J Wood Sci (2000) 46:279–283

ORIGINAL ARTICLE

Yoshitaka Kubojima · Hiroshi Yoshihara · Hisashi Ohsaki
Masamitsu Ohta

Accuracy of shear properties of wood obtained by simplified Iosipescu shear test

Received: February 24, 1999 / Accepted: September 8, 1999

Abstract We examined the accuracy of the shear properties of wood by the Iosipescu shear test using specimens whose shape was simplified. Quartersawn boards of sitka spruce (*Picea sitchensis* Carr.) and shioji (Japanese ash, *Fraxinus spaethiana* Lingelsh.) were used. Two types of specimen for the Iosipescu shear test were compared: a "standard specimen" whose notch angle is 90° and a "keyhole type specimen", which is more easily prepared than the standard type. The shear modulus, yield shear stress, and failure shear stress of the keyhole-type specimen were compared to those of the standard specimen. Shear stress analysis was conducted using the finite element method (FEM). The results obtained were as follows: (1) The failure pattern obtained by the simplified Iosipescu shear test was similar to that seen with the standard Iosipescu shear test. (2) The shear modulus, yield stress, and failure stress obtained by the simplified Iosipescu shear test coincided with those by the standard Iosipescu shear test. (3) The principal strain angle and principal stress angle of the simplified Iosipescu shear test were about 45°. (4) It is recognized that pure stress is applied to the strain-gauge regions in the simplified Iosipescu shear test, and it is expected that the shear properties are independent of the notch angle.

Key words Iosipescu shear test · Keyhole-type specimen · Shear properties · Principal stress angle · Stress analysis

Introduction

In our previous work[1] we examined the shear modulus of wood obtained using the Iosipescu shear test, by which pure shear stress can be applied to specimens.[2,3] We believe that the shear modulus obtained by this testing method is useful and that the test is an ideal method for measuring the shear properties of wood.

During the Iosipescu shear test for isotropic materials or orthotropic materials, the shear modulus is subject to the notch angle.[4] Hence, it is necessary to investigate the effect of the notch angle during the Iosipescu shear test for wood. For this purpose, keyhole-shaped specimens were made. This type of specimen can be made more easily than the 90° notch specimen normally used for the Iosipescu shear test: The line constructing the 90° notch must be at an angle of 45° to the long axis of a specimen and must be tangent to the hole.[1] Making such notches is not easy.

In this study, the shear properties were measured through the Iosipescu shear test using this simplified specimen. Stress analysis of the center part of the specimen of the Iosipescu shear test was also conducted using the finite element method (FEM).

Experiment

Specimen

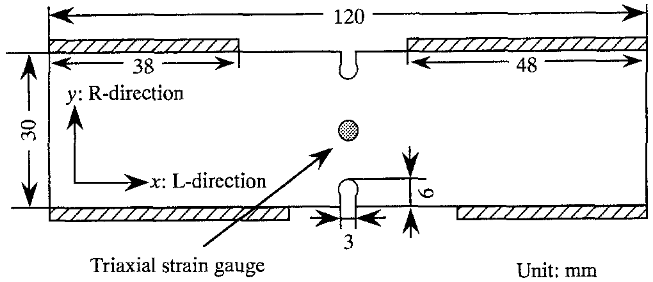
Sitka spruce (*Picea sitchensis* Carr.) and shioji (Japanese ash, *Fraxinus spaethiana* Lingelsh.) were used. The specimens were conditioned at 20°C and 65% relative humidity before and during the tests. Specimens for the Iosipescu shear test, compression test, and vibration test were prepared from the same lumber.

Y. Kubojima (✉)
Forestry and Forest Products Research Institute, Ministry of Agriculture, Forestry and Fisheries, PO Box 16, Tsukuba Norin Kenkyu Danchi-nai, Ibakaki 305-8687, Japan
Tel. +81-298-73-3211; Fax +81-298-73-3798
e-mail: kubojima@ffpri.affrc.go.jp

H. Yoshihara
Faculty of Science and Engineering, Shimane University, Matsue 690-8504, Japan

H. Ohsaki
Hokkaido Forest Products Research Institute, Asahikawa 071-0198, Japan

M. Ohta
Graduate School of Agricultural and Life Sciences, The University of Tokyo, Bunkyo-ku, Tokyo 113-8657, Japan



Notch radius = 2 mm
Thickness = 8 mm

Fig. 1. Specimen for simplified Iosipescu shear test. *Hatched zones* represent the supports of the specimen

Iosipescu shear test

Iosipescu shear tests were conducted to measure the shear modulus, yield shear stress, and failure shear stress. Two types of specimen were considered. One is the "standard type" specimen. Here a notch angle of 90° and the outline of the specimen were shown as an LR specimen in our previous work[1]. Another is the "keyhole type" specimen, the shape of which is shown in Fig. 1.

Rectangular specimens with dimension of 120mm (L) ×30mm (R) ×8mm (T) were prepared. Two holes with a radius of 2mm were drilled at the same point as in our previous study.[1] The slit was then made using a 3mm thick circular saw. The Iosipescu shear test was conducted on the standard and keyhole specimens (called here the "standard Iosipescu shear test" and the "simplified Iosipescu shear test", respectively). Five specimens were used for each species.

The Iosipescu shear testing method is standardized for fiber-reinforced plastics (FRP) according to the American Society for Testing Materials (ASTM) D-5379. However, fabricating the specimen in accordance with ASTM is difficult because the specimen size defined by ASTM is small. Hence, we determined the dimensions of the specimen as in Fig. 1. The shape of the specimen is approximately proportional to that of ASTM specifications.

The apparatus, strain gauges, and position where the strain gauges were bonded for the simplified Iosipescu shear test were the same as in our previous study.[1] A vertical load of 1 mm/min loading velocity was applied to the specimen, and the load–strain relations were recorded by an XY recorder. The shear modulus was obtained from the initial linear segment of the shear stress – shear strain curve. The plastic shear stress component, γ_{xy}^{p}, was separated by the following equation:

$$\gamma_{xy}^{p}=\gamma_{xy}-\frac{\tau_{xy}}{G_{xy}} \tag{1}$$

where γ_{xy}, τ_{xy}, and G_{xy} are the normal shear strain, shear stress, shear modulus of the xy-plane, respectively. The shear stress – plastic shear strain relation was formed by Ludwik's power function represented as follows[5]:

$$\tau_{xy}=Y_{xy}+a\left(\gamma_{xy}^{p}\right)^{n} \tag{2}$$

where a and n are parameters. The yield shear stress Y_{xy} was calculated where $\gamma_{xy}^{p}=0$. The shear strength was determined by dividing the maximum load by the products of the thickness of the specimen and the distance between the notches.

Compression test

To measure the Young's modulus in the L-direction (E_L) and in the R-direction (E_R) as well as Poisson's ratio of the LR-plane (ν_{LR}), which are needed for stress analysis, a static compression test was carried out using the specimens with dimensions of 40mm (L) ×20mm (R) ×20mm (T) for measuring E_L and ν_{LR} and those of 20mm (L) ×20mm (R) ×20mm (T) for measuring E_R.

Vibration test

To measure the shear modulus of the LR-plane, G_{LR}, needed for the stress analysis, a vibration test was done. The dimensions of the specimen for measuring G_{LR} were 180mm (L) ×20mm (R) ×20mm (T). Resonance frequencies of several modes were measured by the free-free flexural vibration test,[6] and G_{LR} was calculated using Goens-Hearmon regression method[7,8] based on Timoshenko's theory of bending.[9] Here, elastic moduli obtained by dynamic tests are larger than those obtained by static tests, generally. However, we think that the differences between dynamic elastic moduli and static ones are too small to affect the results of the stress analysis.

Stress analysis

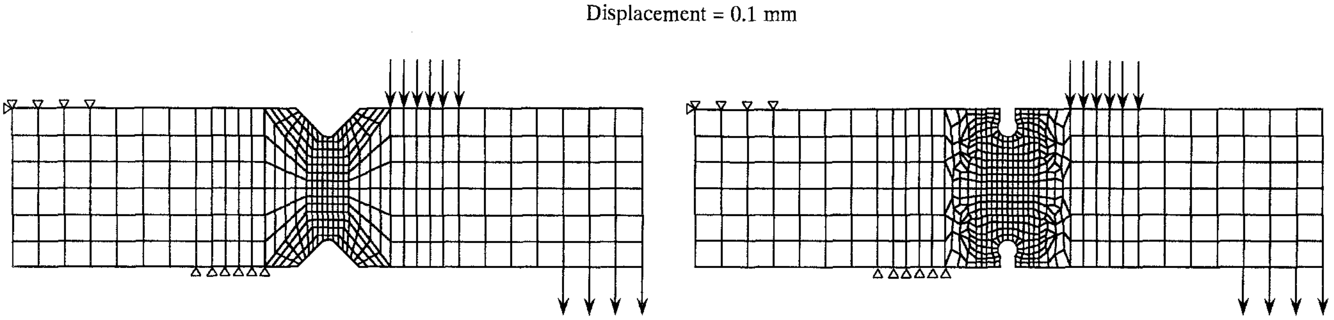
The stress distribution near the center part of the specimen was calculated with an existing FEM program. The program used was a universal FEM program ("ISAS-II"), which is a library program of the Computer Center of The University of Tokyo.

The finite meshes of the standard-type specimen and those of the keyhole-type specimen are shown in Fig. 2. The simulated examples were sitka spruce and shioji. Material parameters used here obtained by the compression test and the vibration test mentioned above are shown in Table 1. In this calculation, the longitudinal and radial directions coincided with the x- and y-axes, respectively. The displacement applied to the loading point was 0.1 mm.

Table 1. Parameters used for finite element method

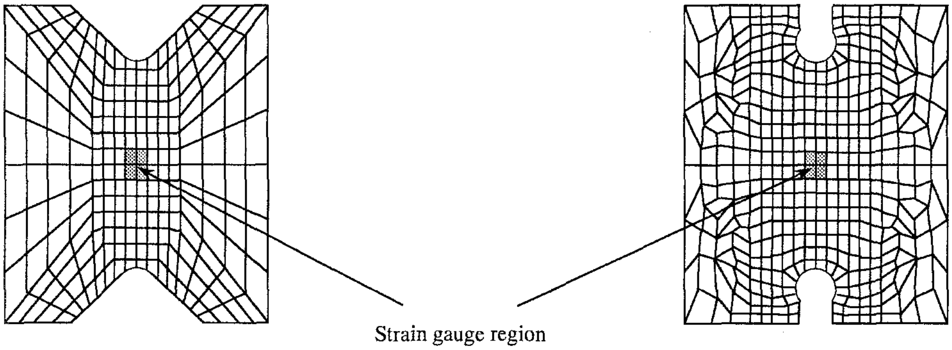
Species	ρ [g/cm^3]	E_L [GPa]	E_R [GPa]	G_{LR} [GPa]	ν_{LR}
Spruce	0.43	8.0	0.44	0.92	0.48
Ash	0.56	10.1	0.71	0.99	0.55

ρ, density; E_L, Young's modulus in longitudinal (L) direction; E_R, Young's modulus in radial (R) direction; G_{LR}, Shear modulus of LR plane; ν_{LR}, Poisson's ratio of LR plane when compression force is applied to L direction



(a) Entire meshes and boundary conditions for the standard Iosipescu shear test.

(c) Entire meshes and boundary conditions for the simplified Iosipescu shear test.



(b) Central test region of the standard Iosipescu shear test.

(d) Central test region of the simplified Iosipescu shear test.

Fig. 2. Finite element mesh used for the calculations

Results and discussion

Figure 3 shows the typical patterns of the shear stress – shear strain curve obtained with the simplified Iosipescu shear test. The patterns were similar to those of the LR-specimen of the standard Iosipescu shear test, whose long axis coincided with the longitudinal direction. The failure did not occur suddenly but rather gradually.[1]

Table 2 shows the shear modulus obtained by the Iosipescu shear test. There was not a significant difference of the average of G_{LR} between the standard Iosipescu shear test and the simplified Iosipescu shear test by *t*-test. Consequently, we believe that G_{LR} from the standard Iosipescu shear test coincides with that from the simplified Iosipescu shear test.

Table 3 shows the yield shear stress obtained by the simplified Iosipescu shear test. From the *t*-test the average of the yield shear stresses were similar for both specimens.

Figure 4 shows the typical patterns of the principal strain angle, φ, during the loading process in the simplified Iosipescu shear test. The value of φ was calculated from the following equation:

$$\varphi = \frac{1}{2}\tan^{-1}\left(\frac{\gamma_{xy}}{\varepsilon_y - \varepsilon_x}\right) \tag{3}$$

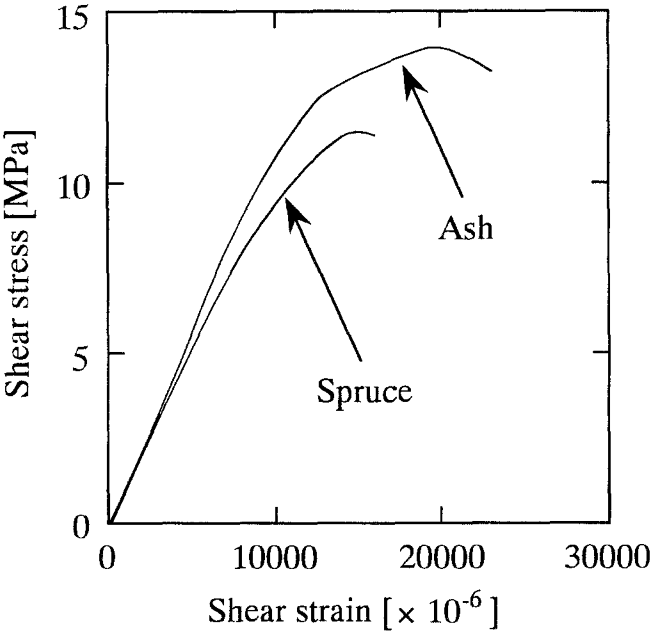


Fig. 3. Typical patterns of the shear stress – shear strain curve during the loading process of the simplified Iosipescu shear test

where ε_x, ε_y, and γ_{xy} are normal strains in the *x*-direction and *y*-direction, respectively. The principal angle of the keyhole-type specimen was about 45°, as is the case for the standard-type specimen.[1] Hence, it is thought that the pure

Table 2. Shear moduli obtained by the standard and simplified Iosipescu shear tests

Species	Shear modulus of LR plane (GPa)		t
	Standard	Simplified	
Spruce	1.04 ± 0.38	1.01 ± 0.11	0.170 (NS)
Ash	1.05 ± 0.13	1.07 ± 0.088	0.301 (NS)

NS, not significant

The t values were obtained by t-tests between the standard test and the simplified test

Results are averages ± SD

Table 3. Yield shear stresses obtained by standard and simplified Iosipescu shear tests

Species	Yield shear stress of LR plane (GPa)		t
	Standard	Simplified	
Spruce	6.2 ± 1.4	7.6 ± 0.81	2.015 (NS)
Ash	7.8 ± 2.1	8.6 ± 1.6	0.726 (NS)

The t values were obtained by t-tests between the standard test and the simplified test

Results are averages ± SD

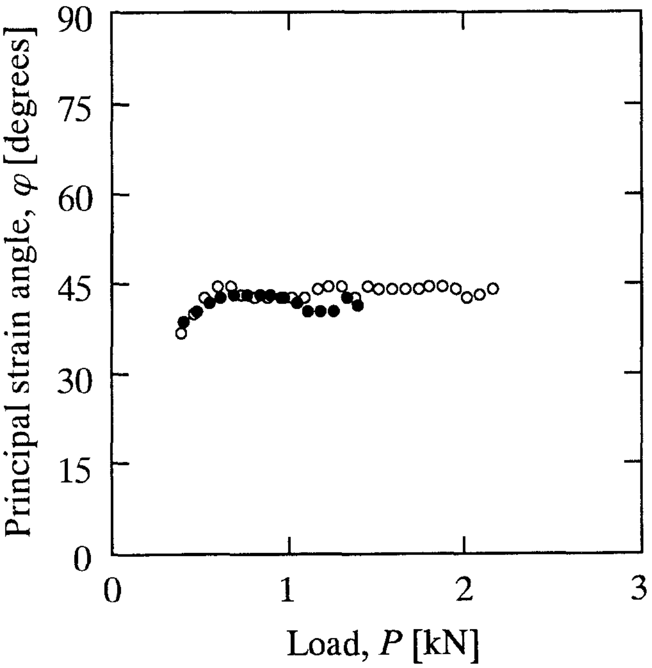


Fig. 4. Typical patterns of the principal strain angle during the loading process of the simplified Iosipescu shear test. *Filled circles*, spruce; *open circles*, ash

Table 4. Failure stresses obtained by the standard and simplified Iosipescu shear tests

Species	Failure stress of LR plane (GPa)		t
	Standard	Simplified	
Spruce	10.3 ± 1.6	11.6 ± 0.66	1.706 (NS)
Ash	13.7 ± 1.2	14.0 ± 0.76	0.496 (NS)

The t values were obtained by t-tests between the standard test and the simplified test

Results are averages ± SD

Table 5. Shear moduli from the finite element method

Spcies	$G_{\mathrm{LR}}^{\mathrm{TGH}}$	$G_{\mathrm{LR}}^{\mathrm{FEM}}$ (GPa)	
		Standard	Simplified
Spruce	0.92	0.76	0.93
Ash	0.99	0.83	1.02

$G_{\mathrm{LR}}^{\mathrm{TGH}}$, shear modulus obtained by Goens-Hearmon regression method (G_{LR} in Table 1)

$G_{\mathrm{LR}}^{\mathrm{FEM}}$ is calculated by $(P/S)/(\tau_{\mathrm{LR}}/G_{\mathrm{LR}}^{\mathrm{TGH}})$, where P is the summation of forces of single-point constraint, S is the product of thickness and distance between the notches, and τ_{LR} is the average of shear stresses in the strain gauge region

Table 6. Principal strain angles in the strain-gauge region

Species	Strain angle (degrees)	
	Standard	Simplified
Spruce	46.7 ± 1.6	42.5 ± 0.4
Ash	45.9 ± 1.1	42.1 ± 0.4

Results are averages ± SD

shear stress conditions occur in the region where the strain gauge was bonded.

Tables 4 and 5 show the results of the stress analysis. The shear modulus from FEM, $G_{\mathrm{LR}}^{\mathrm{FEM}}$, is calculated as follows: The shear stress is obtained by P/S, where P is summation of forces of single-point constraint, and S is the products of the thickness and distance between the notches. The shear strain is determined by $\tau_{\mathrm{LR}}/G_{\mathrm{LR}}^{\mathrm{TGH}}$, where τ_{LR} is the average of shear stresses in strain-gauge region, and $G_{\mathrm{LR}}^{\mathrm{TGH}}$ is the shear modulus determined by the Goens-Hearmon regression method. Then $G_{\mathrm{LR}}^{\mathrm{FEM}}$ is $(P/S)/(\tau_{\mathrm{LR}}/G_{\mathrm{LR}}^{\mathrm{TGH}})$.

The shear moduli obtained by FEM were similar to those obtained with the vibration test. The value of the principal stress angle in the strain-gauge region was about 45° for both specimens. These results also indicate that the pure shear stress condition occurred at the center part of the specimen.

Table 6 shows the failure shear stress measured by the shear tests. The results of the t-test indicated that the values for failure shear stress coincided with each other.

From these results it is recognized experimentally and theoretically that pure stress is applied to the strain-gauge regions during the simplified Iosipescu shear test, and it is expected that the results of the Iosipescu shear tests are independent of the notch angle in the range 0°–90°. Therefore, we believe that the simplified Iosipescu shear test is useful for measuring the shear modulus and yield shear stress of wood. The shear strength obtained by the simplified Iosipescu shear test is discussed later.

It was observed that the failure started at the notch roots, and the catastrophic failure occurred between the notches by continuous loading after failure initiation in the simplified Iosipescu shear test, as is the case with the standard Iosipescu shear test.[1] There was a serious deformation in the tested specimen. Although pure stress is applied to the strain-gauge regions, it is possible that the pure shear stress conditions over the entire region between the notches are not achieved because of the serious deformation. A more detailed investigation of the configuration of the specimen and the supporting condition is needed in order to cause the catastrophic failure between the notches without a serious deformation in the specimen.

Conclusions

We examined the accuracy of the shear properties of wood obtained by the simplified Iosipescu shear test. This test method is distinguished when using the keyhole type specimen. The results were as follows:

1. The failure pattern obtained with the simplified Iosipescu shear test was similar to that seen with the standard Iosipescu shear test.
2. The values of the shear modulus, yield stress, and failure stress obtained with the simplified Iosipescu shear test coincided with those by the standard Iosipescu shear test.
3. The principal strain angle and the principal stress angle of the simplified Iosipescu shear test were about 45°.
4. From the results of items 1–3, it is recognized that pure stress is applied to the strain-gauge regions during the simplified Iosipescu shear test, and it is expected that the shear properties are independent of the notch angle. Therefore, we believe that the simplified Iosipescu shear test is useful for measuring the shear modulus and yield stress of wood. As for the shear strength, a more detailed investigation of the configuration of the specimen and the supporting condition to cause the catastrophic failure between the notches without serious deformation of the specimen is needed.

References

1. Yoshihara H, Ohsaki H, Kubojima Y, Ohta M (1999) Applicability of the Iosipescu shear test on the measurement of the shear properties of wood. J Wood Sci 45:24–29
2. Iosipescu N (1967) New accurate procedure for single shear testing of metals. J Mater 2:537–566
3. Janowiak JJ, Pellerin RF (1991) Iosipescu shear test apparatus applied to wood composites. Wood Fiber Sci 23:410–418
4. Adams DF, Walrath DE (1987) Current status of the Iosipescu shear test method. J Composite Mater 21:494–507
5. Yoshihara H, Ohta M (1997) Stress-strain relationship of wood in the plastic region. III. Determination of the yield stress by formulating the stress-plastic strain relationship. Mokuzai Gakkaishi 43:464–469
6. Kubojima Y, Yoshihara H, Ohta M, Okano T (1996) Examination of the method of measuring the shear modulus of wood based on the Timoshenko's theory of bending. Mokuzai Gakkaishi 42:1170–1176
7. Goens E (1931) Über die Bestimmung des Elastizitätsmodulus von Stäben mit Hilfe von Biegungsschwingungen. Ann Phys 5F11:649–678
8. Hearmon RFS (1958) The influence of shear and rotatory inertia on the free flexural vibration of wooden beams. Br J Appl Phys 9:381–388
9. Timoshenko SP (1921) On the correction for shear of the differential equation for transverse vibrations of prismatic bars. Phil Mag 6th Ser 41:744–746