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Effect of Specimen Shape on Panel Shear Testing

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Panel shear testing based on American Standards for Testing and Materials (ASTM) was analyzed by computer simulation with finite element method (FEM) to clarified the effect of specimen shape on panel shear testing. The analytical object was a 5-ply lauan (*Shorea* spp.) plywood. The stress distribution of six different shapes of plywood specimens were analyzed. The proportion of length / thickness (ℓ/t) were 6.7, 8, 10, 13, 20, 33.3. Four of them are set in accordance with ASTM D 2719-76, where a length thickness ratio of 20:1 is prescribed as a maximum. However, only the thickness of the specimen was variable.

A finite element method using a four-node bilinear thick shell element capable of modeling the behavior of layered composite panel was used in this study.

The calculated results indicate that the shape of the specimens had significant effect on their panel shear properties. Because of the undesired out-plane deformation occurred in the specimen during panel shear testing. The greater the length thickness ratio, the larger the out-plane displacements of the specimens. The necessary in plane compression strain for calculating the shear rigidity could not be measured accurately since the buckling of the specimen which length thickness ratio is greater than the limitation of 20 defined by ASTM panel shear testing standard.

Key words : panel shear testing, plywood, finite element method, ASTM

1. Introduction

Shear strength and rigidity are usually determined according to American Standards for Testing and Materials (ASTM) or Swedish Larsson-Wästlund (LW) panel shear testing method. However, the values obtained from these two methods are quite different, due to the differences in equipment proper and the restrained conditions[1], amongst others.

In order to clarify the difference between these two testing methods, stress analysis was conducted for each testing condition by computer simulation using finite element method. This initial study focuses on the American standard for panel shear testing method (ASTM).

Fig. 1 shows the apparatus and the method for applying load for panel shear test of ASTM[2]. A plywood specimen having a square shear area bounded on each side by solid wood blocks glued to both sides of the specimen is loaded in compression along one diagonal in a conventional testing machine. The load is applied by special steel loading blocks which articulate with the rollers and pins attached to the test specimen. The angle between faces of the loading block is 90° and between each face and the base the angle is 45°. A spherical bearing block, preferably of the suspended, self -aligning type, is employed in the loading system. The load is applied continuously through-out the test with a uniform motion of the movable head of the testing machine. Each of the eight reinforcing blocks is loaded through roller brackets clamped to the reinforcing block across its width or attached by other means and applying a compressive force to the end of the reinforcing block through a surface contact area. These bearing surfaces are firmly seated against the ends of their respective reinforcing blocks during assembly. Rollers are centered at the inner edge of the reinforcing block and apart from the loaded end of the reinforcing block. Moderate clamping pressure holding brackets to the reinforcing blocks applied perpendicular to the plane of the plywood is permitted but shall not be excessive. Therefore, forces are applied to the glued-on

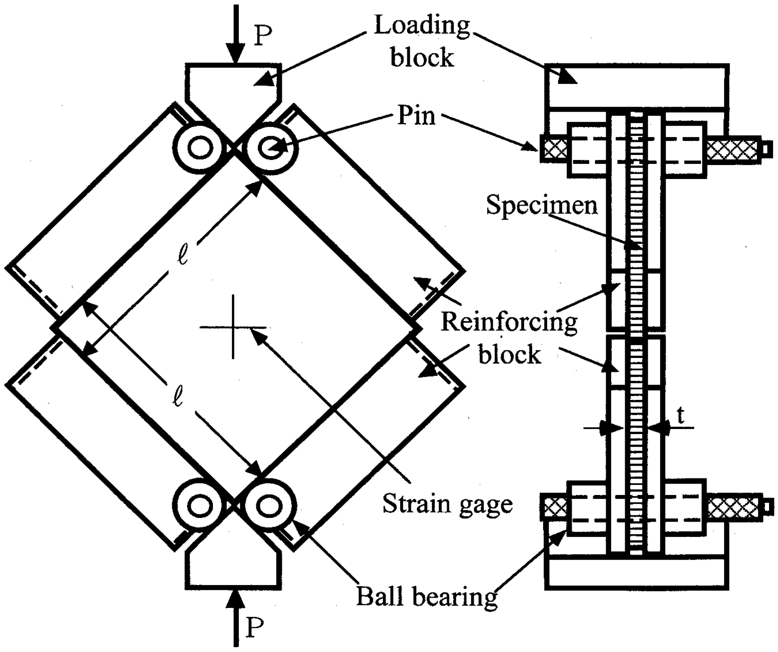

Fig. 1 Apparatus and method of panel shear testing (ASTM).
Notes: P: Load; ℓ and t: Length and thickness of specimen.

blocks through a roller bracket assembly which causes the resultant forces to act collinearly with the edge of the shear test area.

Fig. 2 shows the axes of coordinates for the plywood specimen. The relationship between the elastic principal axes of veneer and the axes of coordinates could be expressed as follows:

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix} = \begin{bmatrix} \sin^2\theta & \cos^2\theta & -\sin 2\theta \\ \cos^2\theta & \sin^2\theta & \sin 2\theta \\ -\frac{1}{2}\sin 2\theta & \frac{1}{2}\sin 2\theta & \cos 2\theta \end{bmatrix} \begin{Bmatrix} \sigma_L \\ \sigma_T \\ \tau_{LT} \end{Bmatrix} \tag{1}$$

where the subscript letters of x and y show the directions of x and y in the coordinate system, L and T denote the longitudinal and tangential directions of veneer, respectively. Since the degree between L direction and x axis is 45°, in the case of panel shear testing, Formula (1) could be rewritten as:

$$\left.\begin{aligned} \sigma_x &= \frac{\sigma_L + \sigma_T}{2} - \tau_{LT} \\ \sigma_y &= \frac{\sigma_L + \sigma_T}{2} + \tau_{LT} \\ \tau_{xy} &= \frac{-\sigma_L + \sigma_T}{2} \end{aligned}\right\} \tag{2}$$

However, there is no any normal stress occurred along the elastic principal axes of veneer during testing, i.e., $\sigma_L = \sigma_T = 0$, subsequently,

$$\tau_{TL} = \sigma_x = -\sigma_y \tag{3}$$

Therefore, this loading method most nearly produces uniform pure shear. Shear strength is determined from maximum load, and modulus of rigidity could be calculated from measurements of compression strain along the compression diagonal of the specimen. When deformation data are desired for calculation of elastic properties, strain-measuring devices having minimum gage length of 2.5 cm shall be attached to both sides of the specimen and shall measure compression strain of the vertical diagonal, the gages being centered at its midpoint on each side.

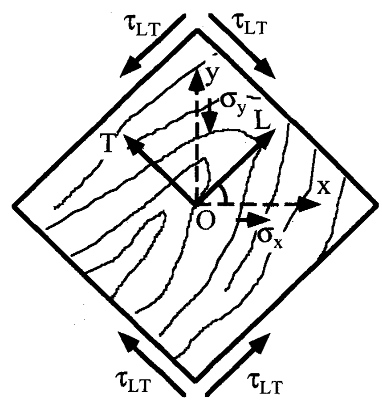

Fig. 2 Diagram used to calculate stress and strain in panel shear of plywood with face grain paralled to edge.
Notes: σ: Normal stress; τ: Shear stress; L and T: Longitudinal and tangential direction of wood.

2. Analytical method

Fig. 3 illustrates the analytical model in a two dimensional system based on the testing condition shown in Fig. 1. Since the configuration is symmetrical, only a quarter of the testing apparatus was analyzed. The specimen is a 5-ply lauan (*Shorea* spp.) plywood, its shear area is 100 mm long and 100 mm wide. The proportion of length / thickness (ℓ/t) were set as 6.7, 8, 10, 13, 20, 33.3. Four of them are in accordance with ASTM D 2719-76, where a length thickness ratio of 20 : 1 is prescribed as a maximum. However, only the thickness of the specimen was variable so as to clarify the effect of the dimension of the specimen. Six kinds of the thicknesses (t) were 3, 5, 7.5, 10, 12.5 and 15 mm, respectively. The solid wood used for the reinforcing block is Japanese birch (*Betula maximowicziana* Regel).

Assuming the plywood to be perfectly elastic and homogeneous, the veneers can be considered as the orthotropic materials. However, the mechanical properties of veneer in the state of plywood are quite different from those of the solid wood and free veneer, because of the formation of knife

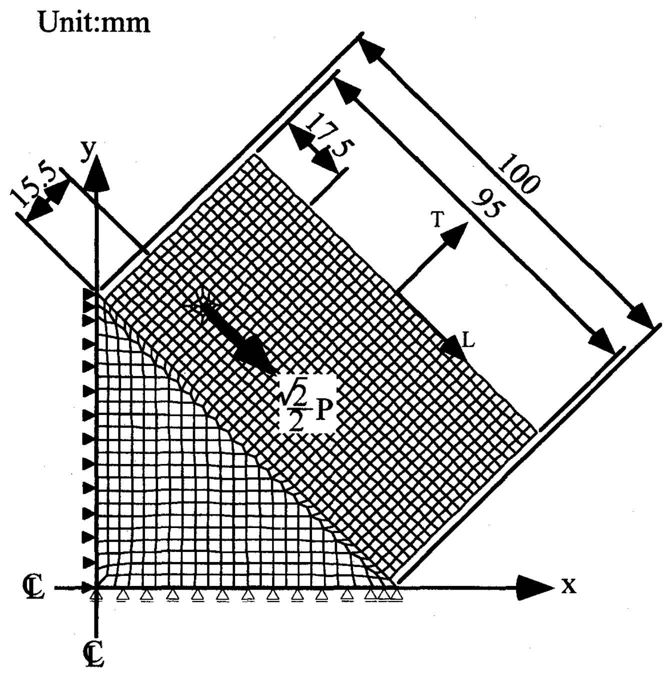

Fig. 3 Analytical model for finite element method.
Notes: L and T: Direction of longitudinal and tangential direction of wood, ℄: Center line.

checks during veneer peeling, addition of resin adhesive, hot-pressing and other manufacturing processes. The elastic constants of veneer and reinforcing block used in the computation, as based on the literature[3~4], are tabulated in Table 1. However, the elastic constants of each material used in the computation should be transformed from the principal elastic axes of orthotropy (L and T or V) to the rectangular coordinate system (x and y), since the wood fiber is parallel to the edge of the specimen, which is inclined at 45° to the x-axis.

Table 1. Properties of the materials used in the calculation.

Materials	Young's modulus (10^3kgf/cm²)	Shear modulus (10^3kgf/cm²)	Poisson's ratio
Lauan veneer (plywood) *Shorea* spp.	E_L 170 E_T 12.4	G_{LT} 11.7	μ_{LT} 0.61
Solid buna (reinforcing block) *Fagus crenata* Blume	E_L 170 E_V 9.75	G_{LV} 8.25	μ_{LV} 0.45

Notes: Subscript letters L, R and T denote the longitudinal, radial and tangential directions of wood, respectively. Two-lettered subscripts LT, LR and LV indicate the planes of LT, LR and LV, respectively. For the solid wood buna, its properties in the transverse direction V were set as the average values in radial and tangential direction: $E_V=(E_R+E_T)/2$, $G_{LT}=(G_{LT}+G_{LR})/2$, $\mu_{LV}=(\mu_{LT}+\mu_{LR})/2$, respectively.

It was also assumed here that the thickness of gluelines were very thin, and the adhesion between the veneers and the reinforcing blocks were rigidly. It means that either slip or movement was neglected at the interfaces.

The analytical model is divided into 1210 elements with a total of 1276 nodes. The element used is a 4-node bilinear thick shell element capable of modeling the behavior of layered composite panel. There are three translational and rotational degrees-of-freedom at each node of the element. The element of specimen is composed of five layers of lauan rotary cut veneers with cross orientation to the adjacent layers. The element of reinforcing block consists of 5-lay plywood glued with solid wood blocks to both sides.

In order to fully restrain the rigid body modes without introducing any elastic constraints, a special set of boundary condition is applied. Three translational and two rotational out-of plane degrees-of-freedom are suppressed at the origin node which is the midpoint of the specimen. The translational degrees-of-freedom in x-axis is suppressed along the entire left edge, and the translational degrees-of-freedom in y-axis is suppressed along the entire bottom edge. The specification of additional rotational constraints at the left edge is irrelevant.

According to ASTM for panel shear testing, the specimen is loaded by special steel loading blocks in compression along one diagonal of the specimen in a conventional testing machine. Subsequently, forces applied to the glued-on blocks through a roller bracket assembly cause the resultant forces to act collinearly with the edge of the shear test area. For simplicity in the analysis, the point load was acted on the pin center along the edge of the specimen so as to create a state of shear for a certain part within the plywood.

Based upon that the compression load along the vertical diagonal of the specimen (P) was set as 15 kgf, the point load applied to the pin center along the edge of the specimen was 10.605 kgf. The computer simulation was executed for 15 times repetitively, with the increment of the point load 0.707 kgf in each step.

MARC Programs developed by MARC Analysis Research Corporation USA were used and all the computations were performed by using Fujitsu computer (VPX-210/10S) at the Information Processing Center of Kumamoto University.

3. Results and Discussion

Fig. 4 shows the deformations of each specimens analyzed. For better visualization of the specimen deformation, their values were magnificated by 50. The displacements in y-direction (dy) of all the specimens were smaller than 0.01 mm, except for the specimen which length thickness (ℓ/t) exceeds the ASTM standard limitation of 20. Furthermore, the out-plane deformations in z-direction (dz) were also investigated and shown in Fig. 5. The tendency was found that all the specimens rotate around the z-axis during panel testing. The greater the length thickness ratio, the larger the out-plane displacements of the specimens. This means that the thinner specimens would be much easier to buckle during panel shear testing.

ℓ/t	6.7	8	10	13	20	33
dy (10^{-3}mm)	3.2	3.7	4.5	5.9	9.1	262

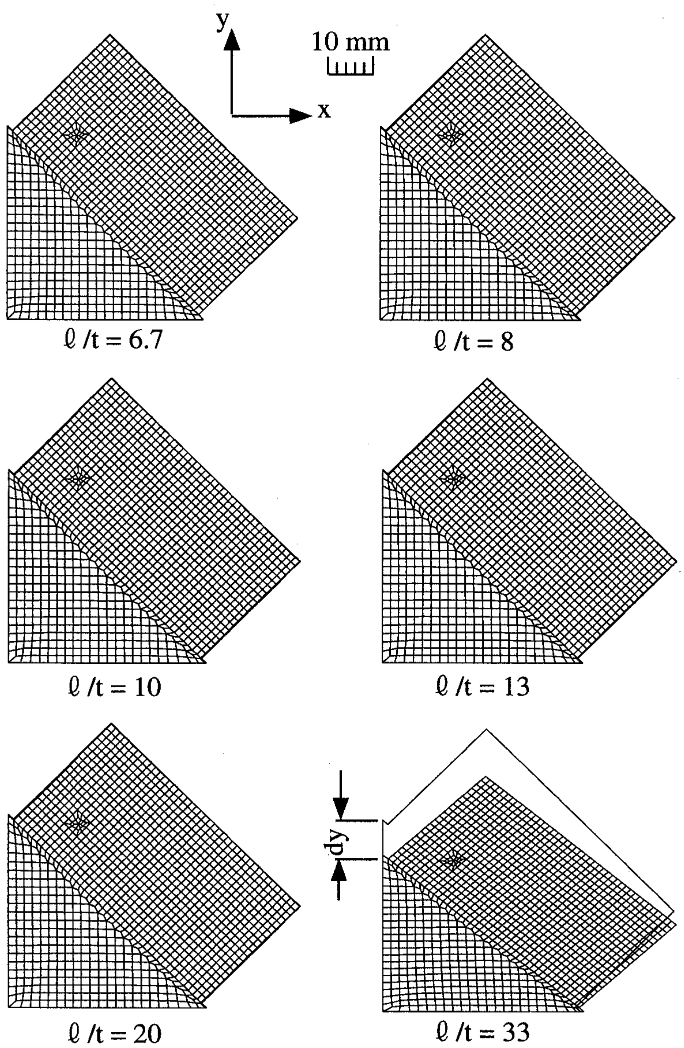

Fig. 4 Deformations of the speciments with different length thickness rarios (ℓ/t).
Note: Values of the displacement are expressed in magnification, ×50.

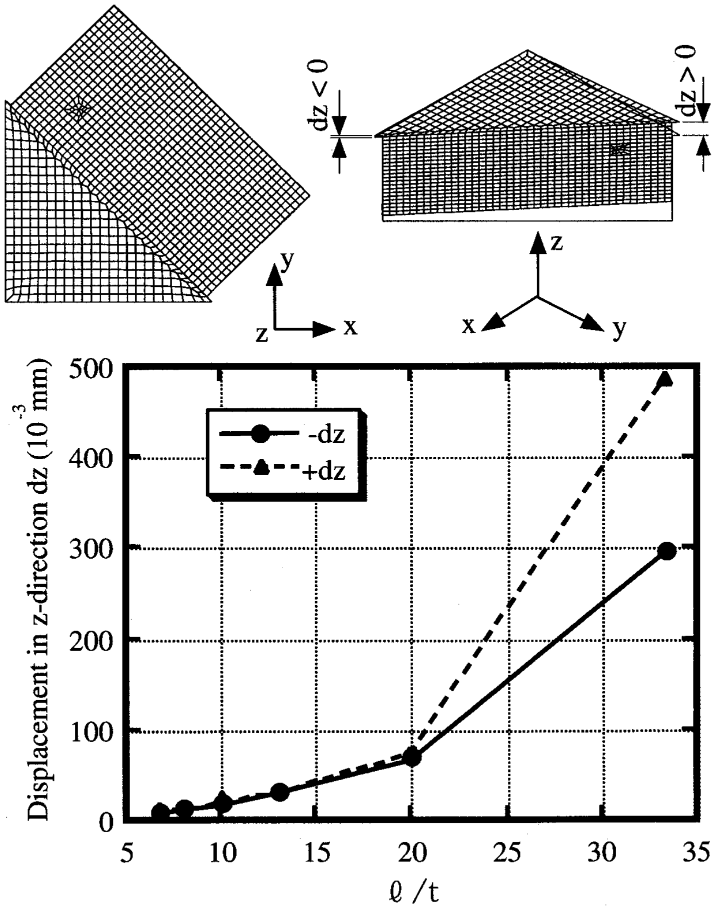

Fig. 5 Maximum displacements in z-direction.
Notes: ℓ/t: Length thickness ratio of specimen.

Fig. 6 shows the distribution of the maximum and the minimum principal stress σ_1 and σ_2 in the specimen with the length thickness ratio (ℓ/t) of 20. The arrows are convergent or divergent of the point correspondent to the gravity center of the element, respectively. For the specimens utilized in this study the stress distribution were almost uniform except the portions at two diagonal. The maximum principal stress in tension (σ_1) concentrated around the reentrant corners of the specimens significantly. The same tendency was found in the distribution of shear stress and for all the shapes of the specimens. The effects of the specimen shape on the concentrated magnitude of maximum principal stresses σ_1 and τ are shown in Fig. 7. It is evident that the concentrated stresses increased with increasing the length thickness ratio (ℓ/t). Especially, the increasing gradient was much greater when ℓ/t goes greater than 20.

According to panel shear testing standard of ASTM, shear modulus of rigidity should be calculated from measurements of compression strain along the compression diagonal of the specimen. When deformation data are desired for calculation of elastic properties, the gage length of 2.5 cm shall be attached to both sides of the specimen and shall measure compression strain of the vertical diagonal. A larger gage length is preferred, but shall not exceed the region from 2.5 cm to one half the length of the diagonal of the specimen. Fig. 8 shows the comparison of the compression strains amongst six specimens within the region mentioned above. It was found that the compression strains changed slightly for the standard specimen which ℓ/t was lower than 20. However, comparing with those the value was one order greater and with more significant variation for the

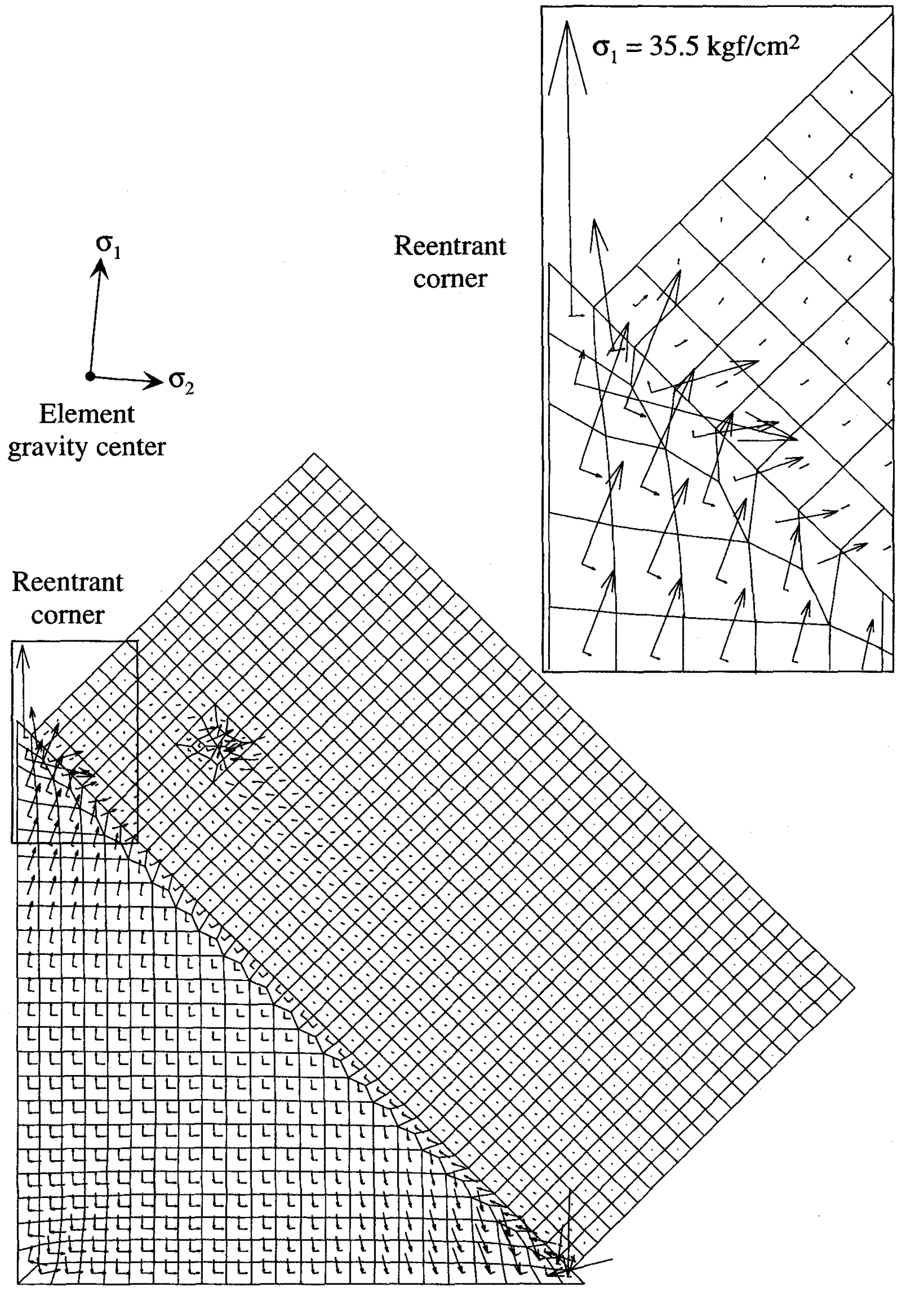

Fig. 6 Distribution of principal stresses σ_1 and σ_2 in specimen with length thickness ratio of 20.

specimen which shape was not in according with ASTM panel shear testing standard. Therefore, it could be concluded that the difficulty would be faced to calculate the correct shear modulus from the compression strain of the thinner specimen which length thickness ratio is greater than 20.

4. Conclusions

The results of this study could be summarized as follows:

1. The greater the length thickness ratio, the larger the displacement occurred in the specimen. Not only the in-plane but also the out-plane deformations occurred in the specimen which length thickness ratio (ℓ/t) of 33.3 was extreme greater compared with other specimens. The buckling failure should be notable during panel shear testing of the thinner specimen.

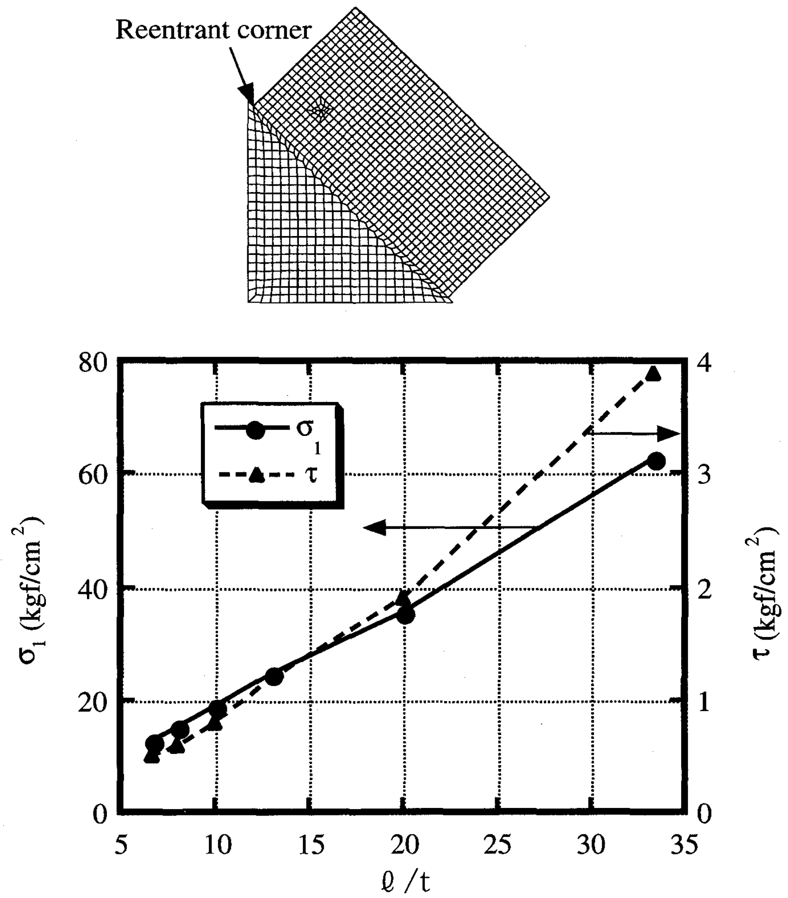

Fig. 7 Maximum principal stress σ_1 and τ at the reentrant corner of the specimens.

Notes: ℓ/t: Length thickness ratio of specimen.

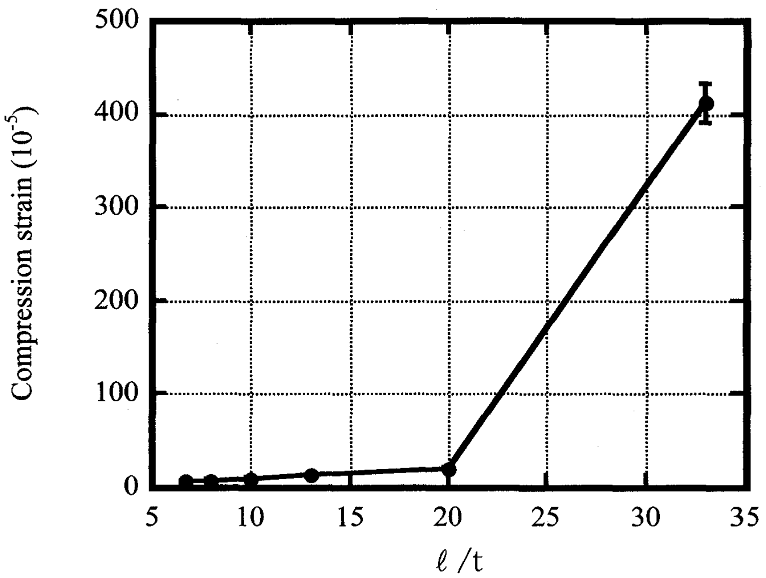

Fig. 8 Average compression strains versus length thickness ratio of specimen.

2. Exception of the portions at two diagonal, the stress distribution in the shear area of the specimen was quite even, and fairly lower stresses were observed in the reinforcing block. However, the maximum principal stresses concentrated around the reentrant corners of the specimens significantly. The greater the length thickness ratio (ℓ/t), the severer the concentrated magnitude of maximum principal stresses occurred in the specimen. Especially while ℓ/t goes greater than 20, the increasing gradient was observed in the concentration versus ℓ/t relationship.

3. If the specimen shape does not satisfy with the ASTM standard of panel shear testing, which length thickness ratio should be within 20, the shear modulus of rigidity would be difficult to obtained correctly from the compression strain of the specimen, since the bigger error occurred in measuring the compression strain along the compression diagonal of the specimen.

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