Studies on Particle Board (VIII).

Influence of specific gravity of particle board on dowel joint strength.*

by

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ABSTRACT

The effect of specific gravity on dowel joint strength was determined by the dowel-withdrawal-test technique. Red lauan (*Shorea negrosensis* FOXW.) particle boards of 6 different specific gravity levels and spiral-grooved-compressed dowels were used in the study. Among the variables considered, aside from the specific gravity, were dowel-fitting grade and inserted-dowel length. The results of the study showed that, as the specific gravity of the particle board is increased, higher-density dowels must be used. Particle boards with specific gravity greater than 0.5 are suitable for dowel joints.

INTRODUCTION

This report concerns the joining of two component parts. Using particle boards in construction has always created problems in the wood-using industries, particularly the furniture industry. Basic data on the method of preparing joints on the boards are scanty. Moreover, pivot tenoning and lapped dovetailing, commonly used in solid wood, are difficult to apply in particle boards, especially if the boards are of low dencity. To promote the practical use of particle boards in the wood-using industries, a study in this field was carried out to solve these problems. It was necessary to determine the influence of specific gravity of board on dowel joint strength, and to determine the lower limit of the specific gravity of particle board wherein dowel jointing is possible.

The manufacture of the particle boards used, the determination of the properties of the board, optimum glue spread, and the dowel joint strength were carried out as described in the following text.

MATERIALS AND METHODS

Manufacture of Particle Board

Particle boards of six different specific gravities were manufactured and their basic pro-

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perties were determined. Their specific gravities were 0.3, 0.4, 0.5, 0.6, 0.7 and 0.8.

The raw materials used were rotary-cut red-lauan veneers, 1.2 mm thick. The veneers were crushed, screened through a 5 × 45 mm mesh wire in the crusher and the coarse and fine particles were separated and rejected. Red lauan veneers, 1.2 mm thick, were used as overlay.

The adhesive used was urea resin, 45 percent solids, and the hardener was 20 percent solution of ammonium chloride, mixed in 3 percent of the urea resin (Table 1). The particles were spray-coated to a resin content of 10 percent, based on dry weight. The glue spread for veneer 17.5 grams per square foot single glue line.

Table 1. Formulas and component parts of mixtures of adhesives used.

Components		Proportional parts (by weight)				
		Glue I	Glue II	Glue III	Glue IV	Glue V
Resins :	Urea (67% solids)	100	100	–	100	–
	Polyvynil acetate	–	–	100	–	100
Hardener :	Ammonium chloride (20% solution)	3	5	–	3	–
Extenders :	Wheat flour	–	3	–	–	–
	Betaseal	–	–	–	5	5

The size of boards processed was 45×45×2 cm. The veneer was overlaid simultaneously during hot pressing. No cross banding of veneer was made. The specific pressures used were 5, 10, 15, 25, 30 and 40 kg/cm², resulting in boards of specific gravity 0.3, 0.4, 0.5, 0.61, 0.68 and 0.78, respectively. Thickness was controlled by the use of spacer bars. The pressure for individual board was applied by the step down method. The temperature of the hot plate during pressing was 140°C and the pressing period was 20 minutes. For each specific gravity, four sheets of particle boards were manufactured. These boards were divided equally into two groups, i.e., one group for determination property and the other for dowel joint strength.

Except for the tensile strength of surface layer, which was determined by the German method "Abhebefestigkeit"[3)]**, the board properties were determined by applying the testing method prescribed by the Japanese Industrial Standards (JIS, A-5908 [1957])[2)]. The fiber direction of the overlaid veneer for the bending-test specimen was perpendicular to the longitudinal direction of the specimens.

Determination of Gluing Properties of Particle Board Edge.

As basic tests for dowel joint strength, the following were conducted : (a) determination, between particle-board edge and solid wood, of the influence of specific gravity of particle board on gluing properties, and (b) determination of suitable adhesives for such bonding.

a. **Preliminary test to determine the amount and influence of glue spread.**-To determine the amount and influence of suitable glue spread, preliminary tests were conducted, using specimens of commercially-processed veneer-overlaid particle board (specific gravity 0.5), 2 by 2 by 13 cm, and solid wood of birch (*Betula maximowicziana* REIGEL) 2 by 2 by 13 cm and of specific gravity 0.67. First, the particle board and solid wood were glued together into 2 by 4 by 13 cm blocks. The face of the particle board that was glued to the solid birch was the plane perpendicular to the overlaid veneers. Two types of specimens were pre-

** Numbers in parentheses refer to Literature Cited.

pared, based on the gluing surface of the solid wood. They were, first, with the particle boards glued to the end section of the solid wood and, second, with the particle boards glued to the radial section (Fig. 1).

Two adhesives, Glue II and III were used (Table 1). The amounts of glue spread used for each kind of adhesive were 5, 10, 20 and 30 grams per square foot. The pressing conditions were 5 kg/cm² pressure at 20 °C temperature, maintained for 24 hours. After gluing, the specimens were conditioned to constant weight at 20°C temperature and 65 percent relative humidity for 14 days, after which, shear test specimens with a shear area of 2 by 2 cm were cut from the blocks (Fig. 1).

Shear strengths parallel and perpendicular to the veneer faces were determined. For each type of glue, level of glue spread and type of glued surfaces, two specimens each were tested, for each of the parallel and perpendicular shear strengths determination. Thus, a total of 64 shear specimens were tested.

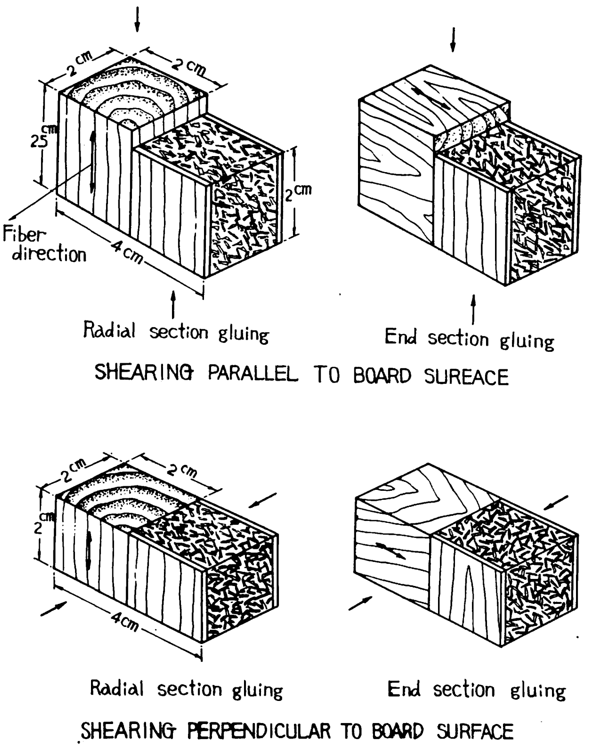

Fig. 1 Shearing test specimens showing the dimensions, 2 types of surface gluing and 2 types of shearing directions.

b. **Main test to determine suitable adhesives.**-The determination of suitable adhesives to be used was conducted. The specific gravity aforementioned. The four adhesives used (Glues IV and V in addition to Glue II and III), and their formulations are given in Table 1. The extenders used were wheat flour and silicic anhydride (the commercial name : Betaseal). The pressing conditions used in the preliminary test were followed. Based on the results of preliminary test run on the determination of optimum glue spread, a glue spread of 20 grams per square foot was used. As control specimen, solid to solid birch species were included in the test specimen. The preparation of specimens, method of test and other experimental conditions were the same as those in the preliminary test.

Determination of the Influence of Specific Gravity of Board on Dowel Joint Strength.

Studies made on dowel joint strength of solid woods showed that spiral-grooved-compressed dowel types are more effective in joints because the adhesive remains along the groove of the dowel when it is inserted into the dowel hole and, also, because the dowel produces a higher contact ratio as a result of the swelling of the dowel[1]. This swelling is caused by the absorption of glue water by the dowel. It was further reported that constant trend of dowel fitting grade could not be obtained in solid wood joints[4][5]. This is because of the different types of dowel and adhesives used. However, it is considered that this relationship will change in the case of porous materials like particle boards.

Based on the previous study on the determination of gluing properties of particle board edge, the effect of specific gravity of board on dowel joint strength, and at the same time using spiral-grooved-compressed dowels, the effect of dowel fitting grade and inserted dowel length were studied.

The particle board specimens previously processed were used in this test. The boards were conditioned to about 12 percent moisture content. The wood specimens for the dowel were of straight-grained heartwood of beech (*Fagus crenata* BLUME), of 0.6 specific gravity. The dowels were kiln-dried at 12 to 14 percent moisture content.

In the processing of dowels, dowel making and cutting machines were used. The diameter of the processed spiral-grooved-compressed dowel was 8.25cm, with 0.03 mean standard deviation. The diameter of the individual dowels was measured with a micrometer at 10 different points about 4 cm distant from the end portion, that will be fitted to the hole of the particle board specimen. The average mean value of the diameter of one dowel was computed from these 10 measurements. The standard deviation was then computed from the entire diameter mean value of all the dowels used.

A small boring machine, with a spindle revolution of 1,600 rpm, was used to bore the dowel hole on the particle board edge. The dowel-hole sizes were 8.05, 8.25 and 8.45 mm resulting respectively into +0.2, 0 and −0.2 mm dowel-fitting grades. Measurements of dowel-hole sizes were made by using hole-diameter fitting gauge of 5/100 mm interval and 1/100 mm accuracy. The length of the portion of the dowel that was inserted was 2.0, 2.5 and 3.0 cm.

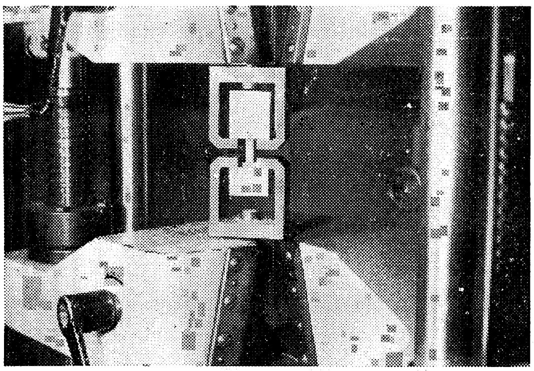

Fig. 2 The dowel withdrawal test method showing the withdrawal tast fixture and the specimen in position for test.

The dowel-withdrawal test was performed to determine the dowel joint strengh. The withdrawal fixtures and universal testing machine used in the test are shown in Figure 2. This method was introduced by Aoki[1]. Solid heartwood of beech species (0.6 specific gravity) was used as the upper wood block for particle board test specimen, having 0.6 specific gravity and above. Those specimens below 0.6 specific gravity have their upper block made of high density (0.65 specific gravity) particle board. The loading speed of the universal testing machine during test was 500 kg per min. The adhesive used was Glue Ⅳ (Table 1). The adhesive was spread by using a painter's hand brush on both the dowel surfaces and dowel hole. The glue spread was about 60 grams per square foot, based on the results of the preliminary test previously conducted. Before testing, the specimens were conditioned for one week at a controlled room, with 12 percent EMC. Six specimens were used in each test condition and the total number of specimens tested was 324.

The dowel-joint-strength values were calculated by using the equation $S=P/A$, where S is the joint strength in kg/cm^2, P is the maximun load in withdrawal in kg, and A is the dowel surface area inserted into the board in cm^2.

RESULTS AND DISCUSSION

Manufacture of Particle Boards.

The relationship between specific gravity and properties of the boards are shown in Figures 3 through 9. Of the seven figures, only Figure 6, wood-screw-holding power, showed linear relationship. Based on the analysis of variance, the following results were obtained :

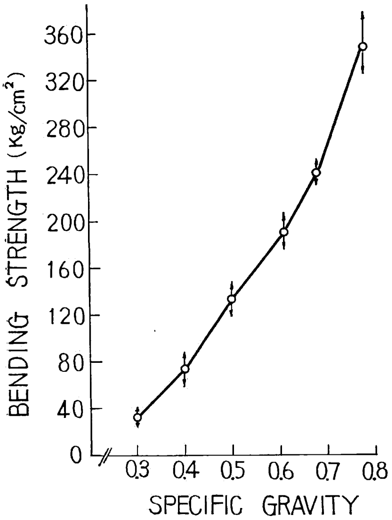

Fig. 3 The relationship of board specific gravity and bending strength.

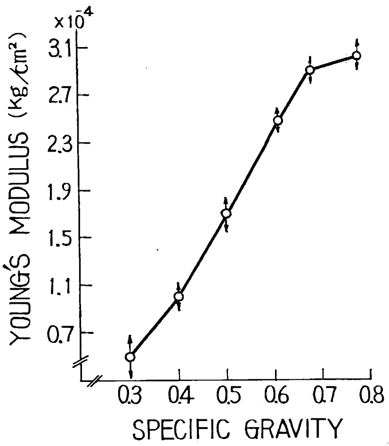

Fig. 4 The relationship of board specific gravity and Young's modulus in bending.

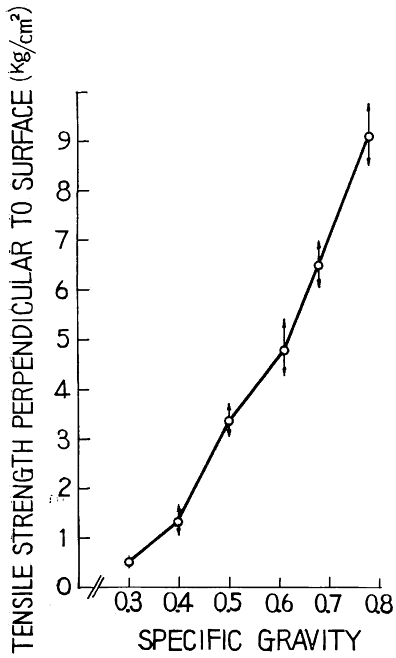

Fig. 5 The relationship of board specific gravity and tensile strength perpendicular to surface.

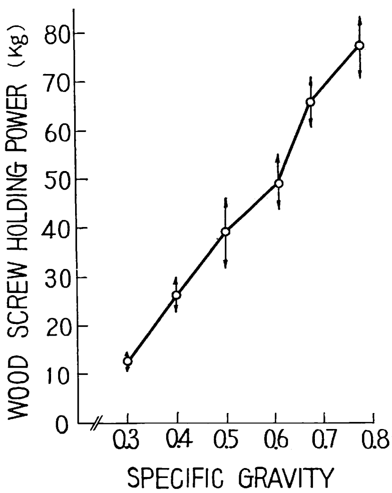

Fig. 6 The relationship of board specific gravity and wood screw holding power.

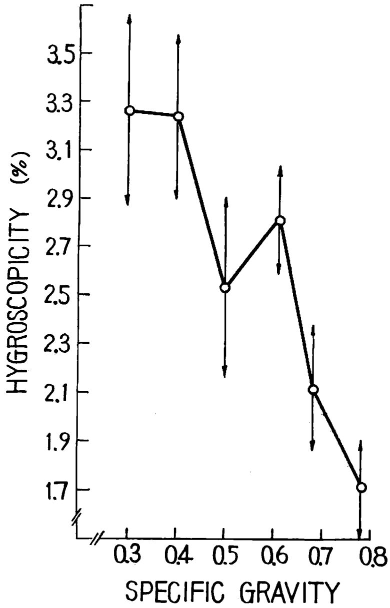

Fig. 7 The relationship of board specific gravity and hygroscopicity.

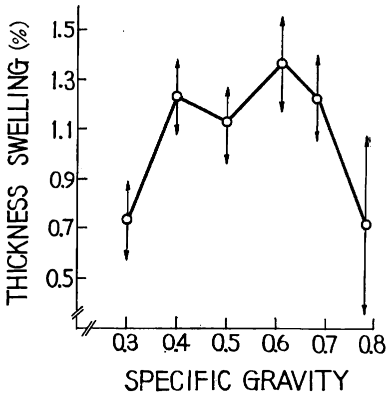

Fig. 8 The relationship of board specific gravity and thickness swelling.

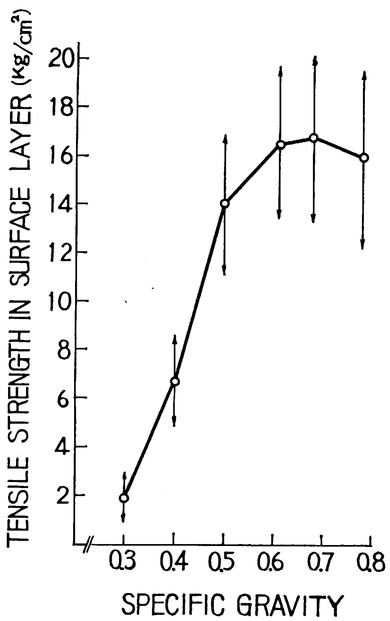

Fig. 9 The relationship of board specific gravity and tensile strength of surface layer.

(a) Bending and tensile strengths perpendicular to the surface and wood-screw-holding power are significant at 1 percent level.

(b) Young's modulus is not significant between 0.68 and 0.78 specific gravity.

(c) Tensile strength of surface layer is not significant among 0.5, 0.61, 0.68 and 0.78 specific gravity.

From these results it appears that particle board with specific gravity 0.5 can not be used as component parts in the furniture industry.

Determination of Gluing Properties of Particle Board Edge.

Influence of quantity of glue spread on gluing properties of board edge. - The results of the preliminary test on the relationship of the quantity of glue spread and shear strength are shown in Table 2. The results indicate that the shear strength, in all gluing conditions, increases with the increase of the quantity of glue spread, and shear strength parallel to board surface (Fig. 1) has higher values. In solid wood bonding, as the quantity of glue spread is increased above certain limits the bonding strenght does not increase. On the other hand, in the light of the porosity of the particle board edge, it is considered that, the heavier the glue spread within the same area, the higher is the shear strength.

Table 2. Shear test results obtained in the trial test run for the determination of suitable glue spread.

Quantity of adhesives (gr/ft²)	Shearing direction	Urea Resin		Polyvynil Acetate	
		End Sec.	Radial Sec.	End Sec.	Radial Sec.
30	∥	35.5	50.0	63.2	52.8
	⊥	27.1	50.0	44.4	40.3
20	∥	36.8	46.5	41.0	55.6
	⊥	18.8	32.5	32.6	30.6
10	∥	27.5	34.7	5.6	44.4
	⊥	21.5	22.2	0	28.5
5	∥	0	12.5	0	7.6
	⊥	0	27.1	0	7.6

Unit : kg/cm²

Table 3. Relation of bonding strength to specific gravity of particle board, direction of shearing, adhesives used and types of gluing surface.

Adhesives	Shearing direction \ Specific gravity	0.3	0.4	0.5	0.6	0.7	0.8	Control
Radial Section								
Urea	∥	15.6	26.3	38.1	78.8	105.0	94.4	123.8
	⊥	11.9	25.6	40.0	61.9	88.1	70.6	143.8
Polyvynil Acetate	∥	11.3	25.6	31.9	41.9	58.1	84.4	81.3
	⊥	6.6	18.8	31.9	46.3	60.6	83.7	91.9
Urea+Bitaseal	∥	9.7	38.1	48.1	88.1	105.6	121.9	181.3
	⊥	12.2	29.4	41.9	87.5	94.4	117.5	183.8
Polyvynil Acetate +Bitaseal	∥	13.5	9.4	30.0	50.6	58.1	66.3	120.0
	⊥	6.3	13.1	30.6	60.6	61.2	84.4	138.8
End Section								
Urea	∥	22.2	33.1	49.4	56.9	98.1	90.0	51.3
	⊥	9.6	15.6	38.1	44.4	78.1	84.4	58.8
Polyvynil Acetate	∥	20.0	21.9	41.9	51.9	49.4	63.7	76.3
	⊥	9.7	18.8	25.6	45.0	53.1	60.6	86.3
Urea+Bitaseal	∥	28.1	31.2	68.1	45.0	73.1	58.3	115.0
	⊥	12.8	14.4	35.6	35.0	66.3	54.7	103.8
Polyvynil Acetate +Bitaseal	∥	18.1	22.5	34.4	41.9	53.8	60.0	65.0
	⊥	12.8	20.6	35.0	36.3	68.1	61.3	67.5

Unit : kg/cm²

Influence of kinds of adhesives on gluing properties of board edge. - The results of the test on the determination of suitable adhesives to be used are shown in Table 3. These results show that the gluing strength of both urea resin and polyvynil acetate with extender are higher than those without. Urea resin glue appears to impart higher shear strength than polyvynil acetate resin. Generally, in wood bonding, urea resin imparts higher intial bonding but below par in durability. Addition of extender therefore is necessary to urea resin to improve its durability. The table also shows that shear strength increases with increase of specific gravity and, although the board specific gravity is 0.8 at 20 grams per square foot glue spread, still the gluing strength is below the value of the solid to solid, of the control, and of wood bonding. This indicates that an additional amount of glue spread is needed in the actual dowel jointing.

The Influence of Specific Gravity and Dowel Joint Strength.

The results of dowel-withdrawal test and analysis of variance are shown in Figures 10 through 12 and Table 4, respectively. In the analysis of variance, dowel-joint strength among the specific gravities of particle boards are significant at 1 percent level of probability.

The dowel-joint-strength values of boards below 0.5 specific gravity show the same values and trend as the gluing strength of board edge. However, particle boards with specific gravity greater than 0.5 did not increase in dowel-joint strength, while the gluing strength of board edge increased with the increase in specific gravity. This is because boards below 0.5 specific gravity failed ahead of the dowels in the test; on the other hand, dowel failures occurred in boards with specific gravity greater than 0.6 (Table 5, Figs. 13 and 14). When the dowels failed, the dowel-joint strengths tended to decrease, unlike when the dowel was withdrawn without failure from the board. These dowel failures occurred because, during dowel withdrawal without failure of dowel, the strain within the dowel caused by tensile stress remained

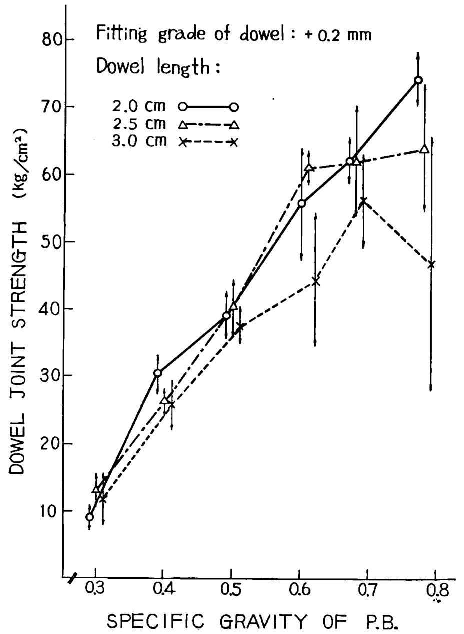

Fig. 10 Relationship between dowel joint strength and specific gravity of particle board as to dowel length, with +0.2mm dowel fitting grade.

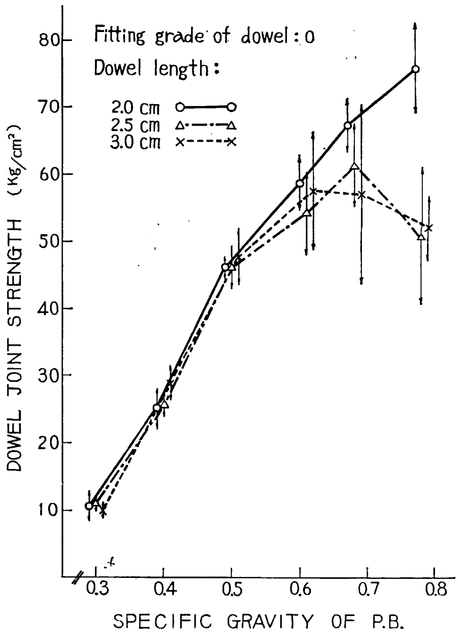

Fig. 11 Relationship between dowel joint strength and specific gravity of particle board as to dowel length, with 0 dowel fitting grade.

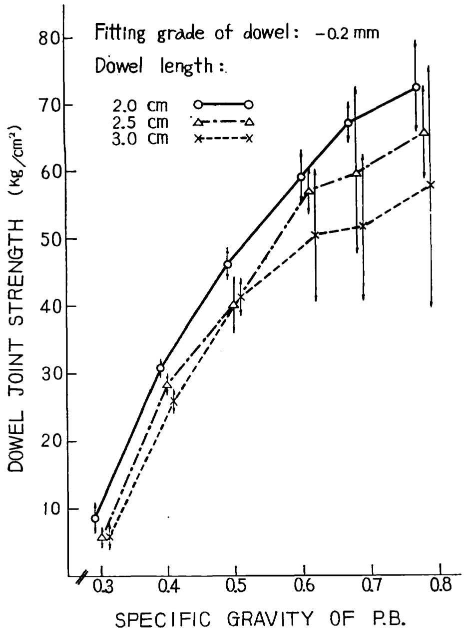

Fig. 12 Relationship between dowel joint strength and specific gravity of particle board as to dowel length, with −0.2 mm dowel fitting grade.

Table 4. Analysis of variance.

Items	Dowel joint strength	
	Sig.	ρ (%)
A-Specific gravity of particle board	**	84.8
B-Length of dowel	**	2.2
C-Fitting grade of dowel		13.0
A×B	**	
A×C	**	
B×C	**	
A×B×C	**	
E		

Note : ** Significant at 1% level.

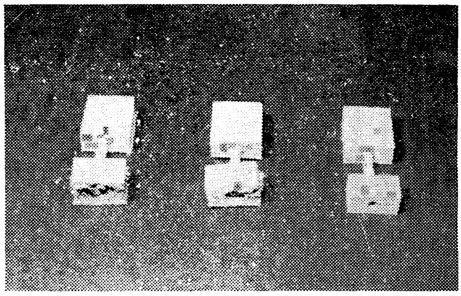

Fig. 13 Test specimens below 0.5 specific gravity showing the particles giving way.

Fig. 14 Dowel failure on test specimens above 0.6 specific gravity.

within certain limits. When the dowel did not withdraw, there was too much strain in the dowel, resulting in dowel breakage at low joint strength.

The tensile strength perpendicular to the surface showed the bonding strength between particle of the boards increased with increase of specific gravity (Figure 5). On the other hand, the tensile strength of the surface layer (Figure 9) showed the bonding strength between particle of the boards and surface veneer, was not significant in specific gravity greater than 0.5. This means that, when the specific gravity of the board increased, the bonding strength between particles of the board increased. This condition caused breaks on the surface veneer. As mentioned previously, the gluing strength of the board edge increased with the increase of specific gravity. Of course, this is not compatible with the dowel-joint performance in this experiment because the beech dowels (specific gravity 0.6) broke when used with higher density board. These results imply that the lower limit of specific gravity of the board in dowel jointing is about 0.5.

Table 5. Coded description of dowel joint strength failure on lauan particle board test specimens.

Hole size	Rep. \ Specific gr. / D.l.	0.3 2cm	0.3 2.5cm	0.3 3cm	0.4 2cm	0.4 2.5cm	0.4 3cm	0.5 2cm	0.5 2.5cm	0.5 3cm
0.805cm	1	A	A	A	A	A	A	A	A	A
	2	A	A	A	A	A	A	B	A	A
	3	A	A	A	A	A	A	A	A	A
	4	A	A	A	A	A	A	A	A	A
	5	A	—	A	A	A	A	A	A	A
	6	A	A	A	A	A	A	A	C	A
0.825cm	1	A	A	A	A	A	A	B	B	D
	2	A	A	A	A	A	A	A	B	B
	3	A	A	A	A	A	A	B	B	D, E
	4	A	A	A	A	A	A	A	A	D
	5	A	A	A	A	A	A	A	D, E	D, E
	6	A	A	A	A	A	A	B	A	D, E
0.845cm	1	A	A	A	A	A	C	B	D	D, E
	2	A	A	A	A	A	A	D	A	A
	3	A	A	A	A	A	A	B, E	B	A
	4	A	A	A	A	A	A	A	C	A
	5	A	A	A	A	A	A	B	D	B
	6	A	A	A	A	A	A	A	B	D

Hole size	Rep. \ Specific gr. / D.l.	0.6 2cm	0.6 2.5cm	0.6 3cm	0.7 2cm	0.7 2.5cm	0.7 3cm	0.8 2cm	0.8 2.5cm	0.8 3cm
0.805cm	1	D	F	D	B	D, E	F	D	F	D, E, F
	2	D	A	F	B	F	F	B	F	D
	3	F	F	F	B	F	F	D	F	F
	4	A	F	F	D	D	F	D, E	G	G
	5	D	D, E	F	D	F	F	D	F	F
	6	D	B	F	F	F	F	D, E	F	F
0.825cm	1	B, E	B, E	F	D, E	F	F	D, E	F	F
	2	B	D, E	D	D, E	F	F	B, E	F	F
	3	B, E	F	B	D, E	D	D	F	F	F
	4	D	F	G	D	F	F	F	F	F
	5	D, E	D, E, F	F	D	F	F	D, E	D	F
	6	D, E	F	F	D	D	D, E	D, E	F	F
0.845cm	1	D	F	F	D	F	D, E	D	D, E	G
	2	D	D	D	D, E	F	F	D, E	F	F
	3	B	A	D	D	F	D	D, E	G	F
	4	D	D, E	D	D, E	D, E	D	D, E	D, E	F
	5	D, E	D	D	D, E	D, E	F	D	D	F
	6	D, E	F	F	D	D, E	F	D, E	D	D, E

(Note) D.l. : Dowel length, Rep. : Replication.

A : Specimen cracked (some separated) with particles attached to dowel.

B : Specimen cracked and dowel shearing off along the groove line inside the core.

C : Specimen did not crack and core sheared.

D : Specimen did not crack with dowel shearing off on the groove line inside the core.

E : The dowel sheared at the middle.

F : The dowel broke by split cut.

G : The dowel broke by sharp cut.

The Influence of Fitting Grade and Dowel-Joint Strength.

From the analysis of variance, dowel-joint strengths among fitting grades of dowels are not significant at 5 percent level of probability. The differences among fitting grades are not clearly evident because low density particle boards are porous, and although dowel specimens of higher density broke, they were included in the analysis.

The Influence of Dowel Length on Joint Strength.

When the dowel length was increased, the maximum absolute dowel-withdrawal-strength value was higher. On the other hand, the dowel joint strength per unit area tended to decrease because of uneven glue spread. In this study, since the absolute withdrawal strength became higher when the dowel length increased, and the strength of the beech dowel was lower than the absolute withdrawal strength, the dowel tended to break. Hence, especially in higher density board, the dowel joint strength tended to decrease.

GENERAL CONCLUSION

Within the limitations of this study, it may be concluded that particle boards above 0.5 specific gravity can be used for dowel jointing, and that with particle boards of high specific gravity, wood with compatible specific gravity must be used for dowel. With respect to the adhesives to be used for dowel jointing of porous materials such as particle board, a certain amount of extender must be added to the adhesives.

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パーティクルボードに関する研究（Ⅷ）

パーティクルボードの比重がダボ接着力におよぼす影響

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概　　要

パーティクルボードの緊結法として，ダボ接ぎによる緊結法の基礎データーを得るために，比重の異なるラワン・パーティクルボードを製造し，ボード比重がダボ接着力におよぼす影響を検討した。

予備試験において，ボード材質とボード端面の接着性を調べ，最適の接着剤塗付量と接着剤の種類を選んだ。ダボ接着力試験ではダボとしてスパイラル溝付圧縮ダボを使用し，ボード比重，嵌合度，ダボ埋込み深さの影響を検討した。

その結果，ボード比重が大になるにつれて，ダボ接着力は大となるが，ボード比重大なる場合は比重の大なる材質のダボを使用する必要が認められた。しかし嵌合度と埋込み深さは，ボードの多孔性ならびに高比重ボードの場合のダボ破壊に影響されて明瞭な差違が認められなかった。

なお，パーティクルボードにダボ緊結法を用いる場合は，0.5 以上の比重のボードが適当である。

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