(Research note)

Bending-shear Test for Laminated Veneer Lumber

By

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Summary : Although block shear test is commonly used as a method for evaluating the shear strength of solid wood or adhesive of glued laminated timber(Glulam), it could not be directly adopted for laminated veneer lumber(LVL), mainly due to technical difficulties in testing. The possibility of using short span bending test as a shear test was examined taking into account the effects of diameter of loading head, loading direction, length of overhang and the depth to span ratio of the specimen.

In order to obtain consistent result in shear strength, a depth to span ratio of three or four was found to be appropriate, and the diameter of loading head should be between 50 and 100mm. In the case where loading direction was parallel to the gluelines (edgewise loading), horizontal shear failure did not always take place but was dependent upon species used in LVL manufacturing. On the other hand, when loading direction was perpendicular to the gluelines (flatwise loading), almost all specimens failed in horizontal shear. In most cases, shear strength of the former was greater than that of the latter.

Whereas the length of the overhang had little effect on the shearing strength, the existence of butt joint and aging treatment reduced its strength significantly.

Introduction

Laminated Veneer Lumber (LVL) is a wood composite derived from rotary peeled veneers which are aligned and glued in the same direction. Because of the dispersion of defects in veneer, more uniform mechanical properties are expected than those of solid sawn wood. Rotary peeling also gives rise to higher timber yield over sawn timber processing. Nevertheless, lathe checks induced by rotary peeling, drying and processing sometimes reduce shear strength along the grain of the product even if a part of them may be filled up by adhesive. Thus, establishing the shear strength of LVL is essential, as far as structural application is concerned.

In the case of solid wood[1)] or glued laminated timber[2)], block shear test has long been adopted as an evaluation method for the shear strength of the wood itself and adhesive, respectively. This method is however inappropriate for LVL mainly because of their gluelines which are close to each other and not always as straight as in the case of glulam. Consequently, preparation of block shear specimens becomes difficult and time consuming. Additionally as the knots are dispersively distributed within LVL, further difficulty is faced when removing knotty portions, whenever test specimens are prepared. Thus an alternative method is necessary to evaluate the shear strength of

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structural LVL.

In this paper, the feasibility of bending-shear test as a method of evaluating shear strength of structural LVL was discussed. Several factors which might affect shear strength such as the diameter of the loading head, span to depth ratio (l/h) of the specimen, direction of loading with respect to glueline, length of overhang, soaking and boiling treatments were also considered.

Strictly speaking, bending-shear test as well as block shear test would not provide the actual shear strength of the material as a result of the embedment of loading head which takes place during the test. Nevertheless, the value obtained could serve as a bench mark for a production standard, where experimental data could be compared for quality control purposes. This study was carried out as part of the investigation prepared for "Japanese Agricultural Standard for Structural Laminated Veneer Lumber".

Material

Wood species used on this study were Douglas fir (*Pseudotsuga menziesii*), Western hemlock (*Tsuga heterophylla*), Akamatsu(*Pinus densiflora*), Hinoki (*Chamaecyparis obtusa*) and Sugi(*Cryptomeria japonica*), as shown in Table 1. Akamatsu, Hinoki and Sugi LVL were made with a continuous laminating machine equipped with a high frequency heating system at the Forestry and Forest Products Research Institute. Douglas fir and Western hemlock LVL were made by hot press in a commercial mill. The adhesive employed was thermosetting phenol-formaldehyde resin commonly used for structural products such as structural plywood.

Basic information and values of MOR that represent the mean of the maximum bending stress of 22 specimens[3] are given in Table 1. The cross-section of the bending specimens used was 40×40 mm with butt joints located at every third lamina.

In each series of test, specimens were cut from the same board as it seemed that the variability of strength data within board was less than that between boards.

Two kinds of specimens with different directions of loading with respect to gluelines, were prepared (Fig.1) ; parallel (edgewise loading) and perpendicular to each other (flatwise loading).

In the case of W. hemlock LVL, a certain degree of poor adhesion was observed at the glueline of the specimen. This was due to improper heating during hot pressing. Nevertheless, in order to examine whether bending-shear test is effective in detecting poor adhesion, these specimens were intentionally used for the test.

Procedure

The schematic diagram of the testing method is shown in Fig.2. A universal testing machine with a loading capacity of 5 tons was used. Loading heads with diameters ranging from 20 to 750 mm were also prepared. In order to prevent the embedment of a support into the specimen, a steel plate (width=2cm) was put between the specimen and support. Load was applied to the center of the specimen through the loading head until failure took place. The speed of loading was adjusted such that failure was only accomplished within 2 to 4 minutes. Although data for load and displacement relationship were obtained, only maximum load values were used in the analysis. Values of modulus of elasticity (MOE) obtained were not useful, as the embedment of loading head into the test specimen was confounded in the displacement values obtained.

The shear strength of the LVL was calculated based on:

Table 1. Description of LVL used for the test (Ref. (3))

Species	No. of Veneer	Size of board (cm)	Specific gravity	MOR (kgf/cm²)
Douglas fir	11	4×90×420	0.55	*F : 550 *E : 602
Western hemlock	13	4×60×360	0.47	F : 471 E : 496
Akamatsu	15	4×30×360	0.54	F : 497 E : 573
Hinoki	13	4×30×360	0.50	F : 656 E : 693
Sugi (Sapwood)	15	4×30×360	0.40	F : 406 E : 411
Sugi (Heartwood)	15	4×30×360	0.40	F : 274 E : 295

Legend : *F : Flatwise
*E : Edgewise

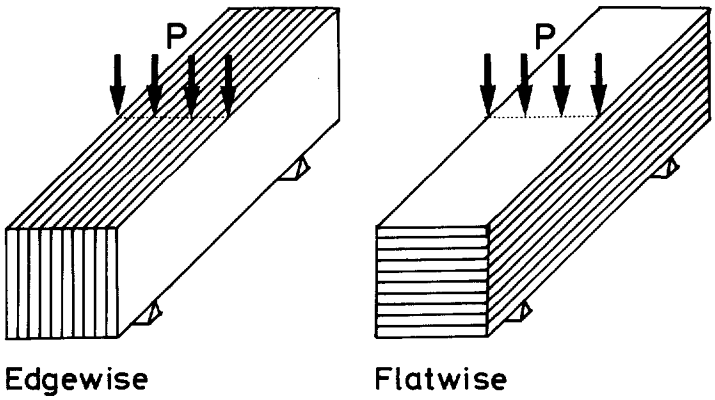

Fig. 1. Schematic diagram of loading direction. P : Load

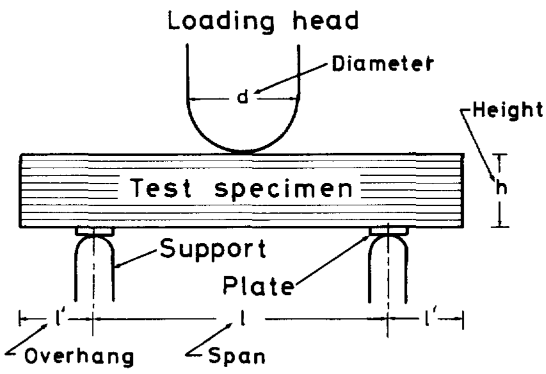

Fig. 2. Schematic diagram of bending-shear test.

$$\text{Shear strength} = 3 \times \text{Pmax} / (4 \times b \times h)$$

where Pmax = maximum load (kgf)

b = width of specimen (cm)

h = depth of specimen (cm)

Block shear test as stipulated in JAS for glue laminated timber[2] was also conducted for comparison purposes.

Results and discussion

1. Span to depth ratio (l/h).

Bending-shear tests were conducted on Douglas fir specimens with span values of 12 cm (l/h=3) and 16cm (l/h=4) in order to examine the effects of diameter of loading head and direction of loading. Loading heads of different diameters, ranging from 20 to 150 mm, were used. Overhang on both ends of specimens was 4 cm. A total of 12 specimens were used in each test condition.

The relationship between shear strength and diameter of loading head are as shown in Fig. 3. Each plot in the figure indicates the average of 12 specimens. Based on the results obtained, shear strength was found to increase with increasing diameter in both types of loading condition. This could be explained as follows ; smaller diameter heads which exerted higher stresses due to smaller contact area gave rise to deeper embedments which in turn reduced the effective cross-section of the specimen. As a result, smaller maximum load was attained.

As for the failure mode of the specimens, all F type specimens failed in horizontal shear while about 40 % of E type specimens failed in bending (Table 2). The shear strength of E type specimens was higher than that of F type in all loading conditions. The ratio of F type to E type specimen was around 80 %. This is due to the fact that the planes of glue line resisted against horizontal shear stress in the case of edgewise loading, but it was not so at flatwise loading.

The effects of l/h ratio on shear strength are also clear from Fig. 3. In the case of l/h=4, the curves were lower than that of l/h=3 in both loading directions, but the difference between the two extremes was not as large as that of l/h=3.

The result of these two series of tests shows that the diameter of loading head, loading directions and l/h ratio have a significant influence on the shear strength of LVL. In order to establish appropriate testing conditions, additional tests were carried out by including four other species, namely W. hemlock, Akamatsu, Hinoki and Sugi, under the same testing conditions.

Figure 4, 5, 6 and 7 show the results of W. hemlock, Akamatsu, Hinoki and Sugi respectively. Since only one specimen was used for each testing condition, each plot represents the shear strength of one specimen. Although smooth curve was not obtained, the same effects as shown in the former tests (Fig. 3) were observed ; the shear strength increased with increasing diameter of loading head and l/h ratio, and the value of E type was higher than that of F type.

In the case of Akamatsu and Hinoki, specimens under the condition of l/h=3 and D=150 show a higher value than the others. This is because the specimen did not fail in either horizontal shear or bending but was similar to the one under partial compression test. For W. hemlock, it is clear that low shear strength was attributed to poor adhesion, which was successfully detected by bending-shear test. The failure modes of the specimens were summarized as in Table 3.

It is noticed that the mode of failure varies from species to species. In the case of flatwise loading, specimens with l/h=5 had a tendency to fail in bending. Nevertheless, there are cases

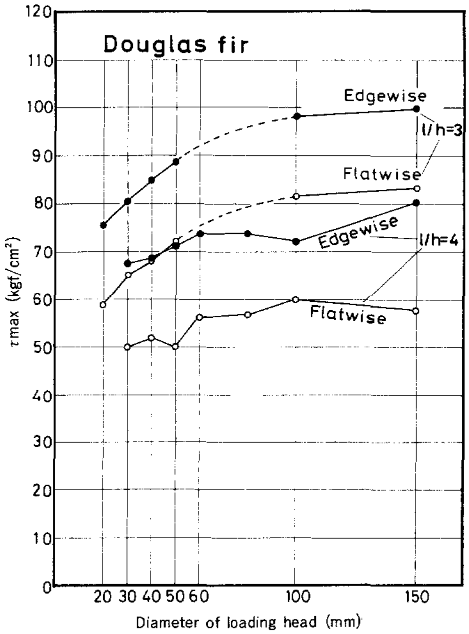

Fig. 3. Relationship between diameter of loading head and shear strength. Species : Douglas fir

Table 2. Shear Strength of Douglas fir LVL.

Diameter of loading head (mm)		τmax (kgf/cm²)	σ (kgf/cm²)	c.o.v (%)	Number of sheared specimen	τ_F/τ_E (%)
20	*F	58.7	4.15	7.06	11	78.0
	*E	75.5	3.57	4.73	5	
30	F	65.2	3.90	5.99	9	81.2
	E	80.3	5.23	6.72	7	
40	F	68.0	5.01	7.37	12	82.5
	E	84.6	4.77	5.64	6	
50	F	70.0	5.95	8.26	12	81.3
	E	88.6	5.76	6.50	7	
100	F	81.3	4.33	5.33	12	82.9
	E	98.1	5.55	5.66	8	
150	F	83.0	8.30	10.00	12	83.4
	E	99.4	7.26	7.30	7	

Note : Number of the specimens is twelve.

$l/h=3,\ \tau max=\frac{3Pmax}{4bh}$

Legend : *F : Flatwise
*E : Edgewise
τmax : Maximum shear strength
σ : Standard deviation
τ_F : τmax of flatwise specimen
τ_E : τmax of edgewise specimen

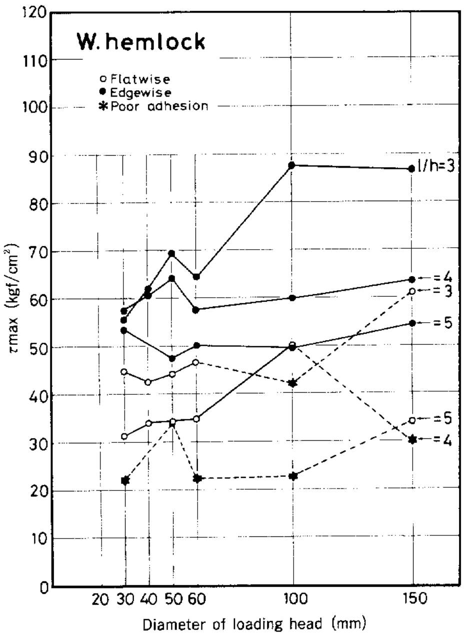

Fig. 4. Relationship between diameter of loading head and shear strength. Species : W. hemlock

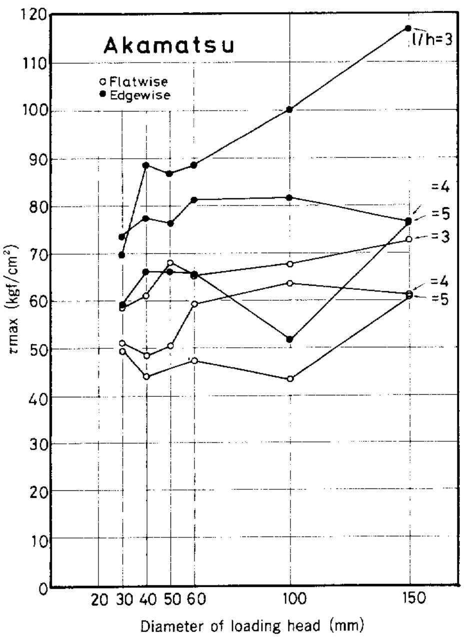

Fig. 5. Relationship between diameter of loading head and shear strength. Species : Akamatsu

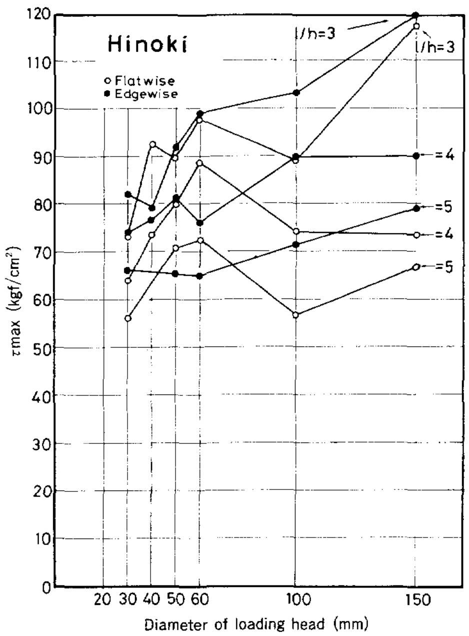

Fig. 6. Relationship between diameter of loading head and shear strength. Species : Hinoki

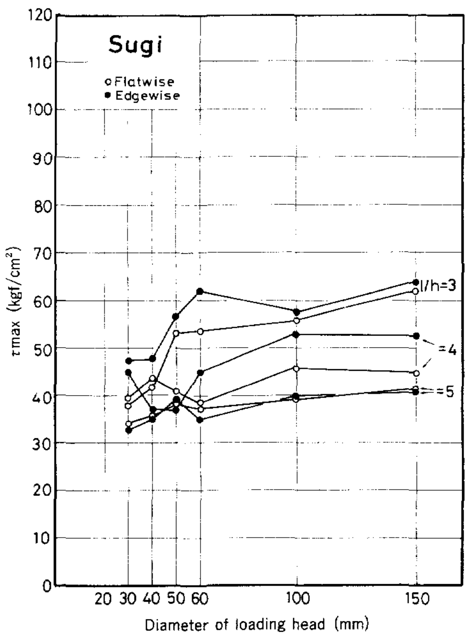

Fig. 7. Relationship between diameter of loading head and shear strength. Species : Sugi

Table 3.　Failure mode of specimens.

			Diameter of loading head (mm)					
Species		l/h	30	40	50	60	100	150
Western hemlock	F	5	△	○	○	△	△	○
		4	○	○	○	○	○	△
		3	○	○	○	○	△	○
	E	5	○	○	○	○	○	○
		4	○	○	●	○	○	●
		3	○	○	○	○	○	○
Akamatsu	F	5	○	○	○	○	●	●
		4	○	○	○	○	●	○
		3	○	○	○	○	○	○
	E	5	●	●	●	●	●	●
		4	●	●	●	●	●	●
		3	●	●	●	●	●	□
Hinoki	F	5	○	○	○	○	○	○
		4	○	○	○	○	○	○
		3	○	○	○	○	○	□
	E	5	○	○	○	○	○	○
		4	○	○	○	○	○	○
		3	○	○	○	○	○	□
Sugi (Sapwood)	F	5	○	●	●	○	○	○
		4	○	○	○	○	○	○
		3	○	○	○	○	○	○
Sugi (Heartwood)	E	5	●	●	●	●	●	●
		4	●	●	●	●	●	●
		3	●	●	●	●	●	●

Legend : ○ : Shear failure
● : Bending failure
□ : Partial compression failure
△ : Poor adhesion
F : Flatwise
E : Edgewise

where specimens with l/h=3 failed in compression even when D was 150 mm.

In the case where failure in bending takes place, the shear strength calculated by the formula is always lower than the actual shear strength. But as stated in introduction, the calculated shear strength value could be used as a minimum requirement value for a production standard.

Judging from the above mentioned test results, it is suggested the l/h ratio of either three [3] or four [4] , and diameter of loading head of between 50 and 100 mm should be employed in order to achieve consistency in shear strength results.

2. Effects of overhang

In order to examine the effect of overhang of the specimen on shear strength, specimens with three degrees of overhang (20, 30 and 40 mm) were tested. The results are shown in Table 4. In any combination of species, loading direction and l/h ratio, there was no significant difference among the values obtained. For instance, in the case of Akamatsu, edgewise loading and l/h=4, the average shear strength values of 5 specimens for the three overhangs were 71.3, 73.7 and 72.4 kgf/cm^2, respectively.

In general, shear strength tends to increase with increasing overhang of the specimen. Nevertheless, the results obtained indicated slight effects for length of overhang over depth of spcimen ratio of between 1/2 and 1/1.

3. Effects of butt joint

It is well known that location and amount of butt joints in LVL influence the bending properties[4]. In order to examine the effects of butt joint location and amount on shear strength,

Table 4. Effects of overhang on shear strength. (kgf/cm^2)

l/h=3 (l=120mm)		overhang 20mm	overhang 30mm	overhang 40mm
Douglas fir	F	66.3 (11.3)	68.7 (7.8)	70.5 (4.9)
	E	76.5 (6.7)	82.9 (5.4)	80.2 (8.0)
Akamatsu	F	61.8 (6.9)	69.9 (8.9)	68.1 (8.2)
	E	*88.2 (7.2)	*89.6 (8.2)	*84.2 (4.4)

l/h=4 (l=160mm)		overhang 20mm	overhang 30mm	overhang 40mm
Douglas fir	F	53.4 (9.8)	50.3 (13.2)	49.9 (12.8)
	E	62.2 (17.3)	67.7 (4.5)	*67.4 (5.5)
Akamatsu	F	52.0 (9.3)	58.5 (9.6)	55.0 (6.7)
	E	*71.3 (10.3)	*73.7 (12.8)	*72.4 (14.4)

Note : Number of the specimens is five.
The value in brackets represents the coefficient of variation(%).
Each value represents the average of five specimens.
Diameter of loading head is 60 mm.

Legend : * : Bending failure

bending-shear tests were carried out on specimens having butt joints at their center. Control specimens without butt joints were cut from the same LVL board and tested under the same testing conditions. The results were summarized in Table 5. The shear strength of the specimens with butt joints was found to be lower than that of without butt joints. The ratio of the former to the latter ranged from 84.9 to 95.3 % with an average value of 90.0 % for the case where shear failure was predominant. In the case where bending failure took place, ratios between 62.7 and 69.7 % and an average value of 65.9 % were obtained.

Although the presence of butt joints resulted in a reduction of shear strength to 90 % of the control, the effect was less pronounced than that of bending strength. However, it should be noted that specimens with butt joints should not be included whenever bending-shear tests specimens are prepared.

4. Effects of soaking and boiling treatments.

It is essential to evaluate the durability of wood based material for structural application against environmental changes. Exposure test under actual service condition is ideal but rather time consuming. Thus, soaking or boiling tests are always conducted as an alternative.

In the JAS standard for Glue Laminated Timber[2)], both soaking and boiling tests are regulated as means for assessing the durability of adhesives. In the soaking test, specimens are soaked in water at room temperature for 24 hours and then dried for 24 hours at 60°C. In the case of boiling test, specimens are put into boiling water for 5 hours, soaked in cold water at room temperature for

Table 5. Effects of butt-joint(BJ) on shear strength.

Species		l/h=4			l/h=5		
		BJ (kgf/cm^2)	Non-BJ (kgf/cm^2)	BJ/Non-BJ (%)	BJ (kgf/cm^2)	Non-BJ (kgf/cm^2)	BJ/Non-BJ (%)
Douglas fir	F	55.9 (12.9)	61.7 (5.3)	90.6	45.6 (15.9)	53.7 (8.0)	84.9
	E	73.2 (9.5)	76.8 (4.2)	95.3	*43.7 (10.0)	*62.7 (5.1)	69.7
Akamatsu	F	5.10 (10.7)	57.6 (3.4)	88.5	45.6 (8.4)	46.9 (13.0)	97.2
	E	*50.6 (17.0)	*80.7 (6.4)	62.7	*42.9 (10.4)	*65.9 (3.4)	65.1
Sugi (Sapwood)	F	37.4 (12.4)	42.9 (7.1)	87.2	32.9 (6.2)	38.1 (4.4)	86.4
(Heartwood)	E	*32.1 (13.0)	*48.1 (8.4)	66.7	*26.0 (15.8)	*39.8 (7.6)	65.3

Note : Number of the specimens is five.
The value in brackets represents the coefficient of variation(%).
Each value represents the average of five spcimens.
Diameter of loading head is 80 mm.

Legend : * : Bending failure

another 1 hour, followed by drying for 24 hours at 60°C. After treatment, extent of crack or open glueline at both ends are inspected.

In order to examine the effect of treatments on shear strength, bending-shear tests were carried out on both soaked and boiled specimens. However, no significant change was observed immediately after each treatment. Each of the specimens was then conditioned to the original moisture content, and specimens without treatment were also prepared as the control.

Data on residual strength after soaking or boiling treatment are summarized in Table 6. The ratio of shear strength of the soaked specimen to the control was found to be ranged from 86.2 to 100.9 % while the average was 94.7 %. On the other hand, the ratio for boiled specimens ranged from 79.0 to 95.1 % with an average value of 87.9 %. In general, strength reduction in accelerated aging test could be due to the degradation of glueline and/or wood substance itself. Nevertheless, based on the results obtained, there was no sign of failure at the glueline. Thus, the strength reduction should be attributed to the deterioration of wood itself, such as that caused by the expansion of lathe checks.

Table 6. Effects of soaking and boiling treatment on shear strength.

Species		After soaking (kgf/cm^2)	After boiling (kgf/cm^2)	Control (kgf/cm^2)	After soaking/Control (%)	After boiling/Control (%)
Douglas fir	F	69.8 (7.8)	60.5 (14.4)	71.6 (10.9)	97.5	84.5
	E	89.4 (6.5)	*74.5 (5.0)	94.3 (5.0)	94.8	79.0
Akamatsu	F	70.4 (6.8)	*68.2 (15.9)	71.7 (8.1)	98.2	95.1
	E	*84.6 (17.5)	*77.9 (8.6)	*93.0 (7.5)	91.0	83.8
Hinoki	F	98.3 (5.9)	88.0 (8.9)	97.4 (6.2)	100.9	90.3
	E	98.5 (10.4)	91.4 (3.6)	103.2 (3.5)	95.4	88.6
Sugi (Sapwood)	F	46.8 (9.0)	50.0 (18.9)	54.3 (7.2)	86.2	92.1
	E	*55.8 (10.2)	*57.3 (6.5)	*62.0 (9.8)	90.0	92.4
Sugi (Heartwood)	F	61.4 (5.0)	*54.8 (3.9)	65.1 (6.2)	94.3	84.2
	E	*68.3 (6.5)	*60.0 (6.3)	*67.8 (6.7)	100.7	88.5

Note : The value in brackets represents the coefficient of variation(%).
Each value represents the average of five specimens.
$l/h=3$
Diameter of loading head is 80 mm.

Legend : * : Bending failure

Table 7. Results of block shear test.

Species	Direction of loding	Shear strength (kgf/cm²)
Douglas fir	V	83.5 (24.2)
	H	88.3 (24.8)
Akamatsu	V	86.2 (16.4)
	H	94.1 (18.3)
Hinoki	V	98.2 (21.9)
	H	91.1 (18.4)
Sugi (Sapwood)	V	53.0 (30.0)
	H	69.7 (13.5)
Sugi (Heartwood)	V	64.8 (20.7)
	H	74.7 (18.5)

Note : The value in brackets represents the coefficient of variation(%).
Each value represents the average of 20 specimens.

Legend : V : Shear plain is pararell to glue lines.
H : Shear plain is perpendicular to glue lines.

5. Comparison of shear strength by block shear test

Table 7 summarizes the results obtained from block shear tests[1]. Each value represents the mean of 20 test specimens. It may not be sensible to compare these values directly with that of bending-shear test. Nevertheless, it should be noted that the data obtained exhibited a larger coefficient of variation than that of bending-shear test (Table 2 and 4), illustrating the sensitivity of block shear results with respect to inconsistency in specimen preparation.

Conclusion

Based on the results of the above study, the following conclusions have been reached;

1. Maximum shear strength values increased with increasing diameter of loading head up to a certain limit after which they flattened off. Thus, in order to eliminate the effect of loading head, diameters between 50 and 100 mm should be used for 40 × 40 mm cross-section beams.

2. Maximum shear strength decreased with increasing span to depth (l/h) ratio. In order to be

predominantly failed in shear, a ratio three or four is recommended.

3. In the case where loading direction was parallel to gluelines (edgewise loading), horizontal shear did not always take place, but was dependent upon l/h ratio of the specimen and species used. On the other hand, when loading direction was perpendicular to gluelines (flatwise loading), almost all specimens failed in horizontal shear. The shear strength of edgewise loaded specimens was greater than that of flatwise in every test condition.

4. In the case where length of overhang to depth of specimen ratio ranging from 1/2 to 1/1, effect of length of overhang on shear strength was of no significance.

5. The presence of butt joints at the center of the specimen resulted in reduction in shear strength. In the case where horizontal shear failure was predominant, shear strength decreased to about 90 % of that of the control. On the other hand, only about 66 % of the strength of the control was achieved when bending failure took place.

6. The coefficient of variation of the shear strength obtained by bending-shear test was lower than that obtained by block shear test. The greater variability of the latter was attributed to the inaccuracy or difficulty in specimen preparation.

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（研　究　資　料）

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摘　　要

LVLのせん断性能は用いられる単板のせん断性能と接着層のせん断性能とによって決定される。従って，LVLのせん断試験法はその両者の性能を同時にチェックできることが好ましい。従来，ブロックせん断試験法が木材及び接着層のせん断強度の評価法として用いられてきたが，LVLのせん断強度の評価法として用いる場合には次のような問題点がある。すなわち，単板内に含まれる節を除去することが困難であること，単板が厚くなればせん断面と裏割れの位置によって強度値が大きく変化する可能性があること，LVLでは接着層が必ずしも直線的に形成されないため，接着層を正確にせん断面と一致させることが困難であること，接着層が多いため接着性能をチェックするためには多量の試験片が必要であること等である。

そこで，ブロックせん断試験に代わるものとして，短スパンを用いる曲げせん断試験が提案されてきた。この試験法は上記のような問題点を持たないが，スパン－梁せい比，荷重ヘッドの曲率，荷重の方向等の因子によってせん断強度値が影響を受けるため，評価法として確立されたものにはなっていない。

本研究では，6種類の構造用LVLを用いて曲げせん断試験を行い，これらの因子がせん断強度に及ぼす影響を実験的に検討するとともに，変動の少ないせん断強度を得るための最も適切な試験条件を求めた。

その結果，次のことが明らかになった。

1. 曲げせん断強度試験によって得られるせん断強度値は，スパン－梁せい比が小さいほど，また，荷重ヘッドの径が大きいほど高い値を示す。
2. 変動の少ないせん断強度値を得るためには，スパン－梁せい比が3ないし4，かつ，荷重ヘッドの径が50～100 mm範囲内にあることが望ましい。
3. 荷重方向と接着層とが垂直な場合（flatwise）では，ほとんどの条件下でせん断破壊が生じるが，逆に平行な場合（edgewise）では，樹種によって曲げ破壊が生じることがある。
4. 試験片のオーバーハングが試験片の梁せいの1／2から1／1程度であれば，せん断強度値はオーバーハング長さの影響を受けない。
5. 2層おきのバットジョイントを中央部に有する試験体のせん断強度値は，せん断破壊を生じる場合には，バットジョイントのないものの約9／10，曲げ破壊を生じる場合には約2／3にまで低下する。

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6．曲げせん断試験により得られるせん断強度値は，ブロックせん断試験により得られる値に比べ変動が少ない。

なお，本試験の一部は日本農林規格の制定に際し，基礎資料として用いられた。