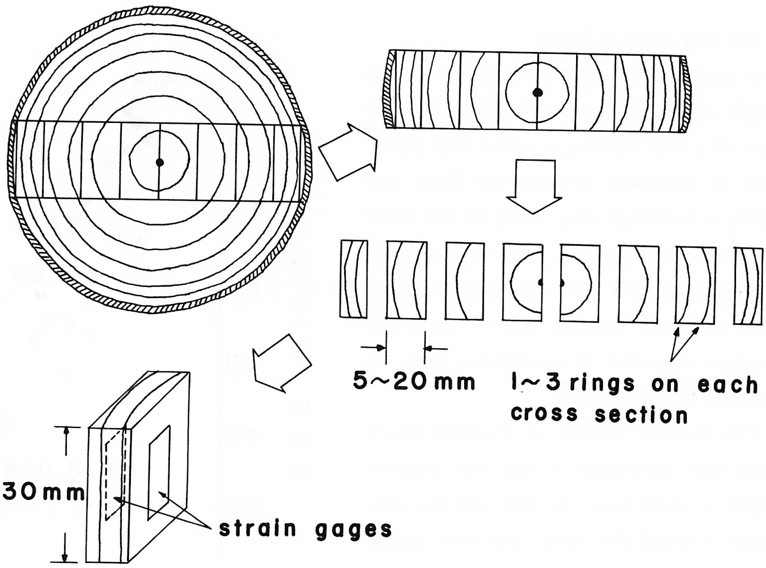

Fig.1 Scheme of preparation procedure of test pieces.

The moisture contents of the test pieces in this study ranged from 12% to 13%, so they could be considered uniform for all pieces.

3 . Results and Discussions

3-1 *The relationship between MOE and ring width*

Fig.2 shows the relationship between the ring width and the specific gravity in air dry of the specimens tested and it can be seen that the specific gravity correlates negatively with the ring width.

As many researchers have found that there is a close relationship between the specific gravity and the ring width of wood, and further have found that the specific gravity correlates positively with the MOE of wood, it can be expected that there will be a negative relationship between the ring width and the MOE of wood.

This relationship is apparent in Fig.3.

Fig.3 indicates that the MOE correlates negatively with the ring width, and that the varying pattern of the MOE in relation

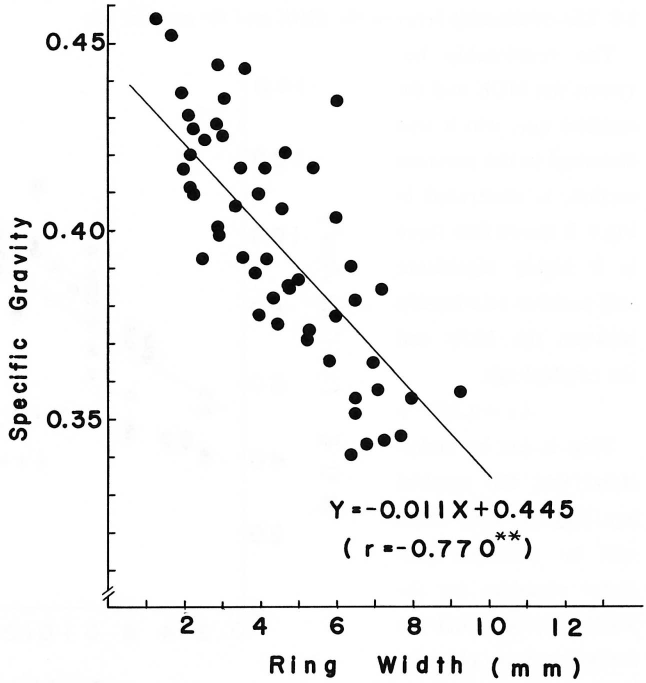

Fig.2 Relationship between the ring width and the specific gravity in air dry.

to the ring width is linear.

In general, the radial growth in a given height from the ground is rapid in the core of a tree forming a wider ring width, then it decreases toward the bark and forms a narrower ring width in the outer region of the stem, i.e., there is a pattern of radial growth that the ring width is wide when the cambial age is young and becomes narrower in accordance with the increase of cambial age.

The varying pattern of tracheid length from pith barkward is that the tracheid length is short near the pith and becomes longer toward the bark and then settles in a definite length (Sanio's law), and as R.D.Preston pointed out, there is a close relationship between the length of a tracheid and the microfibrillar orientation in its S_2 layer.

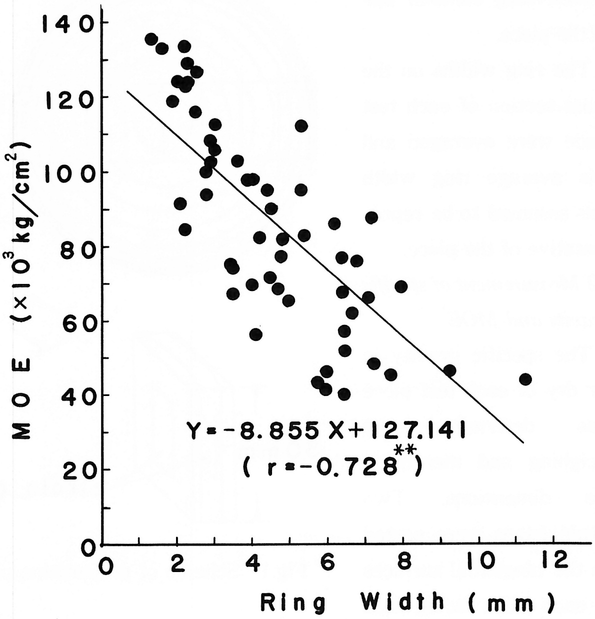

Fig.3 Relationship between the MOE and the ring width.

From these results, the higher MOE in the region of the narrower ring width indicated in Fig.3 can be attributed to a synergistic effect combined with a higher specific gravity, the reflection of the narrow ring width, and the smaller microfibrillar orientation in the zone of the higher cambial age.

Thus, the cambial age also can be considered a factor which affects the MOE of wood.

3-2 *The relationship between the MOE and the cambial age*

The relationship between the MOE and the cambial age, which was discussed in the previous section, is illustrated in Fig.4. It shows that there is a highly significant and positive relationship between the MOE and the cambial age.

(r =0.877**)

Thus it can be understood that the cambial age and the ring width will be effective predictor variables for the MOE of wood, and the former can be obtained simply dy counting the number of rings from the

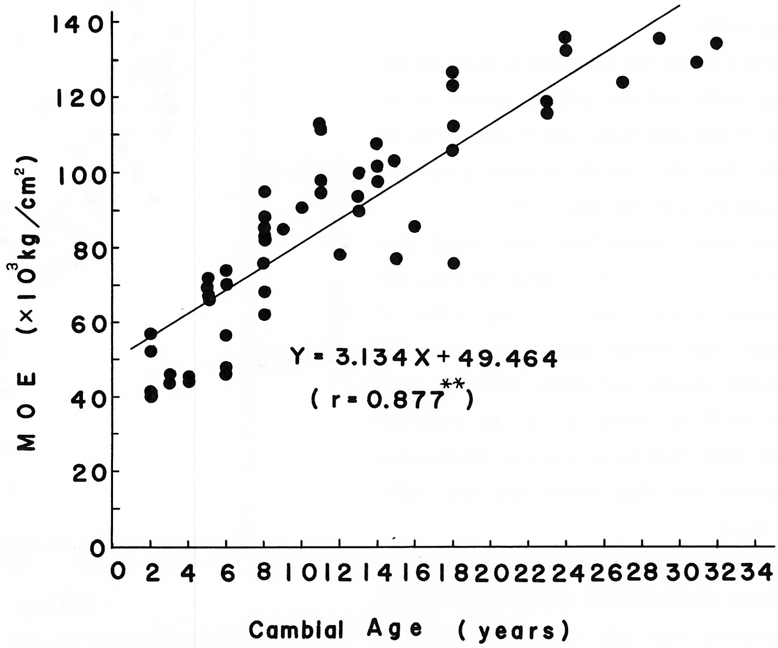

Fig.4 Relationship between the MOE and the cambial age.

pith, and the the latter can be determined by a simple apparatus such as a scale or callipers.

3-3 *Multiple regression analysis of the MOE using the cambial age and the ring width as predictor variables.*

When the MOE (Y) is expressed by the following formula using the cambial age (X_1) and the ring width (X_2) as predictor variables,

$$Y = b_0 + b_1 X_1 + b_2 X_2 \qquad (1)$$

the method of obtaining the best unbiased estimates of the partial regression constant (b_0) and the partial regression coefficients (b_1 and b_2) is called the multiple regression analysis.

The b_0, b_1 and b_2 were determined according to the common method of multiple regression analysis [4] using the data of 56 test pieces from five test trees, and the multiple regression equation obtained was as follows,

$$Y = 73.97 + 2.48 X_1 - 3.59 X_2 \qquad (2)$$

where, Y = MOE ($\times 10^3$ kg/cm²), X_1 = cambial age (years)

X_2 = ring width (mm)

The ratios of the calculated value of MOE (MOE cal.), which is obtained by substituting the observed X_1 and X_2 into the formula (2), to the observed value of MOE (MOE obs.) were calculated, and the ratios, (MOEcal./MOEobs.) ranged from 0.679 to 1.419, and the mean was 1.027 (standard deviation = 0.162).

The multiple correlation coefficient, the correlation coefficient between the MOEcal. and the MOEobs., and the coefficient of determination were 0.906 and 0.821 respectively.

An analysis of variance showed that the cambial age and the ring width were effective as predictor variables (Table2).

In order to examine if the partial regression coefficients, b_1 and b_2, were significant or not, t-tests were performed, and they showed that b_1 and b_2 were significant at a 99% level of probability, and their 95% confidential limits were as follows,

$b_1 = 2.479 \pm 0.537$

$b_2 = -3.591 \pm 1.828$

From the discussions above, it is clear that the MOE of wood at a given location of a stem can be estimated by the cambial age and the ring width which are both easily measurable, but

Table2. Analysis of Variance for Multiple Regression

Source	Degrees of freedom	Sum of squares	Meam square	F
Total	55	41938.839		
Regression	2	34432.973	17216.485	121.568**
Residual	53	7505.867	141.620	
F (2,53;0.01) = 3.975				

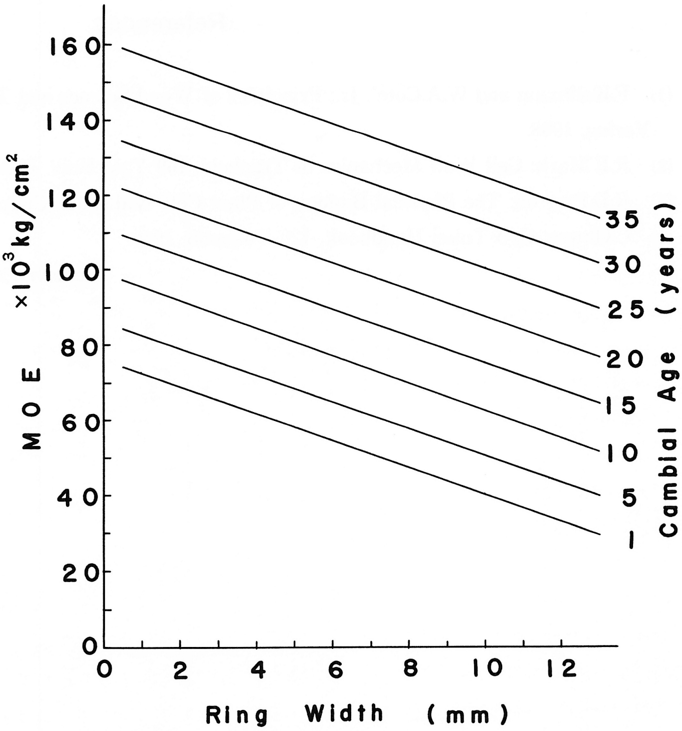

Fig.5 Diagram for estimation of MOE according to the formula(2).

the maximum cambial age in the tested trees was 32 years old, and the ring width ranged from 1.3mm to 11.3mm, so the formula (2) is considered to be only valid in this limitation and range. Further studies involving higher cambial-aged specimens are expected to be performed.

Fig.5 illustrates the relationship among the MOE, ring width and the cambial age according to the formula (2).

4. Conclusions

A multiple regression analysis was performed on the MOE of Sugi wood using the cambial age and the ring width as easily measurable variables.

Conclusions obtained were,

(1) The relationship between the ring width and the specific gravity in air dry was negatively significant ($r = -0.770^{**}$), and that between the MOE and the ring width was in the same manner ($r = -0.728^{**}$).

(2) The relationship between the MOE and the cambial age was recognized to be positively significant ($r = 0.877^{**}$).

(3) The multiple regression equation obtained was,

$$Y = 73.97 + 2.48X_1 - 3.59X_2$$

where, Y = MOE ($\times 10^3$kg/cm²), X_1 = cambial age (years)

X_2 = ring width (mm)

The ratios of MOEcal. to MOEobs. ranged from 0.679 to 1.419 and the mean was 1.027 (S.D. = 0.162), and the multiple correlation coefficient and the coefficient of determination were 0.906 and 0.821 respectively.

The variance analysis on the MOE showed that the cambial age and the ring width are both effective as predictor variables.

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