# The effct of interlocked grain on the mechanical properties of white meranti

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# ホワイト・メランチ材の機械的性質におよぼす交錯木理の影響

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## 1．はじめに

多くの熱帯材が交錯木理を有することが知られている。交錯木理は，熱帯材の特徴の一つとなっている。交錯木理は化粧的な意味合いにおいて珍重されることもあるが，多くの場合その繊維傾斜のために起きる加工の困難さ，製品における物理的，機械的性質の低下等により欠点と考えられている。

本研究は交錯木理のもたらす強度低下を解明するために，１組の交錯した木理をもつ種々の試験片を作り，衝撃曲げ試験を行ったものである。

## 2．測定方法

用いた樹種はホワイト・メランチ（Shorea sp.）である。正確に板目木取りした１×１×16cmの試験片の１つの面に特定の繊維傾斜をもち，対する他の面は通直な木理をもつようにした。夫々の木理（繊維傾斜）をもつ層の厚さは同一である。その他に木理通直の試験片，完全に同一の繊維傾斜をもった一層よりなる試験片，さらには夫々が反対向きの木理（繊維傾斜）をもった２層よりなる試験片による対比試験も行った。得られた繊維傾斜の範囲は0～15°である。

これら試験片を用い，名古屋大学農学部木材物理学教室所蔵のシャルピー型衝撃試験機による衝撃曲げ試験を行った。荷重は試験機のハンマーの重心位置につけた200kgのロードセルにより，また撓みは差動変圧計を用い測定した。直流アンプ，多用途振動計を通じたデーターをデイジタル・ストレイジ・スコープに入力し，$X-Y$ レコーダーに出力し，荷重－撓み曲線を得た。比例限度応力（SPL），衝撃曲げ強さ（MOR），衝撃曲げヤング係数（MOE），弾性域の衝撃曲げ吸収エネルギー（U1），塑性域の衝撃曲げ吸収エネルギー（U2），それらの和として衝撃曲げ吸収エネルギー（U）を求めた。

## 3．結果と考察

1） U1を除いたすべての機械的性質，すなわち，SPL, MOR, MOE, U2, Uはいづれも交錯木理の影響を受け，繊維傾角が大きくなるほどそれらの値は低下した。
2） 板目面荷重の方が，すべての強度的性質において，柾目面荷重に比し高い値の結果を示した。
3） 板目面荷重の中では圧縮側に通直木理層を置いた場合，5°以上の繊維傾斜において，他の荷重方法に比しSPLは大きな値を示した。また引張側に通直木理層を置いた場合にはMORが他の荷重方法に比し大きくなった。
4） 一般的に引張側に通直層を置いたもののMOEは他の荷重方法の結果に比し大きい。
5） 引張側に繊維傾斜をもつ材では13°の繊維傾斜においてSPL, MOR, MOEの急激な減少がみら

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れた。また衝撃曲げ吸収エネルギーの急減は 7° の繊維傾斜でみられた。

以上の結果をふまえ，交錯木理をもつ曲げ材における強度計算において，繊維傾斜のある層の強度を，実際の断面幅でなく，通直な木理をもつ層の断面幅が減少したものと見なして計算する相当断面計算を試みた。その結果引張側に 3～15° の繊維傾斜をもつ材では13.6～50.2%，圧縮側に 3～15° の繊維傾斜をもつ材では19.7～48.6%の断面幅の減少を示した。

このように交錯木理のもつ繊維傾斜による強度の低下が顕著にみられたことにより，熱帯材の利用をより合理的なものとするためには，立木における交錯木理の分布，生成等について深く研究を進める必要がある。

## 1. Introduction

Interlocked grain has been defined as a condition produced in wood by the alternate orientation of fibers in successive layers of growth increments. It is considered as a variation of spiral grain and is a normal characteristic in many of tropical hardwoods (Northcott (1957)).

Noskowiak (1963) and Houkall (1982) mention that from a utilization standpoint spiral grain is important in view of its detrimental effects on the strength, seasoning and machining properties of wood. According to Martley (1920), this grain can often be recognized by a characteristic banded appearance on radial surfaces, due to differences in the reflection of light from a number of zones parallel to the longitudinal axis of the trunk.

Webb (1969) measured interlocked grain on breast height samples taken from 180 Sweetgum trees and found that only a few trees were almost straight grained. There was important variation in interlocked grain within each stand sampled and that interlocked grain varied independently from growth rate. Fibre measurements in *Calophyllum sp.* and *Chloroxylon swietenia* suggest that a longer fibre length is correlated with inclined grain and a shorter fibre length with straight grain, (Martley 1920).

Static bending tests in structural size specimens carried out by Booth (1958) shows that Utile is unsuitable for certain structural purposes due to:

(a) The presence of steeply interlocked grain in the centre of members which is not visible on the surface.

(b) the tendency for members to fail suddenly without initial warning cracks.

Weddell (1961) noted that in Utile and Greenheart the ultimate bending stress and the modulus of elasticity are affected by the presence of interlocked grain.

Fagan & Mclain (1983) found that toughness was very sensitive to small localized grain deviations. The sensitivity of toughness as a measure of the energy required to cause rapid failure in a simply supported, centrally loaded beam, has also been reported by numerous workers (Keith, 1964; Sinclair, 1979). In his discussion of annual layers, Keith (1964) mentions that the average toughness of specimens loaded on the radial surface is less than half of that recorded for specimens loaded on the tangential surface.

Knowledge about the interlocked grain on the tropical wood has been considered to become more important since the use of these wood has recently increased. White meranti is known as one of the tropical wood which usually has interlocked grain.

The present study was initiated to determine the effect of a simple interlocked grain using specimens with a band of slope or straight grain on one tangential surface and a band of slope or straight grain on the other tangential surface. Impact bending testing machine was used for this purpose. Additionally, position of the slope of grain to the applied impact load was also studied.

## 2. White meranti

This timber is produced by trees in the Anthoshorea group of Shorea. Some of the species producing white meranti are *Shorea bracteolata* Dyer., *S. hypochra* Dyer., *S. assamica* Dyer., *S. javanica* K. et V., *S. lamellata* Foxw., *S. bentongensis* Foxw., *S. ochraceae* Sym., *S. retionodes* V. Sl., and *S. virescens* Parijs.

White meranti is also known as melapi in Sabah, bobo in Vietnam, makai in India, weisses meranti in Germany and meranti putih in Indonesia.

White meranti grow to a height of 12 to 55 m and a diameter of 1.8 m except for *S. javanica* K. et V. in which a diameter of 2.1 m can be reached, with long, clean, cylindrical boles above small butresses. Sapwood ill-defined or indistinct when freshly cut, but becoming well defined in the course of drying; Heartwood almost pure white when freshly cut, gradually changing to yellow-brown or buff colour, and weathering to a golden-brown or definite brown; plane surfaces lustrous with a subtle ribbon figure on radial surfaces. The texture is moderately coarse but even, and the grain is interlocked.

White meranti is generally very free from defects, though brittle-heart may occur in large logs.

## 3. Material and experimental procedures

All of the tests in this study were carried out in the Department of Forest Products, Faculty of Agriculture, Nagoya University.

Specimens were prepared in Wood Workshop of the Department of Forest Products, whereas measurement of the specimen's dimensions, degree of grain inclination and weight of each specimen were done in the Wood Physics Laboratory. Impact bending tests were also conducted in the Wood Physics Laboratory.

### 3-1. Material.

The test material used in the study came from White Meranti sawn timber which was in green condition and had the initial size of about 200 cm × 10 cm × 3.5 cm. Material was then cut into shorter section boards of about 34 cm in length.

Shorter section boards were surfaced in such a manner that the tangential surface of the wood is entirely from the same layer and is really parallel to the direction of the layer.

The next procedure was to determine grain direction on the tangential surfaces of the specimens and the manner in which they should be tested. All of the specimens were machined to a dimension of 16 cm × 1 cm × 1 cm.

Three different specimen conditions as are seen in Figure 1 and 2 were prepared i.e.

(1) a stick in which the direction of the grain was parallel to the edges on all of its tangential surfaces

(2) a stick in which the direction of the grain was parallel to the edge on one of its tangential surface and had slope of grain on the opposite one. These two grain directions were maintained to cover the area of the stick in a ratio of 1 : 1

(3) a stick with slope of grain of the same degree on both of its tangential surfaces.

### 3-2. Data Collecting.

Data collected from each specimen were classified into two groups. The first was the group of the detail of each specimen, such as its actual width, height, length, weight, span of beam and grain direction. Except for the weight of specimen, all of those measurements were carried out before testing. The weight of specimen was measured two times i.e. initial weight was measured a minute after testing and oven dried weight which was measured after specimen was tested and oven dried in 100 ± 5℃.

The width, height, length and oven dried weight of each specimen were used for calculating its specific gravity. Initial weight and oven dried weight were used for calculating its moisture content.

The second was the group of the data of load at the proportional limit, maximum load, deflection at the proportional limit and maximum deflection of each specimen. These data were obtained from the graph of each specimen, recorded during the impact bending test (mechanical test). Data from the mechanical test together with the data of the height, width and span of load of the corresponding specimen were used in the calculation of the stress at the proportional limit (SPL), modulus of rupture (MOR), modulus of elasticity (MOE) and absorbed energy (U1, U2 and U)

### 3-3. slope of Grain Measurement.

The slope of grain was measured on the tangential surface of each speciment with a plastic protractor. The angle between the direction of the fibers and the edge of the specimen is used instead of the distance of grain deviation, to express the slope of grain. Preliminary observation on the slope of grain of specimen indicated that in order to get a uniformity illustration, it would be better to classified the available specimens into eight different classes of slope of grain i.e. 0, 3, 5, 7, 9, 11, 13, and 15 degree of slope of grain. All of the specimens were in the green condition and free of any visible defects.

Available specimens were examined following final machining and classified in accordance with the degree of slope of grain and designated in accordance with the application of the impact load on the surface of the specimen. All of the specimens were stored in a refrigerator under polyvinyl sheet cover, to keep its moisture content before testing.

### 3-4. Moisture Content.

Moisture content of each specimen is expressed as a percentage of the oven-dry weight of wood and was determined according to the following equation :

$$Mc = \frac{Wa - Wo}{Wo} \times 100 \qquad (1)$$

where :

$Mc$ : moisture content expressed in per cent and obtained by drying the specimen in an oven set at 100 - 105°C until constant weight was attained.

$Wa$ : weight of specimen prior to drying

$Wo$ : oven-dry weight of the specimen.

### 3-5. Specific Gravity.

Specific gravity is expressed as basic specific gravity i.e. volume in green condition and weight in oven-dry condition.

### 3-6. Testing Method.

#### 3-6-1. Loading Surface.

The term of loading surface is used to express the application of the impact load on the surface of specimen and the condition of the specimen.

Five types of loading surfaces were used in this study. Four of them were applied on the tangential surface and as follows :

(1) specimens had no slope of grain (had straight grain) on both tangential surfaces (tension and compression side)

(2) specimens with slope of grain on tension side and straight grain on compression side.

(3) specimens with straight grain on tension side and slope of grain on compression side.

(4) specimens with the same degree of slope of grain on both of its tangential surfaces (tension and compression side).

The fifth one was carried out on the radial surface of the specimen i.e. (5) specimens with slope of grain on one tangential surface and straight grain on the other tangential surface and load was applied on its radial surface. Of these loading surface types, only the first and the fifth type was put into the same group i.e. loading surface group I, and the other three loading surface types were grouped separately, as they were. Figure 1 and 2 illustrate loading condition of each group.

### 3-6-2. Impact Bending Test.

Specimens were tested in the green condition using a Wood Physics Laboratory Impact Bending Testing Machine which was equipped with automatic recording devices. The machines used for tests in impact is shown in Figure 3.

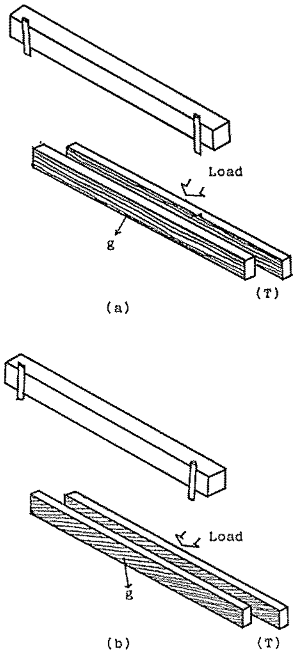



Fig. 1. Specimen & Loading condition Ⅰ.

Notes :

(T) : Impact load applied in tangential surface.

g : The direction of the grain.

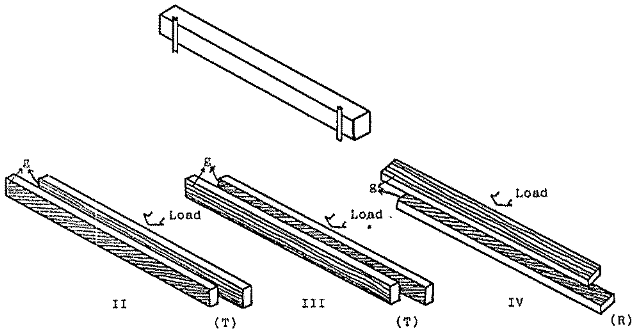


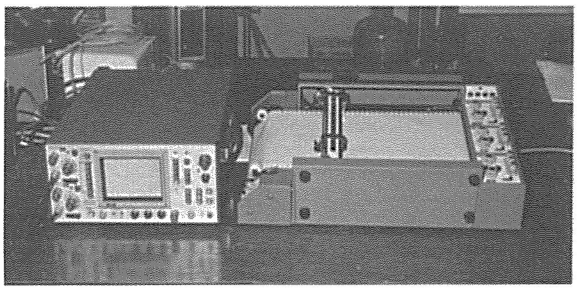

Fig. 2. Specimens & Loading Conditions Ⅱ, Ⅲ and Ⅳ.

Notes :

(T) : Impact load applied in tangential surface.

(R) : Impact load applied in radial surface.

g : The direction rf the grain.



Automatic Recoding Devices of The Impact Bending Testing Machine

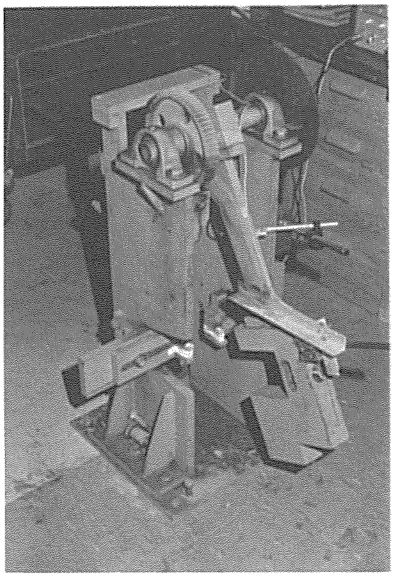


Fig. 3. Impact Bending Testing Machine

After a specimen was measured its actual dimension then depend on the test condition, a concentrated load was applied at midspan of a 12.5 cm to a particular face of each specimen, with the velocity of the hammer drop at $5.2 \times 10^4$ mm/minute.

The load and deflection were measured by the aid of a load cell attached on the centre of gravity of hammer drop and a photoelectric deflection transducer respectively. Mechanism of the data recording is as follows : At the time that the hammer of the machine touches the surface of specimen then a load cell will carry data of the load which are required to break a specimen, to the load amplifier device. At the same time, data of the specimen deflection are also sent to the deflection amplifier. Here the load and deflection data are amplified and afterwards are carried to storage scope which is consist of Oscilloscope and Data memory.

Data stored in the data memory were then transferred to XY recorder in the form of load--deflection curve. A flow chart of the data recording in an impact bending test is shown in Fig. 4.

## 4. Data analysis

### 4-1. Method Of Calculation.

Data of each specimen recorded on the graph paper of the XY recorder were used as a basic data for calculating stress at the proportional limit (SPL), modulus of rupture (MOR), modulus of elasticity (MOE) and absorbed energy (U1, U2 and U). An example of a load-deflection curve recorded on the graph paper of XY recorder is presented in the following figure.

In determining proportional limit for the load-deflection curve, a straight line must be established through this curve. The position where the curve departure from the straight line determine the proportional limit as is shown by point A in Figure 5. Load at the proportional limit is represented in Fig. 5 by a point $P_p$, while the corresponding deflection is represented by point Yp. Point B of Fig. 5 is the highest point before fracture and express the maximum value of the load-deflection curve. Maximum load and maximum deflection are then represented by Pm and Ym respectively.

Based on the dimension and the basic data obtained from the curve of each specimen, its mechanical properties were then calculated according to the following equations :

Stress at the proportional limit :

$$SPL = \frac{3 \cdot P_p \cdot \ell}{2 \cdot b \cdot h^2} \qquad (2)$$

Modulus of rupture :

$$MOR = \frac{3 \cdot Pm \cdot \ell}{2 \cdot b \cdot h^2} \qquad (3)$$

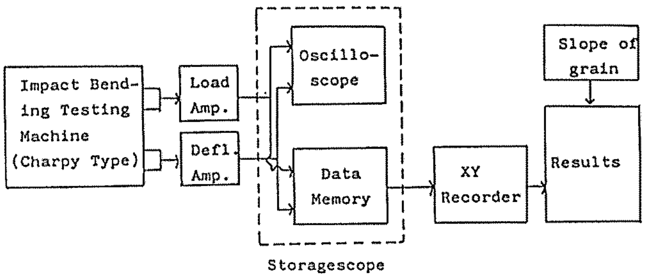



Fig. 4. A Flow Chart of the Data Recording.

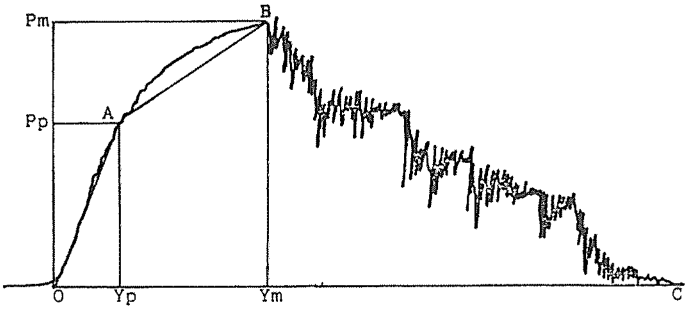



Fig. 5. An example of load-defelection curve

where

- O : Intial point of measurement
- A : Proportional limit
- B : Fracture point
- C : End of recording
- $P_p$ : Load at the proportional limit
- $P_m$ : Maximum load
- $Y_p$ : Deflection at the proportional limit
- $Y_m$ : Maximum deflection

Modulus of elasticity :

$$MOE = \frac{P_P \cdot \ell^3}{4 \cdot b \cdot h^3 \cdot Y_P} \quad (4)$$

Absorbed energy to the proportional limit:

$$U_1 = 1/2 \cdot Y_P \cdot SPL \quad (5)$$

Absorbed energy from the proportional limit to the fracture :

$$U_2 = (SPL + MOR)(Ym - Y_P)/2 \quad (6)$$

Absorbed energy to the fracture / toughness :

$$U = U_1 + U_2 \quad (7)$$

where $\ell$ : span of load = 12.5 cm.

b : width of the specimen ( cm).

h : height of the specimen ( cm).

$P_P$ : load at the proportional limit ( kg).

Pm : maximum load ( kg).

Yp : deflection at the proportional limit ( cm).

Ym : maximum deflection ( cm).

### 4-2. Experimental Design

An analysis of variance was conducted to determine the effects of slope of grain and loading surface in stress at the proportional limit, modulus of rupture, modulus of elasticity, absorbed energy to the proportional limit, absorbed energy from the proportional limit to the fracture and absorbed energy to the fracture. The experiment was a 4 by 7 factorial. Factor D was slope of grain of 3, 5, 7, 9, 11, 13, 15 degree. Factor L was loading surface group I, II, III and IV as shown in Fig. 1 and 2.

## 5. Results and discussion

### 5-1. Stress At The Proportional Limit (SPL).

Stress at the proportional limit of the specimens were calculated according to equation (2).

$$SPL = \frac{3 \cdot P_P \cdot \ell}{2 \cdot b \cdot h^2}$$

Table 1 presents the average values for three replications of stress at the proportional limit on four different loading surfaces and seven different degree of slope of grain. Table 1 is arranged to facilitate comparison of the effects of slope of grain and loading surface.

A completely randomized design of the 7 × 4 factorial experiment with 3 specimens of approximately uniform condition are used to study the

Table 1. Average * Values For Stress At The Proportional Limit.

| Slope Of Grain(°) | Loading Surface I | II | III | IV |
|---|---|---|---|---|
| 0 | 678 | | | |
| 3 | 636 | 639 | 665 | 577 |
| 5 | 611 | 634 | 629 | 564 |
| 7 | 595 | 625 | 599 | 547 |
| 9 | 579 | 621 | 595 | 525 |
| 11 | 552 | 616 | 587 | 518 |
| 13 | 535 | 574 | 563 | 511 |
| 15 | 512 | 544 | 544 | 472 |

Note :
* : Average of 3 replications

Table 2. Anova For Stress At The Proportional Limit.

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Treatment | 27 | 186040.83 | | |
| D | 6 | 104675.90 | 17445.98 | 16.56** |
| L | 3 | 75708.99 | 25236.33 | 23.96** |
| DL | 18 | 5655.94 | 314.22 | 0.30 |
| Within | 56 | 58992.10 | 1053.43 | |
| Total | 83 | 245032.93 | | |

Notes :
** : Significant
D : Degree of slope of grain
L : Loading surface

effect of the various slope of grain and the applied load on the surface of specimen. Data from straight grain specimen were excluded in this statistical analysis. The complete analysis of variance for the stress at the proportional limit is provided in Table 2.

The Anova table for the stress at the proportional limit indicates that the F value for the interaction between slope of grain and loading surface is 0.30, which is smaller than the 1% critical F value. This means that the interaction effect of the slope of grain and loading surface is nonsignificant.

The effect of the slope of grain on the stress at the proportional limit is shown in the Anova of Table 2 by the F value of 16.56, which is bigger than 1% critical F value, hence the effect of degree of slope of grain on the stress at the proportional limit is significant. The result of a significant effect is that, for the same loading surface the higher the slope of grain, the lower the value of the stress at the proportional limit.

The 1% critical F value with 3 and 56 df is 2.80 while F statistics for L main effect is bigger than it. Therefore the effect of the loading surface is also significant. At the same degree of slope of grain, a different loading surface causes a different value of stress at the proportional limit.

Fig. 6 shows that there is a general pattern of rate of reduction in stress at the proportional limit as the degree of slope of grain increases. It is noted that except for three degree slope of grain, specimen which was loaded on the loading surface II generally has a higher stress at the proportional limit than the other three loading

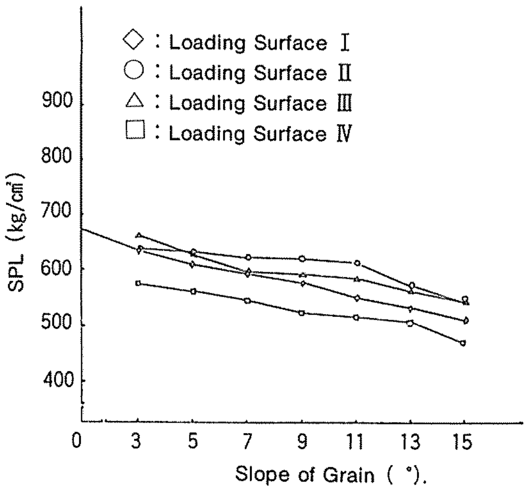
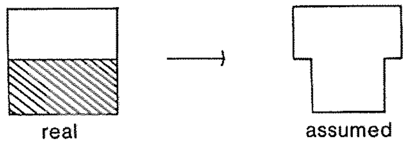


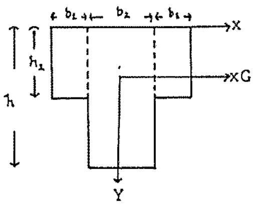

Fig. 6. Stress at the Proportional Limit for Four Different Loading Surfaces.

surfaces. There seems to be a slight tendency for stress at the proportional limit of the loading surface II to decrease less than other loading surfaces, particularly from three to eleven degree slope of grain. Loading surface IV (loading on the radial surface) clearly shows the lowest stress at the proportional limit at any degree of slope of grain.

The fact that slope of grain specimen had a lower stress at the proportional limit than the straight grain specimen has led to an assumption that the exist of slope of grain has reduced the real width of the specimen. In this assumption a transformed section formula was used for calculating the amount of the width reduction caused by slope of grain in a specimen. A modification in the shape of specimen for this assumption is illustrated by a cross section of a specimen as follows :




Method for calculating this type of specimen is as follows :




$$A = b_1(h_1) + b_2(h) + b_1(h_1) \quad (8)$$

$$\bar{Y} \frac{b_1(h_1)^2 + b_2(h)(1/2 \cdot h)}{A} \quad (9)$$

$$I_x = (2/3 \cdot b_1)(h_1)^3 + (1/3 \cdot b_2)(h)^3 \quad (10)$$

$$I_x = I_{xG} + A(\bar{Y})^2 \quad (11)$$

$$I_{xG} = I_x - A(\bar{Y})^2$$

$$\sigma = \frac{M \cdot c}{I} \quad (12)$$

where $M = 1/4 \cdot P \cdot \ell$ (13)

$$\sigma\,\text{comp}\cdot = \frac{1/4 \cdot P \cdot \ell \cdot c_1}{I_{xG}} \quad (14)$$

$(c_1 = \bar{Y})$

$$\sigma\,\text{tens}\cdot = \frac{1/4 \cdot P \cdot \ell \cdot c_2}{I_{xG}} \quad (15)$$

$(c_2 = h - c_1)$

substituting $\sigma = \frac{3 \cdot P \cdot \ell}{2 \cdot b \cdot h^2}$ into equation (14),

we obtain

$$\left(\frac{3 \cdot P_o \cdot h^2}{4 \cdot P_n \cdot b}\right) b_1^2 + \left(\frac{9 \cdot h^2}{2} - \frac{6 \cdot P_o \cdot h^2}{P_n}\right) b_1 + 3 \cdot h^2 \cdot b \left(\frac{P_o}{P_n} - 1\right) = 0 \quad (16)$$

$$WR = 2 \cdot b_1 \quad (17)$$

where :

$A$ = Area.

$b_1$ = Width reduction for one side of T form specimen.

$h_1$ = Height of the upper part of the specimen (=1/2.h).

$h$ = Height of the specimen.

$b_2$ = The remaining width.

$\bar{Y}$ = Centroid.

$I_x$ = Moment of inertia of the entire figure about x axis.

$I_{xG}$ = Moment of inertia of the entire figure about XG axis.

$P$ = Load (In this case is proportional load)

$b$ = Real width of the specimen.

$P_o$ = Proportional load of the zero slope of grain specimen.

$P_n$ = Proportional load of the slope of grain specimen.

$WR$ = Width reduction.

$\sigma$ comp· = Compression stress.

$\sigma$ tens· = Tension stress.

### 5-1-1. Width Reduction Assumption.

Calculations using Transformed section formula give values of the width reduction for various degree slope of grain specimens as are seen in Tables 3 and 4.

The results show that values of the width reduction from 3 to 15 degree slope of grain are in the range of 0.14 cm to 0.50 cm or from 13.6 % to 50.2 % for specimens with the loading surface II and in the range of 0.17 cm to 0.49 cm or from 19.7 % to 48.6 % for specimens with the loading surface III. Comparisons on these two kinds loading surface indicate that from 3 to 11 degree slope of grain, the increase of the width reduction for loading surface III is bigger than loading surface II. An almost equal percentages of the width reduction between these two kinds loading surfaces is found in 13 and 15 degree slope of grain.

Since stress at the proportional limit of the zero degree slope of grain (straight grain) specimen is used as a standard for calculating width reduction hence, at least one side of each specimen would have a more or less stress equal with the stress at the proportional limit of the straight grain specimens, and it seems that this is in the compression side of the loading surface II and in

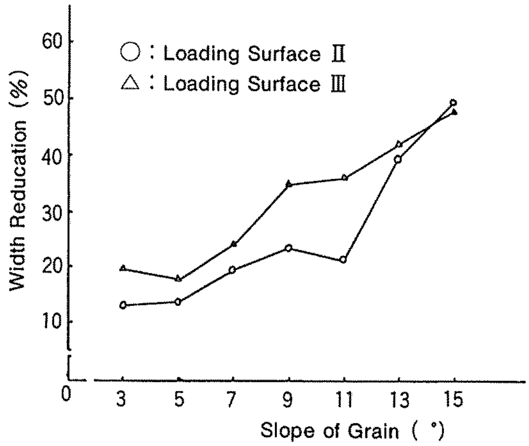



Fig. 6a. Percentage of Width Reducation in Stress at the Proportional Limit.

Table 3. Average* Width Reductions in Stress At The Proportional Limit Of The First Assumption For Loading Surface Ⅱ**

| Slope Of Grain ( °) | $b_1$ (cm) | $WR$ (cm) | $WR$ ( %) | $b_2$ (cm) | $b_2$ ( %) |
|---|---|---|---|---|---|
| 3 | 0.07 | 0.14 | 13.6 | 0.87 | 86.4 |
| 5 | 0.07 | 0.14 | 14.0 | 0.87 | 86.0 |
| 7 | 0.10 | 0.20 | 20.0 | 0.81 | 80.0 |
| 9 | 0.12 | 0.24 | 24.3 | 0.76 | 75.7 |
| 11 | 0.11 | 0.23 | 22.4 | 0.79 | 77.6 |
| 13 | 0.20 | 0.41 | 40.3 | 0.60 | 59.7 |
| 15 | 0.25 | 0.50 | 50.2 | 0.49 | 49.8 |

Notes :
$b_1$ : Reduction on one side of the assumed T form specimen.
$WR$ : Specimen width reduction
$b_2$ : Remaining width
* : Average of 3 replications
** : Values are rounded off upwards

Table 4. Average* Width Reductions in Stress At The Proportional Limit Of The First Assumption For Loading Surface Ⅲ.

| Slope Of Grain ( °) | $b_1$ (cm) | $WR$ (cm) | $WR$ ( %) | $b_2$ (cm) | $b_2$ ( %) |
|---|---|---|---|---|---|
| 3 | 0.08 | 0.17 | 19.7 | 1.05 | 80.3 |
| 5 | 0.09 | 0.18 | 17.9 | 0.83 | 82.1 |
| 7 | 0.15 | 0.29 | 29.1 | 0.73 | 57.2 |
| 9 | 0.18 | 0.36 | 35.7 | 0.64 | 64.3 |
| 11 | 0.19 | 0.37 | 36.8 | 0.64 | 63.2 |
| 13 | 0.21 | 0.43 | 42.6 | 0.63 | 57.4 |
| 15 | 0.24 | 0.49 | 48.6 | 0.52 | 51.4 |

Notes :
* : Average of 3 replications rounded off upwards
$b_1$ : Reduction on one side of the assumed T form specimen
$WR$ : Specimen's width reduction
$b_2$ : Remaining width.

Table 5. Stress At The Proportional Limit Of The First Assumption For Loading Surface Ⅱ.

| Slope Of Grain ( °) | $\sigma_p$ | $P_p$ | $WR$ | $\sigma_c$ | $\sigma_t$ |
|---|---|---|---|---|---|
| 3 | 639 | 34.7 | 13.6 | 663 | 715 |
| 5 | 634 | 34.6 | 14.0 | 659 | 713 |
| 7 | 625 | 34.0 | 20.0 | 662 | 742 |
| 9 | 621 | 33.5 | 24.3 | 668 | 770 |
| 11 | 616 | 33.7 | 22.4 | 659 | 752 |
| 13 | 574 | 31.3 | 40.3 | 662 | 858 |
| 15 | 544 | 29.5 | 50.2 | 666 | 948 |

Notes :

$\sigma_p$ : Stress at the proportional limit (kg/cm²)
$P_p$ : Load at the proportional limit (kg)
$WR$ : Width reduction (%)
$\sigma_c$ : Compression stress (kg/cm²)
$\sigma_t$ : Tension stress (kg/cm²)

Table 6. Stress At The Proportional Limit Of The First Assumption For Loading Surface Ⅲ.

| Slope Of Grain ( °) | $\sigma_p$ | $P_p$ | $WR$ | $\sigma_c$ | $\sigma_t$ |
|---|---|---|---|---|---|
| 3 | 665 | 36.2 | 19.7 | 735 | 659 |
| 5 | 629 | 34.3 | 17.9 | 732 | 662 |
| 7 | 599 | 32.7 | 29.1 | 868 | 660 |
| 9 | 595 | 32.0 | 35.7 | 839 | 671 |
| 11 | 587 | 31.8 | 36.8 | 844 | 666 |
| 13 | 563 | 30.7 | 42.6 | 887 | 662 |
| 15 | 544 | 29.6 | 48.6 | 937 | 663 |

Notes :

$\sigma_p$ : Stress at the proportional limit (kg/cm²)
$P_p$ : Load at the proportional limit (kg)
$WR$ : Width reduction (%)
$\sigma_c$ : Compression stress (kg/cm²)
$\sigma_t$ : Tension stress (kg/cm²)

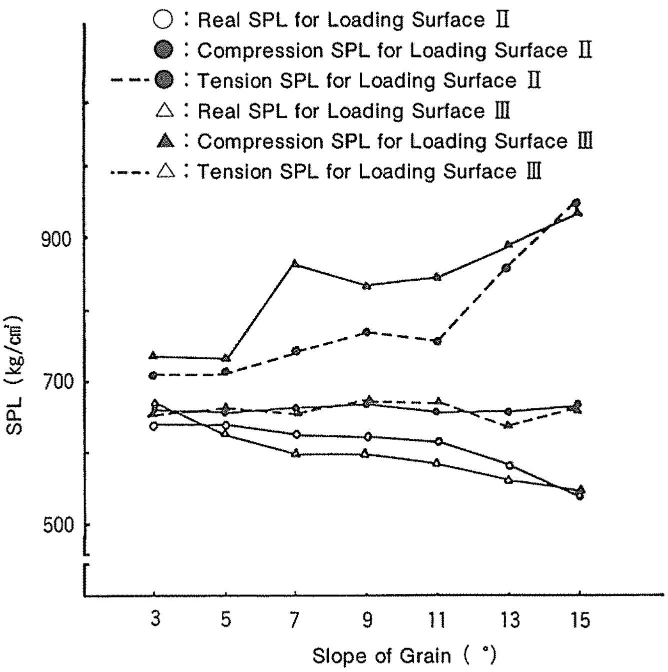



Fig. 7. Stress at the Proportional Limit for The First Assumption.

the tension side of the loading surface III. Compression and tension stress for loading surface II and III are presented in Tables 5 and 6 respectively.

The results in Table 5 and Table 6 also indicate that if the assumption mentioned before is accepted, then a higher stress can be found on the tension side of loading surface II and on the compression side of loading surface III. Values in Table 5 and Table 6 also indicate that tension stress of loading surface II and compression stress of loading surface III are not constant from 3 to 15 degree slope of grain. For loading surface II as shown in Fig. 7 an abrupt increase of tension stress begin at 11 degree slope of grain, and for loading surface III an abrupt increase occured two times i.e. between 5 and 7 degree slope of grain and between 13 and 15 degree slope of grain.

### 5-1-2. Compression and Tension Stress At The Proportional Limit.

A different application of transformed section formula was employed at the same data for calculating compression and tension stress of assumed specimens. In this calculation width reduction is assumed to be equal with the percentage of the stress reduction between slope of grain specimen and straight grain specimen. These width reduction values are then applied in the transformed section formula.

Width reduction of each specimen was calculated as follows:

$$WR = \frac{So - Sn}{So} \quad (18)$$

$$b_1 = 1/2 \cdot WR \cdot b \text{ and } b_2 = b - WR \cdot b \quad (19)$$

where:

$WR$ = Width reduction for both sides of the assumed T form specimen ( %).

$b_1$ = Width reduction for one side of the assumed T form specimen ( cm).

$b_2$ = Remaining width ( cm).

$b$ = Actual width of the slope of grain specimen ( cm).

$So$ = Stress at the proportional limit of the straight grain specimen (kg/cm$^2$).

$Sn$ = Stress at the proportional limit of the slope of grain specimen (kg/cm$^2$).

Values obtained from calculations using this assumption are then compared with the real values of stress at the proportional limit as are seen in Table 7 for loading surface II and in Table 8 for loading surface III, these values are also plotted in Fig. 8.

Table 7 and Fig. 8 show that values for tension stress at the proportional limit for loading surface II are more or less equal from 3 to 15 degree slope of grain. Values for the compression stress at the proportional limit are lower than those for the tension stress. Here a constant value is only found until 11 degree slope of grain.

Table 7. Stress At The Proportional Limit For The Second Assumption Of Loading Surface II *

| Slope Of Grain ( °) | $\sigma_p$ | $P_p$ | $WR$ | $\sigma_c$ | $\sigma_t$ |
|---|---|---|---|---|---|
| 3 | 639 | 34.7 | 5.33 | 648 | 668 |
| 5 | 634 | 34.6 | 6.53 | 644 | 666 |
| 7 | 625 | 34.0 | 7.82 | 638 | 664 |
| 9 | 621 | 33.5 | 8.42 | 635 | 663 |
| 11 | 616 | 33.7 | 9.21 | 631 | 662 |
| 13 | 574 | 31.3 | 12.70 | 599 | 650 |
| 15 | 544 | 29.5 | 19.82 | 575 | 642 |

Notes :

* : Average of 3 replications rounded off upwards

$\sigma_p$ : Stress at the proportional limit (kg/cm²)

$P_p$ : Load at the proportional limit (kg)

$WR$ : Specimen's width reduction (%)

$\sigma_c$ : Compression stress at the proportional limit (kg/cm²)

$\sigma_t$ : Tension stress at the proportional limit (kg/cm²)

Table 8. Stress At The Proportional Limit For The Second Assumption Of Loading Surface Ⅲ*

| Slope Of Grain ( °) | $\sigma_p$ | $P_p$ | $WR$ | $\sigma_r$ | $\sigma_t$ |
|---|---|---|---|---|---|
| 3 | 665 | 36.2 | 1.99 | 669 | 678 |
| 5 | 629 | 34.3 | 7.20 | 665 | 641 |
| 7 | 599 | 32.7 | 11.68 | 657 | 618 |
| 9 | 595 | 32.0 | 12.27 | 656 | 615 |
| 11 | 587 | 31.8 | 13.49 | 654 | 608 |
| 13 | 563 | 30.7 | 16.94 | 647 | 590 |
| 15 | 544 | 29.6 | 19.70 | 642 | 576 |

Note :
See notes for Table 7.

An abruptly low value is then begun at 13 degree and continued at 15 degree slope of grain.

For loading surface III (straight grain on the tension side and slope of grain on the compression side) as shown in Table 8 and in Fig. 8 a constant value is found in the compression stress, whereas the tension stress at the proportional limit of this loading surface shows that an abruptly low value begin at 13 degree slope of grain.

If we compare the result obtained from this assumption and the result obtained from the earlier assumption then it is clear that in the earlier assumption stress of approximately equal to the stress of the straight grain specimen is found in the compression side for loading surface II and in the tension side for loading surface III, with the tension stress for loading surface II and compression stress for loading surface III higher than its compression and tension stress respectively. This is opposite with the result mentioned above.

### 5-2. Modulus Of Rupture (MOR).

Average values for Modulus of Rupture (MOR) of various degree slope of grain and various loading surface are presented in Table 9. These values were calculated using equation (3). Formula used for calculating SPL (stress at the

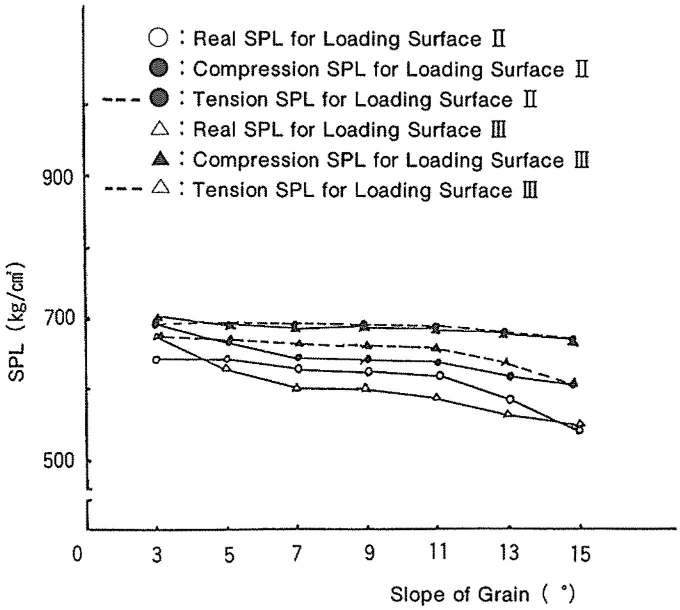



Fig. 8. Stress at the Proportional Limit for The Second Assumption

proportional limit) was used here by substituting the value for maximum load, designated as Pm (the force corresponding to the highest point on the load-deflection curve) for Pp (load at the proportional limit) then

$$MOR = \frac{3 \cdot Pm \cdot \ell}{2 \cdot b \cdot h^2}$$

The effect of the various slope of grain and loading surface are studied using a completely randomized design of factorial experiment, as it has been used for analyzing the effect in SPL. Table 10 presents the Analysis of variance for MOR. The effect of the interaction between slope of grain and loading surface is also nonsignificant as shown by the F ratio of 0.60. Table 10 indicates that the effect of loading surface is significant in modulus of rupture. This means that MOR of the slope of grain specimens depend on the application of the impact load on the surface of the specimen. Examination of the data in Table 9 indicates that specimens with loading surface III (straight grain on tension side and slope of grain on compression side) produce the highest value of MOR and specimens with loading surface IV with the exception for 15 degree slope of grain, produce the lowest value of MOR. Weddell (1961) in a study of the influence of interlocked grain on the bending strength of timber found that in Utile and Greenheart, specimens loaded on the tangential edge produce a Greater average strength than specimens loaded on the radial surface.

Comparisons on the results obtained here and the result obtained in stress at the proportional limit (SPL), then it is clear that for both SPL and MOR, the lowest value is found in the loading surface IV, with the exception for 15 degree slope of grain. A different phenomenon appears if we compare the results of the specimens for loading surface II and III. The highest SPL is found in the loading surface II, whereas the highest MOR is

Table 9. Average* Values For Modulus of Rupture.

| Slope Of Grain(°) | Loading Surface (kg/cm²) I | II | III | IV |
|---|---|---|---|---|
| 0 | 1051 | | | |
| 3 | 938 | 944 | 1033 | 884 |
| 5 | 896 | 921 | 998 | 850 |
| 7 | 875 | 920 | 972 | 835 |
| 9 | 848 | 904 | 943 | 804 |
| 11 | 812 | 886 | 886 | 796 |
| 13 | 757 | 808 | 868 | 744 |
| 15 | 661 | 750 | 777 | 707 |

Note :
* : Average of 3 replications

Table 10. Anova For Modulus of Rupture.

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Treatment | 27 | 640593.08 | – | |
| D | 6 | 434241.92 | 72373.65 | 39.46** |
| L | 3 | 186656.26 | 62218.75 | 33.93** |
| DL | 18 | 19694.90 | 1094.16 | 0.60 |
| Within | 56 | 102699.23 | 1833.91 | |
| Total | 83 | 743292.31 | | |

Notes :
** : Significant
D : Degree of slope of grain
L : Loading surface

found in the loading surface III. This is probably caused by different sensitivity of slope of grain. In the SPL the comporession side of the specimen is supposed to be the most sensitive area for the effect of slope of grain, while in the MOR the most sensitive area is in the tension side.

The F statistic for the effect of the degree of slope of grain gives a value of 16.56 which is bigger that the 1% critical F value, hence the effect of slope of grain is also significant in MOR. For all loading surfaces the higher the slope of grain the

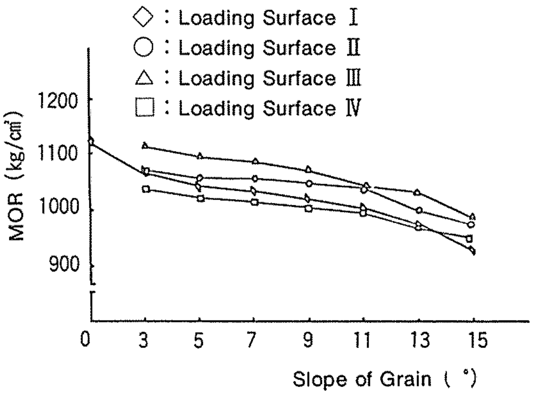



Fig. 9. Modulus of Rupture for Four Different Loading Surfaces.

lower the value for MOR. A different tendency is shown by the entirely 15 degree slope of gain specimens. MOR of these specimens are lower than those of the same degree specimens for loading surface IV. This is probably caused by the fact that percentage of slope of grain between these two kinds specimens is different.

A further investigation must be carried out to ensure this phenomenon. To illustrate how the MOR is affected by slope of grain in various loading surface, the average values in Table 9 are ploted in Fig. 9. as the relationship between MOR and degree of slope of grain. As mentioned before that the higher the slope of grain the lower the MOR, the graph in Fig. 9 shown this phenomenon clearly.

### 5-2-1. Width Reduction Assumption.

An assumption that the exist of the slope of grain reduce the width of the specimen as used in the SPL is also applied to MOR. Therefore the same method and equation mentioned in the SPL were also used for calculating the value of the width reduction. The difference between calculation for width reduction in SPL and MOR is in source of load used in the calculation. Load at the proportional limit was used in the calculation for width reduction of SPL whereas width reduction of MOR was calculated using value of maximum load.

The effect of the slope of grain on the MOR is shown in Table 11 and 12 by the amount of the width reduction. A width reduction of 0.25 cm or 27.6% for loading surface II and a width reduction of 0.11 cm or 8.71% for loading surface III is caused by the exist of 3 degree slope of grain. An increment of more than 1.5% in width reduction is shown by the loading surface II and an increment of more than 1.5% too, for the rise of each 3 degree slope of grain is produced by loading surface III. The highest slope of grain used in this study i.e. 15 degree, shows a reductiion of 0.66 cm or 65.8% for the loading surface II and 0.62 cm or 60.9% for the loading surface III. A similar phenomenon is also shown by the width reduction in Table 11 and Table 12. The amount of maximum compression and tension stress of each loading surface are shown in Table 13 and 14 and in Fig. 10.

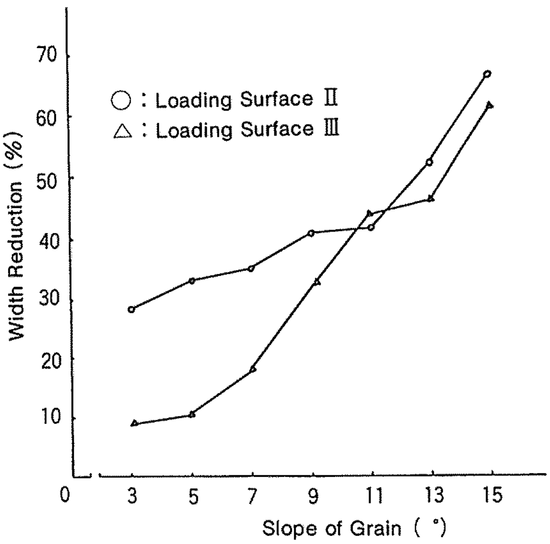



Fig. 9a. Percentages of Width Reduction in Modulus of Rupture.

Table 11. Average Width Reductions In Modulus Of Rupture For The First Assumption Of Loading Surface Ⅱ *.

| Slope Of Grain ( °) | $b_1$ (cm) | $WR$ (cm) | $WR$ ( %) | $b_2$ (cm) | $b_2$ ( %) |
|---|---|---|---|---|---|
| 3 | 0.12 | 0.25 | 27.6 | 0.76 | 75.4 |
| 5 | 0.16 | 0.33 | 32.3 | 0.69 | 67.7 |
| 7 | 0.17 | 0.34 | 34.0 | 0.67 | 66.1 |
| 9 | 0.20 | 0.40 | 39.6 | 0.61 | 60.4 |
| 11 | 0.21 | 0.41 | 40.6 | 0.60 | 59.4 |
| 13 | 0.28 | 0.57 | 56.3 | 0.44 | 43.7 |
| 15 | 0.33 | 0.66 | 65.8 | 0.34 | 34.2 |

Notes :
* : Average of 3 replications rounded off upwards
$b_1$ : Reduction on one side of the assumed T form specimen
$WR$ : Specimen width reduction
$b_2$ : Remaining width

Table 12. Average Width Reductions In Modulus Of Rupture For The First Assumption Of Loading Surface Ⅲ·

| Slope Of Grain ( °) | $b_1$ (cm) | $WR$ (cm) | $WR$ ( %) | $b_2$ (cm) | $b_2$ ( %) |
|---|---|---|---|---|---|
| 3 | 0.05 | 0.11 | 8.7 | 1.05 | 90.1 |
| 5 | 0.05 | 0.10 | 10.3 | 0.90 | 89.7 |
| 7 | 0.09 | 0.18 | 17.5 | 0.83 | 82.5 |
| 9 | 0.15 | 0.31 | 30.9 | 0.69 | 69.1 |
| 11 | 0.22 | 0.43 | 42.9 | 0.58 | 57.2 |
| 13 | 0.23 | 0.46 | 45.2 | 0.55 | 54.8 |
| 15 | 0.31 | 0.61 | 60.9 | 0.40 | 39.1 |

Note :
See notes for Tabel 11.

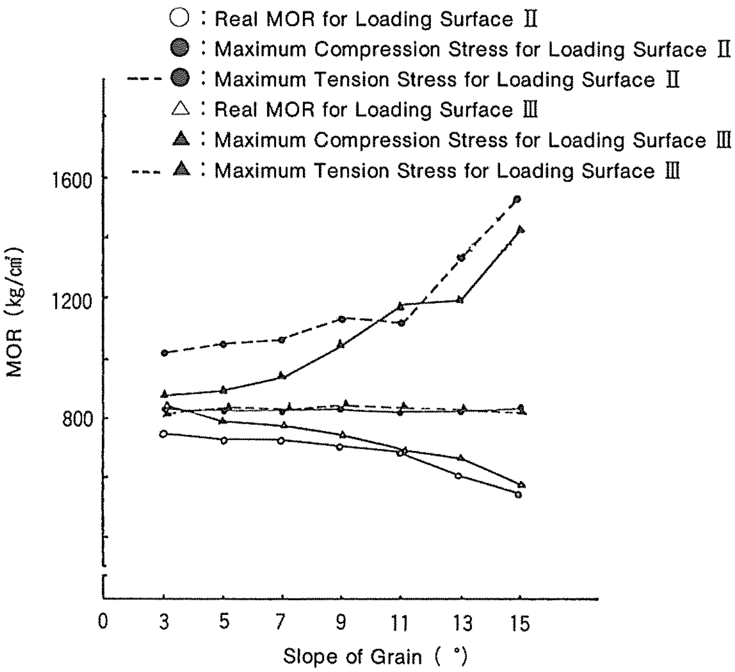



Fig. 10. Modulus of Rupture for the First Assumption

Table 13. Modulus Of Rupture For The First Assumption Of Loading Surface Ⅱ*.

| Slope Of Grain ( °) | σ m | Pm | WR | σ mc | σ mt (assumed) |
|---|---|---|---|---|---|
| 3 | 945 | 51.3 | 27.6 | 1028 | 1216 |
| 5 | 921 | 50.4 | 32.3 | 1022 | 1242 |
| 7 | 920 | 50.1 | 34.0 | 1027 | 1261 |
| 9 | 904 | 48.7 | 39.6 | 1036 | 1331 |
| 11 | 886 | 48.5 | 40.6 | 1021 | 1324 |
| 13 | 808 | 44.1 | 56.3 | 1026 | 1538 |
| 15 | 750 | 40.6 | 65.8 | 1032 | 1707 |

Notes :
* : Average of 3 replications rounded off upwards
σ m : Modulus of rupture (kg/cm²)
Pm : Maximum load (kg)
WR : Specimen's width reduction
σ mc : Maximum compression stress (kg/cm²)
σ mt : Maximum tension stress (kg/cm²)

Table 14. Modulus Of Rupture For The First Assumption Of Loading Surface Ⅲ*.

| Slope Of Grain ( °) | σ m | Pm | WR | σ mc | σ mt (assumed) |
|---|---|---|---|---|---|
| 3 | 1033 | 56.3 | 8.7 | 1076 | 1021 |
| 5 | 998 | 54.3 | 10.3 | 1086 | 1024 |
| 7 | 972 | 53.1 | 17.5 | 1129 | 1023 |
| 9 | 943 | 50.7 | 30.9 | 1249 | 1040 |
| 11 | 886 | 48.0 | 42.8 | 1362 | 1033 |
| 13 | 868 | 47.3 | 45.2 | 1383 | 1026 |
| 15 | 777 | 42.3 | 60.9 | 1623 | 1027 |

Note :
See notes for Table 13.

Table 15. Modulus Of Rupture For The First Assumption Of Loading Surface Ⅱ*.

| Slope Of Grain ( °) | σ m | Pm | WR | σ mc | σ mt (assumed) |
|---|---|---|---|---|---|
| 3 | 945 | 51.3 | 10.2 | 970 | 1023 |
| 5 | 921 | 50.4 | 12.6 | 953 | 1017 |
| 7 | 920 | 50.1 | 12.7 | 952 | 1017 |
| 9 | 904 | 48.7 | 14.1 | 939 | 1013 |
| 11 | 886 | 48.5 | 15.9 | 925 | 1008 |
| 13 | 808 | 44.1 | 23.3 | 865 | 986 |
| 15 | 750 | 40.6 | 28.6 | 820 | 969 |

Notes :
* : Average of 3 replications rounded off upwards
σ m : Modulus of rupture (kg/cm²)
Pm : Maximum load (kg)
WR : Specimen's width reduction
σ mc : Maximum compression stress (kg/cm²)
σ mt : Maximum tension stress (kg/cm²)

### 5-2-2. Maximum Compression and Tension Stress.

The second assumption used in SPL i.e. A different application of transformed section was also carried out for calculating maximum compression and tension stress. The results of this assumption can be seen in Tables 15 and 16 and Fig. 11 succesively.

Table 16. Modulus Of Rupture For The First Assumption Of Loading Surface Ⅲ*.

| Slope Of Grain ( °) | σ m | Pm | WR | σ mc | σ mt (assumed) |
|---|---|---|---|---|---|
| 3 | 1033 | 56.3 | ** | 1039 | 1049 |
| 5 | 998 | 54.3 | 5.1 | 1038 | 1011 |
| 7 | 972 | 53.1 | 7.6 | 1031 | 992 |
| 9 | 943 | 50.7 | 10.3 | 1023 | 970 |
| 11 | 886 | 48.0 | 15.9 | 1008 | 925 |
| 13 | 868 | 47.3 | 17.6 | 1003 | 912 |
| 15 | 777 | 42.3 | 26.3 | 977 | 840 |

Note :
See notes for Table 13.
** : A replication has minus sign.

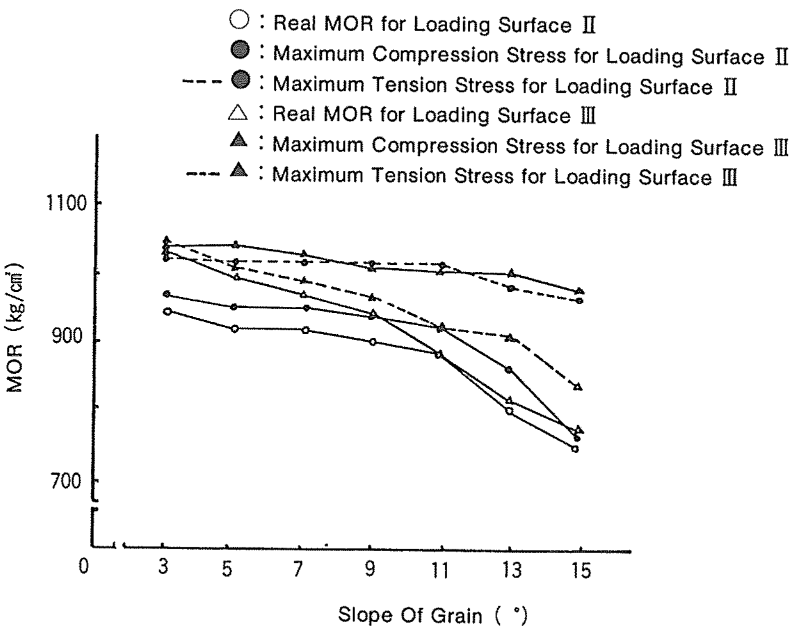



Fig. 11. Modulus of Rupture for the Second Assumption

### 5-3. Modulus Of Elasticity (MOE).

Modulus of elasticity are presented as average of three replications in Table 17. These values are obtained from calculations using equation (4). Values for slope of grain specimens were analyzed statistically using the same design as for SPL and MOR for studying the effect of slope of grain and loading surface in MOE. Analysis of variance for MOE is presented in Table 18.

F value for the interaction between slope of grain and loading surface as provided in Table 18 gives a value of less than one, which means a non-significant interaction effect of these two factors.

Anova table for the modulus of elasticity shows a significant effect for the loading surface source, since the F value for this effect is higher than 1% critical F value. This prove that the application of a different position of loading surface causes a different value of MOE. It appears that the lowest MOE is obtained from specimens for loading surface IV that is loading on the radial surface. This is in good agreement with earlier work. The reason for the increase of strength is attributed to the influence of orientation of the slope layer in the cross-section to the plane of loading i.e. when the load is applied on the radial surface, the slope of grain exerts its maximum influence (Weddell (1961)).

Loading on the tangential surface of different slope of grain position also gives a different value of MOE as clearly shown by the Anova and the value in Table 17. It is also noted that an average value of 111 x $10^3$ kg/$cm^2$ is produced by straight grain specimens.

Analysis for the effect of the degree of slope of grain shows that the F value for the degree of slope of grain source is 61.05. This is bigger

Table 17. Average* Values For Modulus of Elasticitv.

| Slope Of Grain(°) | I | Loading Surface II | III (×10³ kg/cm²) | IV |
|---|---|---|---|---|
| 0 | 111 | | | |
| 3 | 106 | 109 | 107 | 97 |
| 5 | 99 | 101 | 105 | 95 |
| 7 | 96 | 99 | 103 | 90 |
| 9 | 90 | 96 | 98 | 84 |
| 11 | 85 | 93 | 90 | 82 |
| 13 | 81 | 82 | 84 | 78 |
| 15 | 75 | 80 | 78 | 72 |

Note :
* : Average of 3 replications

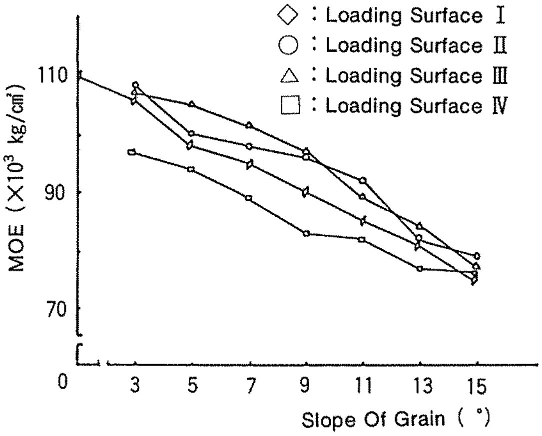



Fig. 12. Modulus of Elasticity for Four Different Loading Surfaces.

Table 18. Anova For Modulus of Elasticity.

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Treatment | 27 | 9021.17 | | |
| D | 6 | 7658.95 | 1276.49 | 61.05** |
| L | 3 | 1183.40 | 394.47 | 18.87** |
| DL | 18 | 178.82 | 9.93 | 0.47 |
| Within | 56 | 1170.93 | 20.91 | |
| Total | 83 | 10192.10 | | |

Notes :
** : Significant
D : Degree of slope of grain
L : Loading surface

than 1% critical F value therefore the effect of the degree of slope of grain also significant in MOE. A reduction of at least 1.4% in MOE caused by three degree slope of grain is found in the specimens with the loading surface II. For any other loading surface and for a higher grain deviation, a higher per cent of reduction in MOE might be expected.

To clarify the effect of slope of grain and loading surface then the average values of MOE presented in Table 17 are plotted in Fig. 12.

Table 19. Modulus Of Elasticity For The First Assumption Of Loading Surface II*.

| Slope Of Grain ( °) | *Yp* (cm) | *MOEr* | *WR* ( %) | *MOEa* |
|---|---|---|---|---|
| 3 | 0.16 | 109 | 13.6 | 117 |
| 5 | 0.16 | 101 | 14.0 | 110 |
| 7 | 0.15 | 99 | 20.0 | 111 |
| 9 | 0.16 | 96 | 24.3 | 111 |
| 11 | 0.17 | 93 | 22.4 | 106 |
| 13 | 0.17 | 82 | 40.3 | 109 |
| 15 | 0.18 | 80 | 50.2 | 118 |

Notes :
* : Average of 3 replications rounded off upwards
*Yp* : Deflection at the proportional limit
*MOEr* : Real modulus of elasticity (×10³ kg/cm²)
*MOEa* : Assumed modulus of elasticity (× 10³ kg/cm²)
*WR* : Specimen's width reduction

Calculations using following equation :

$$E = \frac{P_P \cdot \ell^3}{48 \cdot I_{xG} \cdot Y_P}$$

where : $P_P$ = proportional load ; $\ell$ = span of load

$I_{xG}$ = moment of inertia (see eq. 11)

$Y_P$ = proportional deflection.

Table 20. Modulus Of Elasticity For The First Assumption Of Loading Surface Ⅲ *.

| Slope Of Grain ( °) | *Yp* (cm) | *MOEr* | *WR* ( %) | *MOEa* |
|---|---|---|---|---|
| 3 | 0.15 | 107 | 19.7 | 113 |
| 5 | 0.16 | 105 | 17.9 | 117 |
| 7 | 0.17 | 103 | 29.1 | 144 |
| 9 | 0.17 | 98 | 35.7 | 124 |
| 11 | 0.17 | 90 | 36.8 | 116 |
| 13 | 0.18 | 84 | 42.6 | 116 |
| 15 | 0.18 | 78 | 48.6 | 115 |

Note :
See notes for Table 19.

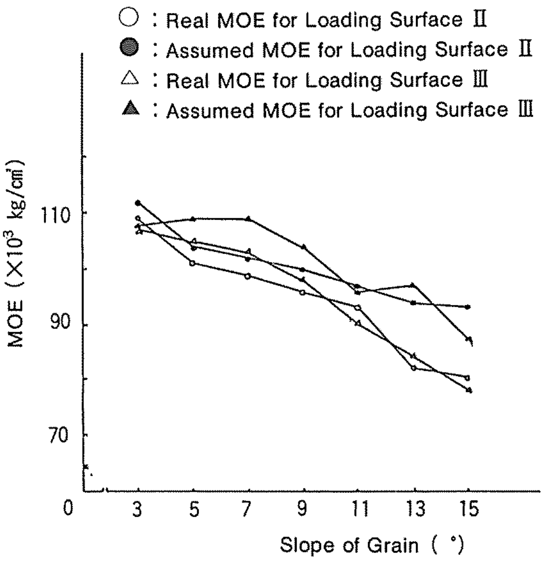



Fig. 13. Modulus of Elasticity for the First Assumption

Table 21. Modulus Of Elasticity For The First Assumption Of Loading Surface Ⅱ *.

| Slope Of Grain ( °) | *Yp* (cm) | *MOEr* | *WR* ( %) | *MOEa* |
|---|---|---|---|---|
| 3 | 0.16 | 109 | 5.33 | 112 |
| 5 | 0.16 | 101 | 6.53 | 104 |
| 7 | 0.15 | 99 | 7.82 | 103 |
| 9 | 0.16 | 96 | 8.42 | 100 |
| 11 | 0.17 | 93 | 9.21 | 97 |
| 13 | 0.17 | 82 | 12.70 | 90 |
| 15 | 0.18 | 80 | 19.82 | 88 |

Notes :
* : Average of 3 replications rounded off upwards
*Yp* : Deflection at the proportional limit
*MOEr* : Real modulus of elasticity ($\times 10^3$ kg/cm²)
*MOEa* : Assumed modulus of elasticity ($\times 10^3$ kg/cm²)
*WR* : Specimen's width reduction

Table 22. Modulus Of Elasticity For The First Assumption Of Loading Surface Ⅲ *.

| Slope Of Grain ( °) | *Yp* (cm) | *MOEr* | *WR* ( %) | *MOEa* |
|---|---|---|---|---|
| 3 | 0.15 | 107 | 1.99 | 109 |
| 5 | 0.16 | 105 | 7.20 | 110 |
| 7 | 0.17 | 103 | 11.68 | 110 |
| 9 | 0.17 | 98 | 12.27 | 104 |
| 11 | 0.17 | 90 | 13.49 | 97 |
| 13 | 0.18 | 84 | 16.94 | 98 |
| 15 | 0.18 | 78 | 19.70 | 87 |

Note :
See notes for Table 19.

and width reduction values of the first assumption in SPL, produce a higher and constant value of MOE as shown in Tables 19 and 20 and in Fig. 13, whereas calculation using second assumption does not produce a constant value from 3 to 15 degree slope of grain as presented in Tables 21 & 22 and in Figure 14.

### 5-4. Absorbed Energy to the Proportional Limit (U1).

Absorbed energy to the proportional limit (U1) was calculated according to the equation (5) i.e.

$$U1 = 0.5 \times Y_P \times SPL$$

Table 23 presents the average values of U1. A completely randomized design of the 7 x 4 facto-

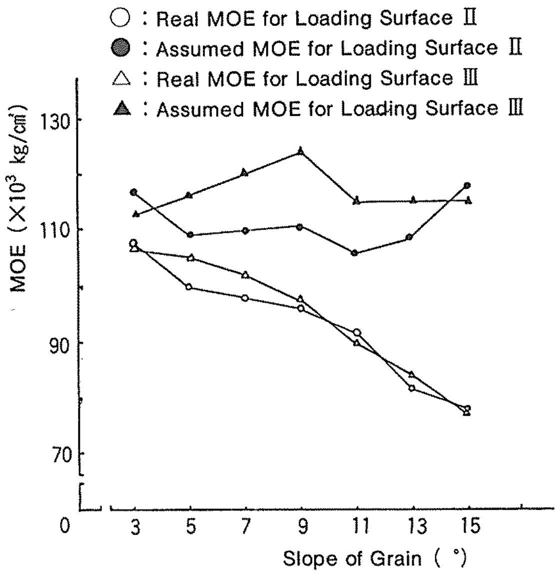



Fig. 14. Modulus of Elasticity for the Second Assumption

rial experiment was also used for analyzing data of the slope of grain specimens.

Analysis of variance for the absorbed energy to the proportional limit is presented in Table 24. A non significant effect on U1 is indicated by the interaction between degree of slope of grain and loading surface. The F value of this interaction as shown in Table 24 is 0.35. Table 24 also indicates that U1 is not affected by the slope of grain, since the F value for the degree of slope of grain source is only 0.53 and is smaller than the 1% critical F value. Therefore a value of absorbed energy to the proportional limit of about the same with the value of straight grain specimen, might be expected from a specimen with slope of grain up to 15 degree.

A significant effect in Table 24 is only shown by the loading surface source with the F value of 9.92. Examination on the data in Table 23 indicates that the lowest U1 is found in specimens tested by loading surface IV (impact load applied on the radial surface)

Table 23. Average* Values For Absorbed Energy To The Proportional Limit (U1).

| Slope Of Grain(°) | I | Loading Surface Ⅱ (kg·cm/cm²) | Ⅲ | Ⅳ |
|---|---|---|---|---|
| 0 | 54 | | | |
| 3 | 50 | 49 | 53 | 45 |
| 5 | 49 | 52 | 49 | 43 |
| 7 | 48 | 52 | 46 | 43 |
| 9 | 49 | 52 | 47 | 43 |
| 11 | 47 | 53 | 49 | 43 |
| 13 | 46 | 52 | 47 | 42 |
| 15 | 45 | 49 | 49 | 40 |

Note :
* : Average of 3 replications

Table 24. Anova For Modulus of Elasticity.

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Treatment | 27 | 1042.90 | | |
| D | 6 | 84.02 | 14.00 | 0.53 |
| L | 3 | 790.95 | 263.65 | 9.92** |
| DL | 18 | 167.93 | 9.33 | 0.35 |
| Within | 56 | 1487.86 | 26.57 | |
| Total | 83 | 2530.76 | | |

Notes :
** : Significant
D : Degree of slope of grain
L : Loading surface

With regard to absorbed energy, earlier workers only mention that the capacity of wood to resist shock on the radial surface is lower than the tangential surface. Data in Table 23 are then plotted in Fig. 15 to illustrate the relationship between slope of grain specimens and U1 in various loading surfaces.

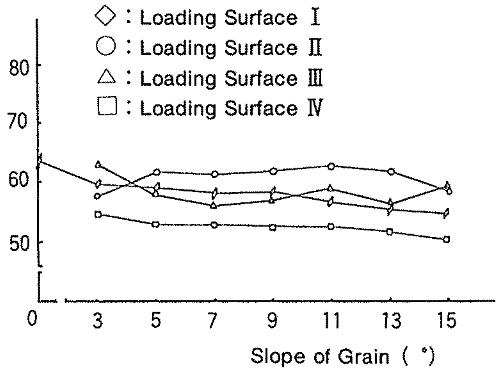



Fig. 15. Absorbed Energy to the Proportional Limit (U1) for Four Different Loading Surfaces.

## 5-5. Absorbed Energy from the Proportional Limit to the Fracture (U2).

The values of SPL and MOR were used in the calculation for absorbed energy from the proportional limit to the fracture (U2) using equation (6) and the equation is as follows:

$$U_2 = 0.5x(SPL + MOR)(Ym - Y_p).$$

The average values of U2 are presented in Table 25. Data of the slope of grain specimens were also analyzed using a completely rendomized design. Analysis in Table 26 reveals a nonsignificant effect for the interaction between degree of slope of grain and loading surface with the F value of 1.11.

Since the loading surface source shows a significant effect, as indicated by the F value of 54.51, then the effect of each loading surface in U2 is different. As it has already been proved in other properties, here the application of the impact load on the radial surface of the slope of grain specimens also caused a lower capacity for absorbing energy. Comparisons on the values in Table 25 show that from 9 degree slope of grain the average absorbed energy of loading surface III (load applied on the tangential surface and slope of grain is on the compression side) is more than twice of that recorded for loading surface IV (load applied on the radial surface of the specimen) of the same grain condition. For example, at 15 degree slope of grain the value of U2 for loading surface III is 213 kg·cm/cm$^2$, whereas the value for loading surface IV is only 101 kg·cm/cm$^2$.

Data in Table 25 indicates that as long as the impact load is applied on the tangential surface then a higher value of U2 than the value of U2 of

Table 25. Average* Values For Absorbed Energy From Proportional Limit To The Fracture (U2).

| Slope Of Grain(°) | Loading Surface (kg·cm/cm²) I | II | III | IV |
|---|---|---|---|---|
| 0 | 431 | | | |
| 3 | 382 | 409 | 403 | 266 |
| 5 | 346 | 372 | 385 | 229 |
| 7 | 292 | 294 | 356 | 201 |
| 9 | 247 | 267 | 351 | 164 |
| 11 | 217 | 222 | 332 | 143 |
| 13 | 172 | 170 | 299 | 126 |
| 15 | 149 | 155 | 213 | 101 |

Note :
* : Average of 3 replications

Table 26. Anova For Absorbed Energy From Proportional Limit To The Fracture (U2).

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Treatment | 27 | 703575.55 | | |
| D | 6 | 404788.79 | 67464.80 | 41.45** |
| L | 3 | 266140.89 | 88713.63 | 54.51** |
| DL | 18 | 32645.87 | 1813.66 | 1.11 |
| Within | 56 | 91138.04 | 1627.47 | |
| Total | 83 | 794713.59 | | |

Notes :
** : Significant
D : Degree of slope of grain
L : Loading surface

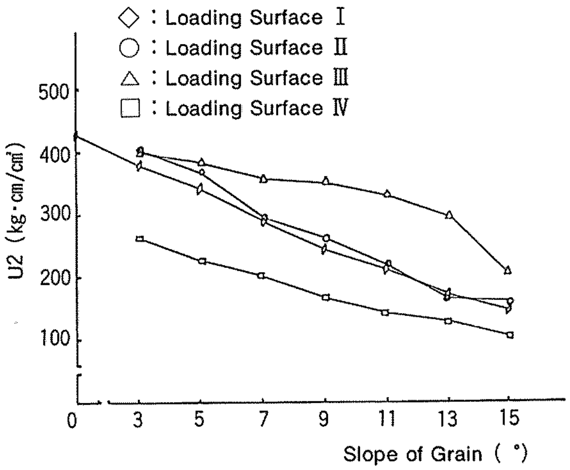



Fig. 16. Absorbed Energy from the Proportional Limit to the Fracture (U2) for Four Different Loading Surfaces.

Table 27. Average* Values For Absorbed Energy To The Fracture (U).

| Slope Of Grain(°) | I | Loading Surface II (kg・cm/cm²) | III | IV |
|---|---|---|---|---|
| 0 | 485 | | | |
| 3 | 432 | 458 | 456 | 310 |
| 5 | 395 | 424 | 434 | 272 |
| 7 | 340 | 346 | 402 | 244 |
| 9 | 296 | 319 | 398 | 206 |
| 11 | 264 | 275 | 381 | 185 |
| 13 | 218 | 222 | 348 | 168 |
| 15 | 194 | 204 | 263 | 142 |

Note :
* : Average of 3 replications
** : Round off upwards cause a slight different value between U and U1 + U2.

specimens loaded on the radial surface, might be expected.

A significant effect in U2 is also caused by the effect of slope of grain as shown by the F value of 41.45. The relationship between U2 and slope of grain with various loading surface is presented in Fig. 16. Based on the analysis in Table 26 and the graph in Fig. 16 then it can be said that the increase of the slope of grain decrease the capacity of a specimen to absorb energy. An average value of 431 kg・cm/cm² energy is required to break a straight grain specimen and an average of only 149 kg・cm/cm² is required to break an entirely 15 degree slope of grain specimens.

Table 28. Anova For Absorbed Energy To The Fracture (U2).

| Source | df | SS | MS | F |
|---|---|---|---|---|
| Treatment | 27 | 735912.74 | | |
| D | 6 | 414481.17 | 69080.20 | 45.87** |
| L | 3 | 290326.09 | 96775.36 | 64.25** |
| DL | 18 | 31105.48 | 1728.08 | 1.15 |
| Within | 56 | 84343.93 | 1506.14 | |
| Total | 83 | 820256.67 | | |

Notes :
** : Significant
D : Degree of slope of grain
L : Loading surface

### 5-6. Absorbed Energy To The Fracture/Toughness (U).

In this study energy required to cause rapid failure in a simply supported, centrally loaded specimen is termed absorbed energy to the fracture/toughness (U).

Depend on the two previous kinds of absorbed energy, this absorbed energy is :

$$U = U1 + U2.$$

Table 27 presents the average value for U. The values of U for slope of grain specimens were subjected to an analysis of variance. A completely randomized design used in the previous analysis was also used here. Analysis of variance in Table 28 shows that the effect of the interaction between loading surface and degree of slope of grain in U is also nonsignificant.

F value for the loading surface source is

64.25, this means that the effect of the loading surface is significant in U. Keith (1964) mentions that the average toughness of specimens loaded on the radial surface is less than half of that recorded for specimens loaded on the tangential surface. Although not all of the U value for loading surface IV (load applied on the radial surface) less than half of those for loading on the tangential surface, the results obtained in this test agree that radial surface has a lower capacity for absorbing energy to the fracture than tangential surface, as mentioned by numerous workers.

If we examine the phenomenon in this absorbed energy and two other absorbed energy mentioned before, it seems that for all three kinds of absorbed energy the effect of the applied load on the surface of a specimen is significant. Since the value of the U is obtained from the two previous kinds of absorbed energy therefore the significant effect in the U is suppossed as a result of these two absorbed energy.

Of the three kinds of tangential loading surface used in this study, in general, the highest capacity for absorbing energy was found in loading surface III (straight grain on the tension side and slope of grain on the compression side). It appears that the exist of slope of grain on the tension side need more attention since the reduction in U caused by this condition markedly. This is clear, by comparing the difference in the U value between loading surface III and loading surface II which is much bigger than the difference between loading surface II and I.

The F statistic for degree of slope of grain source is 45.87, and shows that the effect of slope of grain is significant. Since the interaction between degree of slope of grain and loading surface is nonsignificant, hence it can be said that the increase of the slope of grain always reduces the required energy to failure a specimen. Graphs in Figure 17 illustrate the relationships between absorbed energy to the fracture (U) and degree of slope of grain.

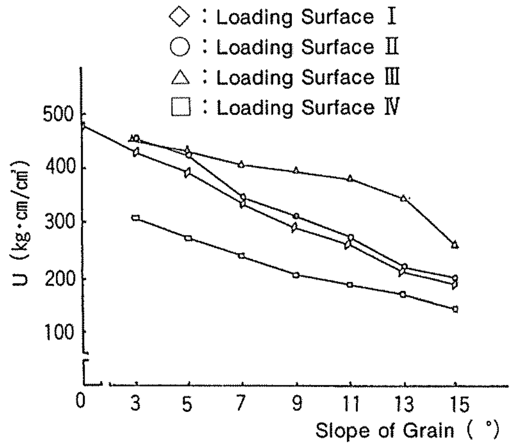



Fig. 17. Absorbed Energy to the Fracture (U) for Four Different Loading Surfaces.

With regard to the effect of slope of grain, Langlands (1933) found that the unit toughness of the interlocked specimen was much higher than that of the straight grain specimen, where Fagan ' Mclain (1983) mention that a deviation of grain on the radial surface of 5 degree resulted in reductions in toughness of 30% and 16% for radial and tangential test respectively.

## 6. Conclusions

Specimens used in this impact bending tests indicate that only few of them had a truly straight grain on either one or both of its tangential surfaces. The results obtained in this study lead to conclusions that :

1. In green condition specimens, the effect of the application of impact load on four different surfaces and slope of grain conditions is significant for six measured properties (SPL, MOR, MOE, U1, U2 and U). A higher strength properties and absorbed energy were found in specimens loaded on tangential surface.
2. Among three tangential surfaces, each had

different slope of grain condition, specimens with the straight grain on the compression side and slope of grain equal or higher than 5 degree on the tension side, produced the highest stress at the proportional limit. Specimens with the straight grain on the tension side and slope of grain on the compression side produced the highest Modulus of Rupture.

3. In general specimens with the straight grain on the tension side and slope of grain on the compression side had the highest MOE than any other slope of grain specimens.
4. The entirely 15 degree slope of grain specimens had a lower MOR than those of the specimens loaded on the radial surface with straight grain on one of its tangential surface and slope of grain on the opposite one. A further investigation must be done to ensure this phenomenon.
5. A more or less equal absorbed energy to the proportional limit was found in straight grain and slope of grain specimens.
6. The effect of slope of grain is only significant in five properties measured in this study i.e. SPL, MOR, MOE, U2 and U. The higher the slope of grain the lower the values of these properties.
7. Calculations using Transformed section formula indicated that in SPL, specimens loaded on the tangential surface with a slope of grain of only 3 degree resulted in width reduction of 13.6% for specimens with straight grain on the compression side and slope of grain on the tensiodsn side, and 19.7% width reduction for specimens with slope of grain on the compression side and straight grain on the tension side. In modulus of rupture the percentage of width reduction of 3 degree slope of grain is 27.6% for specimens with straight grain on the compression side and 8.7% for specimens with slope of grain on the compression side.
8. Specimens with straight grain on the compression side and slope of grain on the tension side shows an abrupt high reduction in strength properties (SPL, MOR and MOE) at 13 degree slope of grain. An abrupt high reduction in absorbed energy begin at 7 degree slope of grain in specimens with straight grain on the compression side and slope of grain on the tension side.
9. Since the effect of slope of grain in strength properties and absorbed energy of wood is significant, then other studies concerning interlocked grain such as the distribution/ the rate of interlocked grain in a stand tree are deeply suggested.

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