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ORIGINAL ARTICLE

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Comparison of internal bond strength and compression shear strength of wood-based materials

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Abstract The purpose of this study was to design a compression shear device for easy and fast measurement of the bonded shear strength of wood-based materials to replace the conventional method used to evaluate internal bond strength (IB). To assess the performance of this device, five differently sized specimens, included group I (dimension 5 × 1 cm), group II (5 × 2 cm), group III (5 × 3 cm), group IV (5 × 4 cm), and group V (5 × 5 cm) cut from commercial particleboard and medium-density fiberboard (MDF) (1.8 cm thick) were tested in compression shear. Only group V (5 × 5 cm) was prepared for the IB test. Results indicated that the compression shear strengths (CS) of particleboard and MDF, loaded in the horizontal or the diagonal direction, were greater than the IB, although a significant correlation existed between the two. This finding suggests that the IB of particleboard and MDF could be accurately estimated from the data collected by the CS test.

Key words Compression shear device · Internal bond strength · Compression shear strength · Particleboard · Medium-density fiberboard

Introduction

It has been reported[1-4] that several fast, simple testing methods have been developed to evaluate the internal bond (IB) strength of particleboard and to replace the conventional IB methods. Although there was high correlation between the values collected from the proposed simple tests and the standard IB test, none of the new tests was sufficiently satisfactory to replace the latter.

In this study, a compression shear (CS) method was developed for collecting shear strength data of wood-based materials, and the results were compared to the tensile strength perpendicular to the surface determined by the conventional IB method. The purpose of this study was not only to determine the relation between results determined by the CS method and the IB method for particleboard or medium-density fiberboard (MDF) but also to assess the applicability of the CS method to adhesives and bond quality control as well as many other possible uses. Because of the heterogeneity of wood-based materials, special consideration must be taken into account when performing the tests using this device.

Materials and methods

Materials

The test specimens were taken from 18 mm thick commercial particleboards (three-layer structure) and MDF bonded with urea-formaldehyde (UF) resin. Thirty-five specimens for each group (based on size) were prepared for IB and CS tests in which specimens were subjected to horizontal and diagonal loads. Five groups of specimens were prepared based on size as follows: group I (5 × 1 cm); group II (5 × 2 cm); group III (5 × 3 cm); group IV (5 × 4 cm), and group V (5 × 5 cm); all were randomly selected. For the IB test, only group V (5 × 5 cm) was tested. Prior to the test, all specimens were conditioned in a controlled-environment chamber: 20°C and 65% relative humidity (RH).

Methods

Traditionally, the method used to determine the IB strength of wood-based materials worldwide is as specified by

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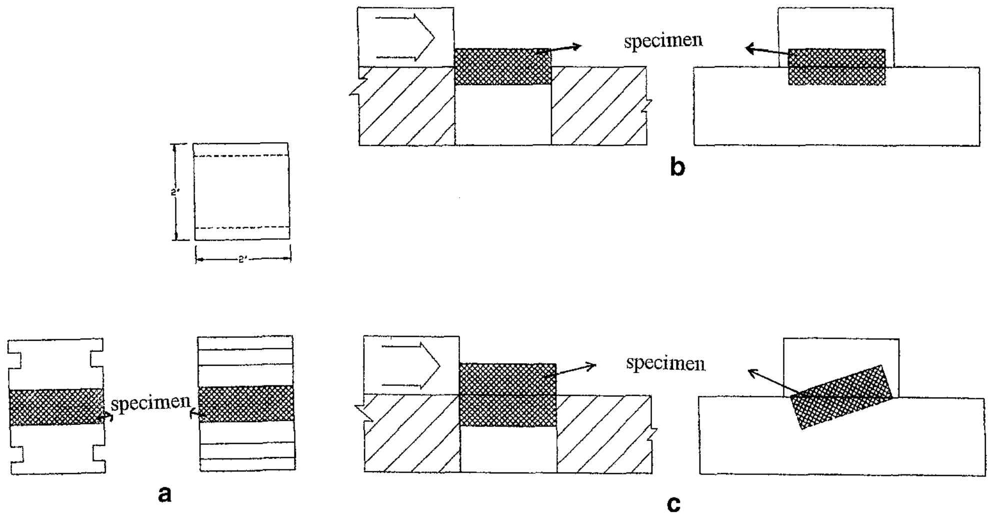

Fig. 1. Loading direction of the internal bond strength (IB) test and compression shear (CS) test with horizontal and diagonal loading. **a** Traditional IB testing. **b** Horizontal loading. **c** Diagonal loading

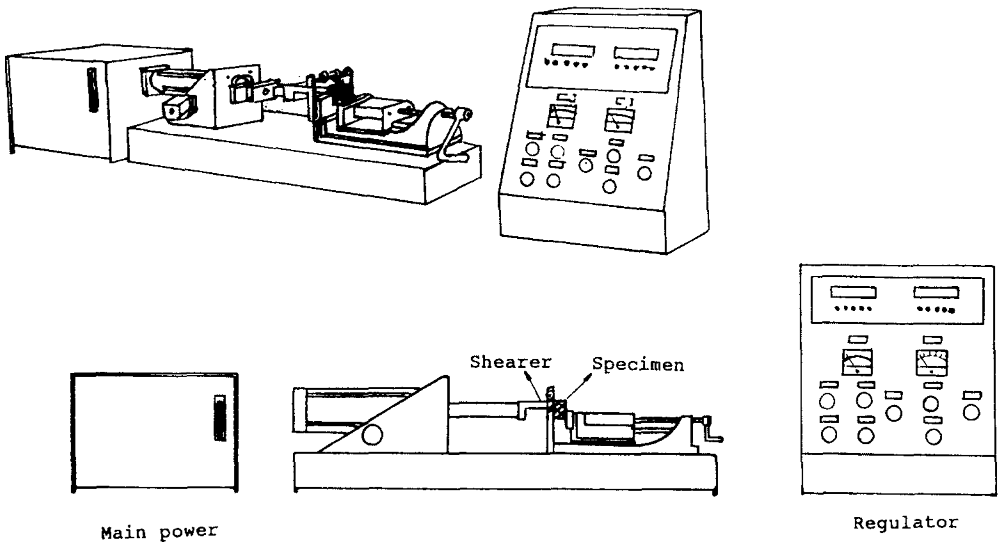

Fig. 2. Apparatus for simple compression shearing

standards such as DIN 52365, JISA 5908, CNS 2216, and ASTM D1037, as shown in Fig. 1a. The CS device is shown in Fig. 2. The specimen is subjected to compression-shear loading until failure occurs. The loading direction for horizontal specimens (Fig. 1b) was set up to be parallel to the surface of the particleboard or MDF as closely as possible, and the cross-head of loading passed through the middle layer at 1 cm (group I), 2 cm (group II), 3 cm (group III), 4 cm (group IV), or 5 cm (group V) of the specimen. In addition, diagonal loading was positioned as shown in Fig. 1c. The constant loading rate was set at 2 mm/min, and the maximum load at failure was recorded.

Results and discussion

Design of the compression shear device

The CS device developed in this study is different from other shear testing apparatuses. The testing device and the specimens are shown in Fig. 1a–c. The tester holds the specimen tightly by hand-turning the fine-threaded rod in the CS device. The device can be adjusted to allow the loading of compression shear at a constant rate through the target layer of the specimen. The specimens also could be loaded in the horizontal or diagonal direction to meet the experimental design.

The stress concentrations and the interactions between the loading head of the CS device and the wood-based specimens were considered in the design of this CS device, which has proved to be one of the most efficient and easiest methods for determining shearing strength.

Comparsion of the conventional IB test and the developed CS test

The design of the CS device is shown in Fig. 2 as a comparison with the conventional IB test, as specified by ASTM D1037 using the universal machine. According to ASTM D1037, the IB test for tensile strength perpendicular to the

Table 1. Results of Duncan's new ranged analysis for compression shear strength among five groups of specimens

Group	Compression shear strength (kgf/cm²)	
Particleboard		
Horizontal loading		
IV	14.1 ± 2.2	NS
III	14.1 ± 1.7	NS
II	15.3 ± 2.3	NS
V	15.8 ± 1.6	NS
I	16.8 ± 2.7	
Diagonal loading		
IV	18.2 ± 2.8	NS
V	19.2 ± 1.2	
III	20.5 ± 2.5	
II	25.3 ± 2.7	
I	28.7 ± 3.2	
Medium-density fiberboard		
Horizontal loading		
I	9.2 ± 2.9	
III	10.8 ± 2.1	NS
IV	12.1 ± 2.6	
II	13.9 ± 3.5	
V	17.8 ± 2.2	
Diagonal loading		
III	24.2 ± 2.6	
IV	24.7 ± 3.8	NS
V	25.7 ± 2.2	
II	30.6 ± 4.9	
I	37.8 ± 4.3	

Results are means ± SD
NS, not significant at $P < 0.05$

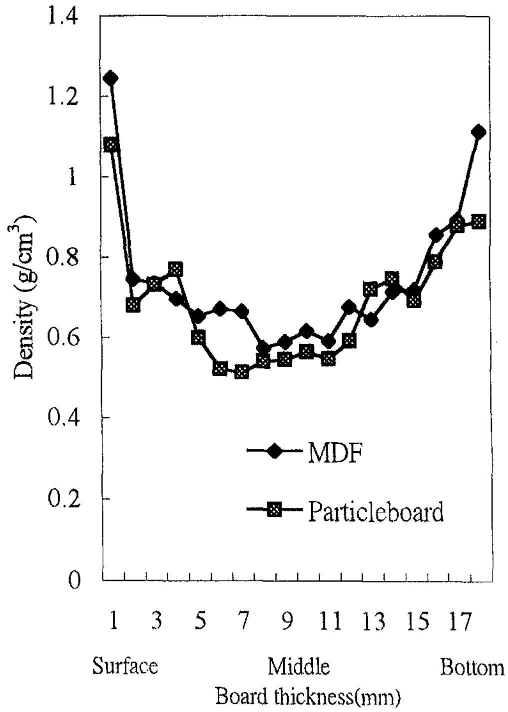

Fig. 3. Density distribution through the thickness of particleboard and medium-density fiberboard (MDF)

surface is made on specimens in the dry condition to determine cohesion of the wood-based materials. The test was designed for quality control of wood-based panels. For obtaining reliable data of IB strength, treatment of the test specimen was suggested in this ASTM D1037-96[5] as follows: Any suitable adhesive that provides an adequate bond may be used for bonding the specimens to the loading blocks (steel or aluminum). Epoxy resins are recommended as satisfactory bonding agents. The pressure required to bond the blocks to the specimens depends on the density of the board and the adhesive used and should not be so great as to measurable damage the specimen. The resulting bond must be at least as strong as the cohesive strength of the material perpendicular to the plane of the panel. The bonding of specimens with two steel or aluminum blocks is time-consuming, so some time-saving shear testing methods were developed,[1–4,6–10] and have been investigated.[3,11–14] The common goal of these studies was to develop a simple, easy, fast shear testing method that can be used for quality control of wood-based panels.

Shear properties of particleboard

The average (±SD) value for the IB strength of particleboard obtained by the conventional testing method as specified by ASTM D1037-96 was 3.19 ± 0.35 kgf/cm². However, the values of CS varied with the dimension of specimens and the loading direction. Results of Duncan's new ranged analysis among these five size groups are presented in Table 1. In the case of horizontal loading, because the three-layer particleboard had a layered structure and the weakest area occurred near or at the center layer of the particleboard, the CS failure followed the center layer of the board. Note also in Table 1 that except for the group V specimen, the CS values for small specimens, such as group I, were significantly greater than those of larger specimens (group IV and III). This may be due to the fact that in the CS test the resulting shearing stress along the center face may vary with the area subjected to compression. Doubtlessly, the largest shearing stress occurred on the shearing face near the loading head; normal stress may also occur in that region. Therefore when shearing failure appears near the shearing contact surface, the resistant force in the specimen may be weakened. The shearing strength was calculated from the shearing force divided by the predicted failure area. Therefore, the specimens with a smaller face area (group I), although they had a smaller shearing failure area, showed larger shearing strength values. Note that the density distribution of particleboard varied along the thickness direction (surface-to-bottom), as shown in Fig. 3. The largest density values (1.078 g/cm³) were observed at the surface layer and decreased inward, and the lowest values (0.512–0.545 g/cm³) were found at distances 7–9 mm from the surface and then increased gradually to 0.889 g/cm³ at the bottom layer. The average (±SD) density was 0.710 ± 0.150 g/cm³, indicating that the weakest area should be at the low-density layer. However, the shearing strength obtained by this CS test was 4.4–5.3 times greater than the IB values. Figure 4 showed the horizontal loading condition and fractured shape of the specimen of particleboard in this CS test.

In the case of diagonal loading, it was thought that the specimens may be displaced during the test, and hence the

Fig. 4. Horizontal loading condition (**a**) and the fractured shape of the particleboard specimen (**b**) in this CS test. *Arrow* indicates the compression shear direction

Fig. 5. Diagonal loading condition (**a**) and the fractured shape of the particleboard specimen (**b**) in this CS test. *Arrow* indicates the compression shear direction

Table 2. Linear regression formulas for IB and CS of particleboard and MDF

Sample	Horizontal loading			Diagonal loading		
	IB	R^2	F value	IB	R^2	F value
Particleboard						
Group I	0.126 CS + 1.014	0.935*	969.5	0.095 CS + 0.457	0.941*	1082.9
Group II	0.137 CS + 1.020	0.899*	605.9	0.119 CS + 0.193	0.940*	1073.5
Group III	0.147 CS + 0.965	0.785*	248.5	0.122 CS + 0.558	0.789*	254.9
Group IV	0.138 CS + 1.111	0.713*	168.7	0.120 CS + 0.900	0.769*	226.8
Group V	0.205 CS − 0.107	0.926*	851.4	0.229 CS − 1.103	0.875*	479.3
MDF						
Group I	0.208 CS + 3.564	0.898*	599.4	0.138 CS − 0.015	0.866*	440.6
Group II	0.108 CS + 4.140	0.545*	81.5	0.104 CS + 2.072	0.937*	1005.4
Group III	0.210 CS + 3.030	0.920*	783.9	0.084 CS + 3.056	0.463*	58.7
Group IV	0.136 CS + 3.461	0.645*	123.5	0.102 CS + 2.591	0.618*	110.1
Group V	0.244 CS + 1.125	0.926*	853.4	0.184 CS + 0.757	0.857*	408.8

IB, internal bond strength; CS, compression shear strength
* Significantly different at $P < 0.01$

shear failure may not develop along the center (weakest) layer of specimen. The CS values obtained from diagonal loading were 1.2–1.7 times greater than those obtained from horizontal loading. Table 1 shows that the CS values had a decreased trend as follows: group I > group II > group III > group IV > group V. A significant difference was not observed between group IV and group V but was seen among other groups (I, II, and III). Again smaller specimens had larger CS values, and the reasons for this trend may be similar to those mentioned above. The CS values of the diagonal loading specimens also were 5.7–9.0 times greater than the IB values. Figure 5 shows the diagonal loading condition and fractured shape of the specimen of particleboard in this CS test.

When the relation between CS and IB values for all specimens were considered, it was found that the IB values increased linearly with the increase in CS values and could be represented by linear regression formulas as shown in Table 2. The coefficients of determination (R^2) ranged from 0.713 to 0.941. A significant difference was observed in, the

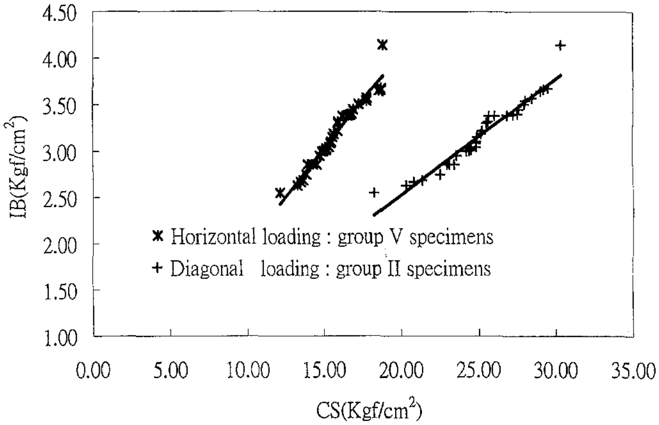

Fig. 6. Relations between IB and CS for particleboard

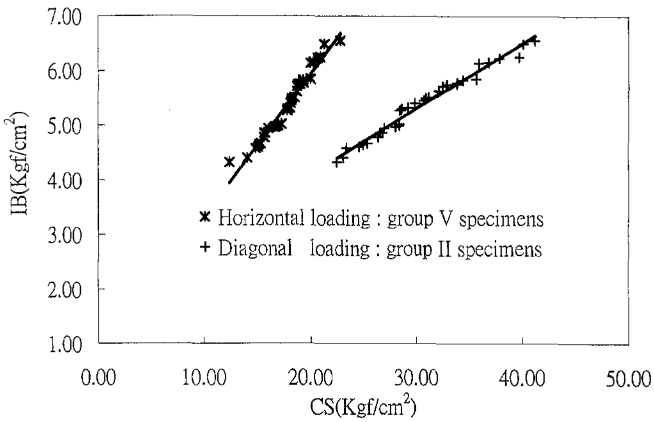

Fig. 7. Relations between IB and CS for MDF

F test. Some examples for the relations between CS and IB are shown in Fig. 6. Therefore, the IB of particleboard may be adequately predicted using the CS value. For the CS test the most suitable specimen dimension was that of group 1 for both horizontal and diagonal loading.

Shear properties of MDF

The average (±SD) value for the IB of MDF obtained using the conventional testing method as specified by ASTM D1037-96[5] was 5.36 ± 0.60 kgf/cm². The CS values also varied with the dimension of the specimens and loading directions. The results of Duncan's new ranged analysis among specimens based on size are presented in Table 1. With horizontal loading, the CS values had a decreasing trend as follows: group V > group II > group IV > group III > group I. Significant differences were not observed between groups IV and III, but significant differences were seen among other groups (V, II, I). This finding was contradictory to those observed in particleboard, in which group I (smallest-dimension specimens) had larger CS values. This may be attributed to the density distribution along the thickness direction of the MDF. As shown in Fig. 3, the largest density values (1.253 g/cm³) occurred at the surface layer and decreased inward, with the lowest value measured at a position about 8 mm from the surface; it then increased and achieved a larger value (1.110 g/cm³) at the bottom. The average (±SD) value of density was 0.755 ± 0.185 g/cm³. The CS values for MDF were 1.7–3.3 times greater than the IB values.

With diagonal loading, a decreasing trend for CS values was observed as follows: group I > group II > group V > group IV > group III. A significant difference did not exist among groups V, IV, and III; but there was a difference between groups I and II. This decreasing trend was just the opposite of those of loaded horizontally, but it was similar to those observed in particleboard. The CS values of MDF obtained by diagonal loading were 4.5–7.1 times greater than the IB values.

When a comparison was made between CS values obtained from tests of horizontal and diagonal loading, it was found that the values from the larger shearing area specimens (i.e., group V) were closer. The CS value obtained from diagonal loading was 1.4 times greater than that obtained with horizontal loading but 4.1 times that in the smaller shearing area specimens (group I). This may be due to the fact that the diagonal face included a larger density zone and therefore yielded larger CS values.

When the relation between the CS and IB values for various specimens were considered, it was found that the IB value increased linearly with the increase in CS value, and their relations could be represented by linear regression formulas, as shown in Table 2. The coefficients of determination (R^2) ranged from 0.545 to 0.937. A highly significant difference was seen in the F test. Some examples of the relations between CS and IB are shown in Fig. 7, which shows that the IB of MDF can be adequately predicted using the CS value. When using the CS test the most suitable dimensions of specimens are those of groups V and II, respectively, for horizontal and diagonal loading.

Conclusion

The designed CS device can be used to evaluate bond strength in the weakest layer of wood-based materials. In the horizontal and diagonal loading tests, the CS values were 4.4–9.0 and 1.7–7.1 times higher than the IB values for particleboard and MDF, respectively. In the horizontal and diagonal loading tests, the IB values for particleboard and MDF increased linearly with the increase in CS values, and their relations could be represented by linear regression formulas, with a high correlation. Therefore, the IB values for particleboard and MDF could be adequately predicted using the CS value.

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References

1. Gertjejansen RO, Haygreen JG (1971) Torsion shear test for particleboard adapted to a universal testing machine. For Prod J 21(11):59–60
2. Hall HJ, Haygreen JG (1983) The Minnesota shear test. For Prod J 33(9):29–32
3. Suchsland O (1977) Compression shear test for determination of internal bond strength of particleboard. For Prod J 27(1):32–36
4. Shen KC, Carroll MN (1969) A new method for evaluation of internal strength of particleboard. For Prod J 19(8):17–22
5. ASTM D1037-96 (1996) Standard test methods for evaluating properties of wood-based fiber and particle panel materials. ASTM, West Conhohochen, PA
6. Grezeczynski T, Basowski S (1963) Verfahren zur schneller bestimmung der zugfestigkeit zur plzttenebene. Holz Roh Werkstoff 21:495–496
7. Gaudert P (1974) New torsion test for particleboard. For Prod J 24(2):35–37
8. Gressel P (1975) Eignung der blockscher-prucefmenthode zur beurteilung der verleimungsqualitact von spanplatten. Holz Roh Werkstoff 33:393–398
9. Liiri O, Kivistoe A, Tuominen M, Aho M (1980) Determination of the internal bond of particleboard and fiberboard. Holz Roh Werkstoff 38:185–193
10. Passialis C, Tsoumis G (1982) A method for testing internal bond of particleboard. Wood Fiber 14:159–161
11. Liu JY (1984) New shear strength test for solid wood. Wood Fiber Sci 16:567–574
12. Meierhofer UA, Sell J, Sommerer S (1977) Blockscher-pruefung von holzspanplatten zur emittlung der guete des spanverbundes. Holz Holzverwertung 29:6–8
13. Noack D, Schwab E (1972) Die scherfestigkeit von holzspanplatten als kriterium des spanvrbundes. Holz Roh Werkstoff 30:440–444
14. Okkonen EA, River BH (1989) Factors affecting the strength of block-shear specimens. For Prod J 39(1):43–50