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Flexural and Shear Properties of Structural Southern Pine 3-Ply Sandwich Wood Panels

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Flexural and Shear Properties Of Structural Southern Pine 3-Ply Sandwich Wood Panels

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INTRODUCTION

SANDWICH WOOD PANELS with particleboard cores have been used in furniture primarily as non-structural components faced with decorative hardwood veneers or plastic laminates. However, the authors are proposing a structural sandwich wood panel with a particleboard core and softwood veneer faces for use in construction of houses and for other structural applications.

This structural wood panel combines structural efficiency with favorable manufacturing cost. By utilizing lower quality wood such as residues from other wood industries and species in less commercial demand, it also helps conserve our forest resources.

Ordinarily, sandwich panels are constructed with faces that are stronger, stiffer, and denser than their cores. This provides structural efficiency in flexure and increases strength/weight and stiffness/weight ratios when these characteristics are important factors in a design. The proposed structural sandwich wood panels are nonconventional only in that core densities are higher than those of the faces. This adds some extra weight to the panel and proportionally increases transportation costs and, perhaps, handling costs on the construction site. These disadvantages, however, are offset by favorable manufacturing costs in comparison to plywood, by higher shear rigidities and by the important factor of contribution to conservation of forest resources.

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Structural wood panels for floors must support primarily uniform and concentrated loads applied perpendicular to the plane of the panel with face grain orientation perpendicular to the direction of supporting joists. Structural wood panels for wall and roof sheathing must resist both flexure and lateral shear loads in the plane of the panel.

Thus, flexural properties of sandwich strips were determined representing three types of sandwich. A flexural analysis, applied previously to plywood strips, also was used here to predict flexural stiffness of sandwich strips at various spans. In addition, shear plate tests were conducted for each sandwich type to determine the edgewise shear modulus. An elementary method also was applied to predict the edgewise shear modulus of the sandwich plates. For comparison, flexural and shear properties of two plywood thicknesses also were determined.

PROCEDURE

The following sandwich panels (4 feet × 8 feet) were fabricated in a southern pine plywood mill:

Sandwich panel total thickness inches	*S. Pine face thickness inches*	*Particleboard core, thickness inches*
7/8	1/8	5/8
5/8	1/8	3/8
0.71	1/6	3/8

The sandwich panels were fabricated in the following manner: Clear straight grain southern pine veneer, dried to less than 6 percent M.C. (moisture content), was used for all panels. Particleboard (underlayment quality) was used for cores after conditioning to approximately 7 percent M.C. Commercial grade, extended phenolic resin (similar to that used in manufacturing southern pine plywood) was used for gluing veneer faces to particleboard cores. Resin was applied only to the veneers. A spread of 85 pounds per MDGL was applied with a curtain coater. Sandwich panels were first cold pressed with 165 psi. for approximately 3 minutes, then pressed with 200 psi. at 295°F. for 5 minutes. Cured panels were cooled under pressure, then stored in a conditioned room at 65 percent R.H. and 72°F. until testing.

In addition, 5/8 inch and 7/8 inch southern pine plywood panels were made simultaneously with the sandwich panels under the same manufacturing conditions. The quality of all veneer used for these plywood panels was select, free of visible defects.

TESTING

From each sandwich and plywood panel, nine strip specimens were cut, each 3 inches wide and 20 inches long, and tested in flexure to failure with central loading and direction of face grain parallel to a 16 inch span. In addition, from each sandwich and plywood panel, seven flexure specimens were cut, each 3 inches wide and a length of 48 times their thickness plus 4 inches. These specimens were tested non-destructively in flexure at six span-to-depth ratios for determination of flatwise (interply) shear modulus (G_{xz}) according to a method used previously by Biblis *(2)*, *(3)*, and Biblis and Chiu *(4)*. For determination of edgewise shear modulus (G_{xy}), four small square shear panels were cut from each construction. Side length was 30 times the panel's thickness. This test was conducted according to ASTM-D805-63 *(1)*, as indicated in Figure 1. In addition, edgewise shear strength of each sandwich and plywood construction were determined by a rail shear test according to the method developed by the U.S. Forest Products Laboratory *(7)* primarily for hardboard. Edgewise shear and interply shear stresses on sandwich specimens are illustrated in Figure 2.

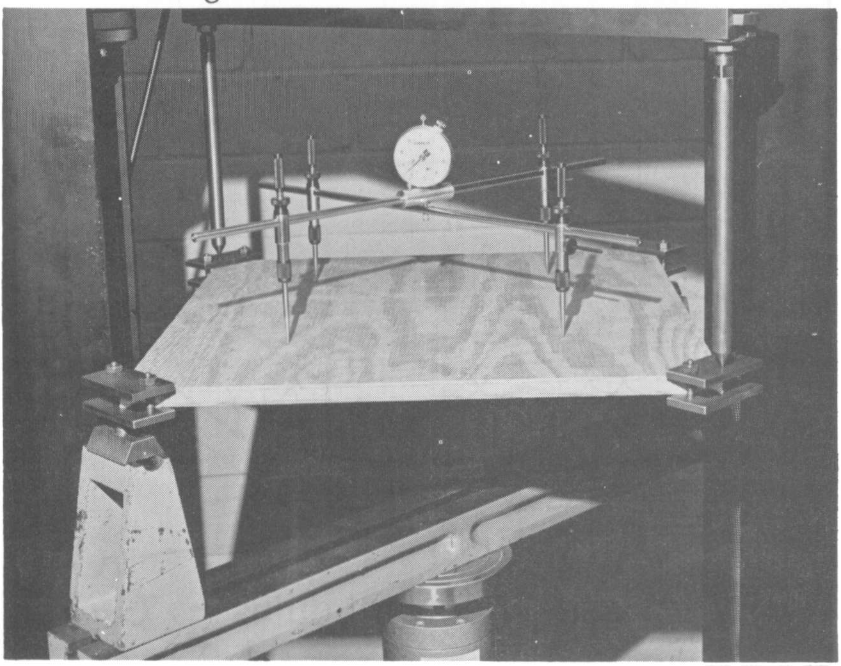

FIG. 1. Plate shear test used for determination of edgewise shear modulus of sandwich panels.

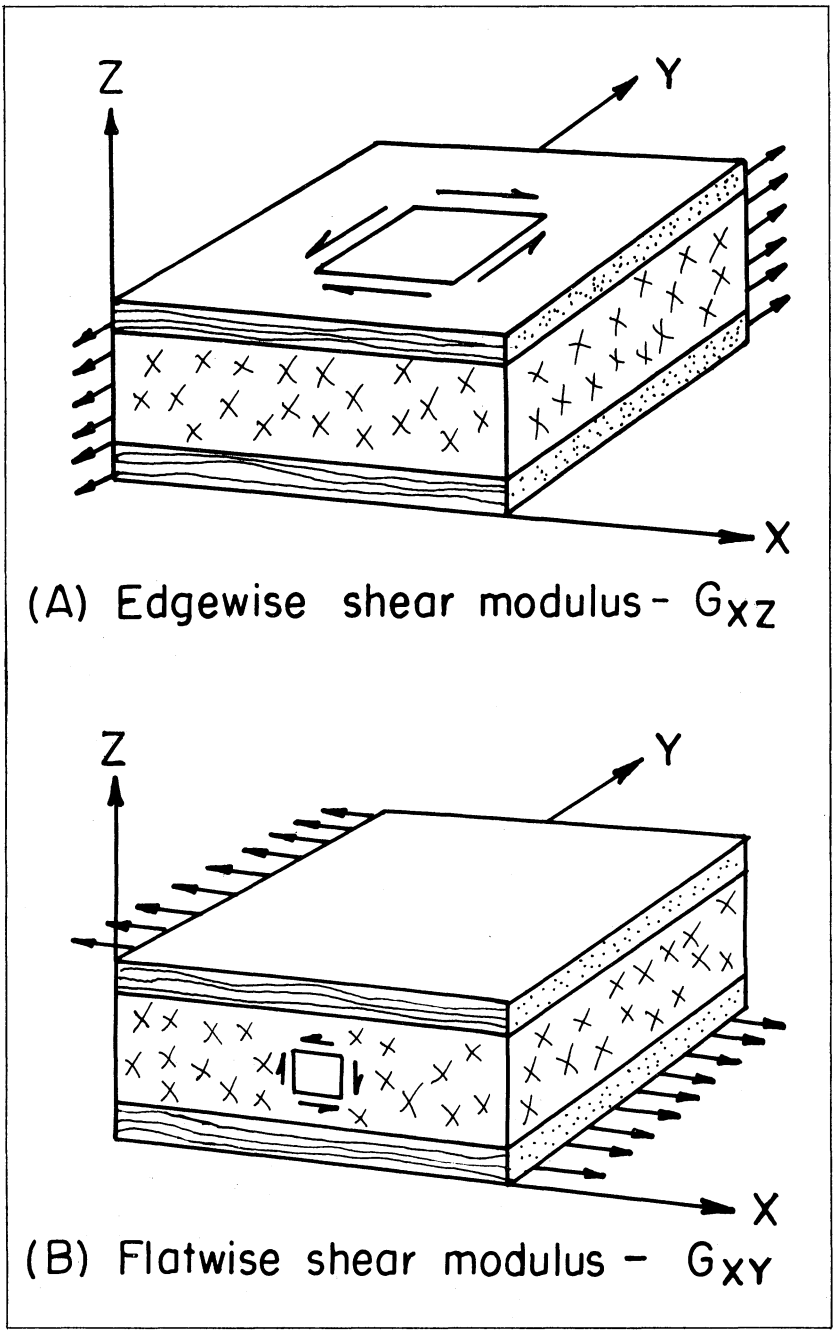

FIG. 2. Illustrations of edgewise and flatwise shear in a sandwich panel.

OBSERVED AND PREDICTED PROPERTIES

Flexure

From specimens tested to failure, the moduli of rupture (MOR) for the sandwich and plywood constructions are listed, along with the observed maximum midspan loads, in Table 1.

From specimens tested non-destructively in flexure at six span/depth ratios, values of pure modulus of elasticity (free of shear deformation) and values of flatwise modulus of rigidity (G_{xz}) for each construction were calculated according to the method used previously by Biblis *(2)* and listed in Table 1. For a more meaningful comparison of stiffness among the various sandwich and plywood constructions, Table 1 also lists the load required to cause 0.1 inch midspan deflection of each type specimen at a 16 inch span.

Experimentally determined values of MOE for each specimen type were plotted against span/depth ratios as shown in Figure 3. Observed values of midspan total deflection at proportional limit (P.L.) load for each type of specimen were predicted by a method which transforms the cross section of a sandwich specimen into a hypothetical cross section of a homogeneous I-beam of unidirectionally laminated veneer with grain direction parallel to span. The transformation is made by reducing the width of the particleboard core by the ratio of modulus of rigidity (flatwise) of the board core ($G_{xz.c}$) to that of face veneer ($G_{xz.f}$) thus by the ratio ($G_{xz.c}/G_{xz.f}$).[1]

Bending deflection of such an I-beam, when centrally loaded and freely supported at the ends, is calculated by the following equation derived by Newlin and Trayer *(8)*.

$$Y = (PL^3/48EI) + (KPL/G_{xz.f}) \qquad (1)$$

where: Y = total elastic deflection at mid-span, inches (in our calculations deflection at proportional limit load was predicted)

P = applied load at center to cause Y deflection, lbs.

L = span of specimen, inches

$EI = (E_f I_f + E_c I_c)$

E_f = pure modulus of elasticity of face veneer (grain parallel to span) p.s.i.

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[1] The first two subscripts designate the plane of shear stress, the third subscript designates core *c* or face *f*.

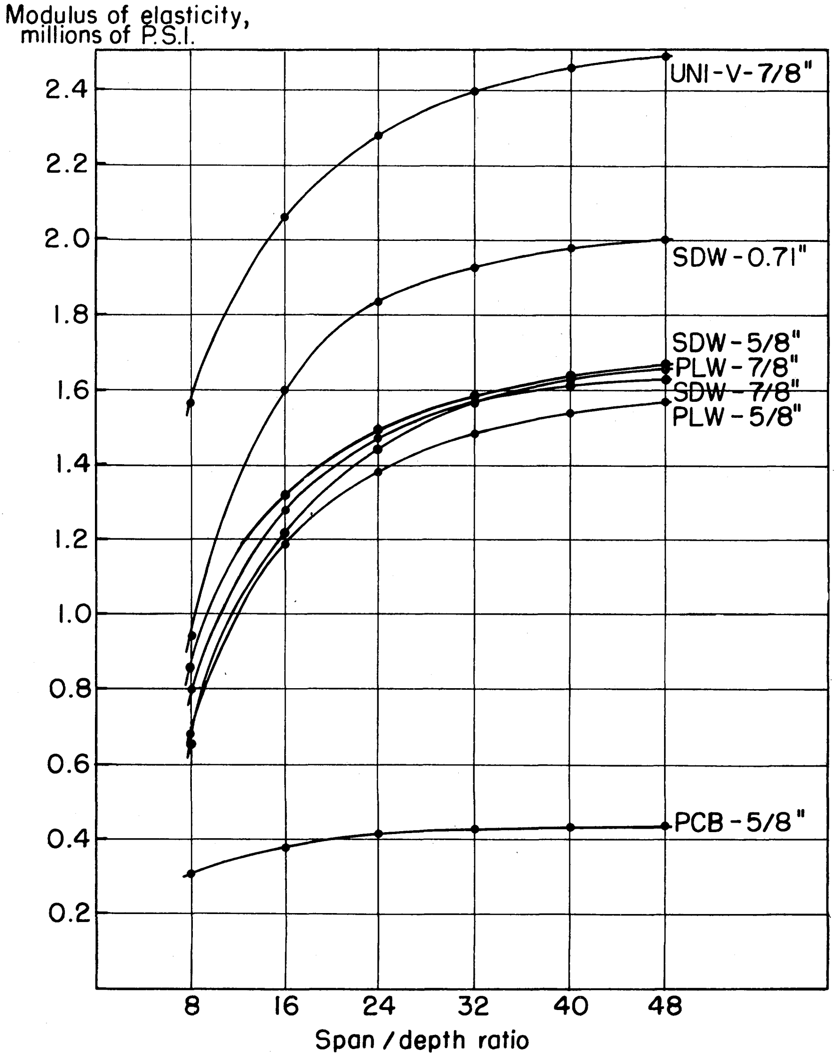

FIG. 3. Effective moduli of elasticity of various flexure specimens (strips) at six span-depth ratios. Face grain orientation of unidirectionally laminated veneer (UNI), sandwich (SDW) and plywood (PLW) strips was parallel to span. Particleboard specimens (PCB) were included for comparisons.

I_f = moment of inertia of face veneer, with respect to neutral axis of sandwich, inches^4

E_c = pure modulus of elasticity of particleboard core, p.s.i.

I_c = moment of inertia of core, with respect to neutral axis, inches^4

$G_{xz.f}$ = modulus of rigidity of face veneers (G_{LR}) determined from unidirectionally laminated veneer, p.s.i.

K = coefficient which according to Newlin and Trayer *(8)* can be calculated by the following simplified equation:

$$K = [1 + \frac{3/2\ (h^2_2 - h^2_1)\ h_1}{h^3_2} (\frac{b_2}{b_1} - 1\ )] \frac{h^2_2}{10I_t}$$

where: h_2 = distance of neutral axis to extreme fiber

h_1 = distance of neutral axis to flange

b_1 = reduced width of core of sandwich strip, (web of I-beam) = ($G_{xz.c}/G_{xz.f}$) b_2

b_2 = actual width of sandwich strip (width of flange of hypothetical I-beam)

I_t = moment of inertia of the transformed cross section (I-section) with respect to neutral axis.

The first term of equation (1) $PL^3/48EI$ represents deflection caused by pure bending. The second term ($KPL/G_{xz.f}$) represents shear deflection. Values of total observed deflection and predicted deflections by equation (1) (pure bending, shear and total) are listed in Table 2.

For each sandwich construction MOR values were predicted by the following equation: $MOR = MOR_f \frac{E}{E_f}$ (2)

where MOR and E correspond to properties of sandwich with face grain direction parallel to span, while MOR_f and E_f correspond to properties of veneer obtained from unidirectionally laminated face veneer tested with grain direction parallel to span. Equation (2) was first suggested (FPL-059, *(9)*) for estimating MOR of plywood at long spans. Estimated MOR values for the three sandwich constructions are listed in Table 3. Values of pure flexure E for each sandwich predicted by the following equation: $E = (E_f I_f + E_c I_c)/I$ and also listed in Table 3.

Table 1. Flexural Properties of Sandwich and Plywood Strips (3-Inch) With Face Grain Parallel to Span[1]

Type of specimen[2]	Pure modulus of elasticity, E	Modulus of rigidity, G_{xz} (flatwise)	Modulus of rupture, MOR		Maximum midspan[3] load, P	Load causing[3] 0.1″ midspan deflection	Effective modulus[3] of elasticity, E′	
	Psi	*Psi*	*Psi*	$s_{\bar{x}}$[4]	*Lb.*	*Lb.*	*Psi*	$s_{\bar{x}}$[4]
SDW-5/8″	1,656,550	25,360	11,730	683	572	106	1,479,580	109,290
SDW-.71″	2,047,120	33,510	12,580	638	788	186	1,790,160	44,430
SDW-7/8″	1,667,890	25,168	8,810	378	843	265	1,347,430	53,900
PLW-5/8″	1,613,000	20,320	9,930	225	485	101	1,408,300	58,320
PLW-7/8″	1,715,660	19,960	8,720	272	835	257	1,311,190	40,380

[1] Specimens were conditioned prior to testing at 65% R.H. and 72°F.
[2] SDW and PLW designate Sandwich and Plywood respectively.
[3] Load applied to specimens 3″ in width over 16″ span.
[4] $s_{\bar{x}}$ designates the sample standard error.

Table 2. Actual and Predicted Midspan Deflections at Proportional Limit Loads of 3″ Wide Sandwich Strips With Grain of Face Veneers Parallel to Span

Specimen construction	Span to depth ratio	Prop. limit load	Predicted pure bending deflection	Predicted shear deflection	Total deflection: Actual	Total deflection: Predicted	Total deflection: Error	Percentage of shear deflection to total
		Lb.	*In.*	*In.*	*In.*	*In.*	*Pct.*	*Pct.*
SDW-5/8″	48	160.7	.74709	.03286	.92446	.77995	−18.53	4.21
	24	321.4	.18677	.03286	.25393	.21963	−15.62	14.96
	14	551.0	.06356	.03286	.10648	.09642	−10.43	34.08
SDW-0.71″	48	190.2	.82883	.03735	.88474	.86618	− 2.14	4.31
	24	380.4	.20721	.03735	.24163	.24456	+ 1.21	15.27
	14	646.7	.07170	.03735	.10144	.10905	+ 7.50	34.25
SDW-7/8″	48	205.6	1.12517	.04374	1.17526	1.16891	− 0.54	3.74
	24	411.2	.28129	.04374	.32322	.32503	+ 0.56	13.46
	14	704.9	.09571	.04374	.13585	.13945	+ 2.65	31.36

Values of pure E and G_{xz} for veneer faces and particleboard core that were used in equation (1) were determined from additional tests and are listed in Table 4.

TABLE 3. PREDICTED VALUES OF PURE MOE AND MOR OF THREE TYPES OF SANDWICH STRIPS WITH FACE GRAIN PARALLEL TO SPAN

Type of specimen	Predicted pure modulus of elasticity, $E_{pred.}$	$\frac{E_{pred.}}{E_{act.}}$ [1]	Predicted modulus of rupture, $MOR_{pred.}$	$\frac{MOR_{pred.}}{MOR_{act.}}$ [1]
	Psi		*Psi*	
SDW-5/8"	1,982,540	1.196	11,660	0.994
SDW-.71"	2,117,870	1.034	12,450	0.990
SDW-7/8"	1,684,020	1.010	9,900	1.124

[1] Ratio of predicted value to actual value obtained from tests.

TABLE 4. FLEXURAL AND SHEAR PROPERTIES OF PARTICLEBOARD CORE AND VENEER FACES

Type of specimen	Pure modulus of elasticity, E	Flatwise modulus of rigidity, G_{xz}	Modulus of rupture, MOR
	Psi	*Psi*	*Psi*
Particleboard	406,500	20,655	1,980
Uni-laminated veneer	2,416,550	42,275	14,210

TABLE 5. EDGEWISE SHEAR PROPERTIES OF SANDWICH, PARTICLEBOARD CORE, AND FACE VENEER

Type of specimen[1]	Actual edgewise modulus of rigidity (G_{xy})act.	$s_{\bar{x}}$[2]	Edgewise shear strength	$s_{\bar{x}}$[2]	Predicted edgewise modulus of rigidity (G_{xy})pred.	$\frac{(G_{xy})pred.}{(G_{xy})act.}$
	Psi		*Psi*		*Psi*	
SDW-5/8"	131,050	3,395	1,125	37	128,140	0.978
SDW-.71"	123,680	4,225	1,010	42	124,570	1.007
SDW-7/8"	131,350	2,875	1,090	23	145,210	1.105
PCB-3/8"	148,410	3,250	930	20	-----	-----
PCB-5/8"	164,200	850	930	19	-----	-----
Face veneer	97,730	3,825	980	22	-----	-----

[1] SDW and PCB designate sandwich and particleboard respectively.
[2] $s_{\bar{x}}$ designates the sample standard error.

Edgewise Shear

Experimental values of edgewise shear modulus (G_{xy}) and edgewise shear strength for each sandwich and plywood construction are listed in Table 5. Edgewise shear modulus was obtained by plate shear test and calculated by the following equation:[2]

$$G_{xy} = \frac{3u^2P}{2h^3w} \qquad (3)$$

where: G_{xy} = edgewise shear modulus, psi
P = load applied to each corner, lbs.
u = distance from the center of the panel to the point where the deflection is measured, inches
h = thickness of plate, inches
w = deflection relative to center, inches

Edgewise shear modulus of each of the sandwiches was predicted by the following equation, which is a special form of a general equation proposed for plywood by the U.S. Forest Products Laboratory *(10)*.

$$G_{xy} = \frac{1}{h}\left(G_{xy.f}\, h_f + G_{xy.c}\, h_c\right) \qquad (4)$$

where: G_{xy} = edgewise shear modulus, psi
h = total thickness of sandwich plate, inches
$G_{xy.f}$ = edgewise modulus of rigidity of faces, psi. (determined from plywood plates of matched veneer)
h_f = thickness of veneer faces, inches
$G_{xy.c}$ = edgewise modulus of rigidity of core, psi. (determined from particleboard plates)
h_c = thickness of particleboard core, inches

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[2] Strictly speaking equation (3) is based on theory of isotropic plates. It has been used by March, Kuenzi, and Kommers *(6)* for orthotropic thin plates (plywood and specially sectioned wood) after making several specific assumptions with respect to geometry, fiber orientation, homogeneity, construction, and specific anisotropicity of these plates (March, *(5)*). The use of equation (3) here for sandwich plates is justified only for two reasons: First, it allows a direct comparison between plywood and sandwich plates through their respective G_{xy} values that were obtained by the same test method and equation. Second, use of equation (3) with the sandwich plate (a nonhomogeneous special orthotropic plate) does not violate the original assumptions any more than the use with plywood plates.

RESULTS

Actual MOR values obtained from tests of 5/8 inch and 7/8 inch sandwich specimens with face grain parallel to the span are larger than MOR values of equal thickness plywood. The larger MOR values of the sandwich constructions might be explained by the fact that the MOR value of the particleboard core is larger than that of crossband veneers in plywood.

The most efficient sandwich panel of the three is the one with a 3/8 inch particleboard core faced with 1/6 inch veneers. The MOR value of this sandwich (a measure of flexural strength in relation to its thickness) is 27 percent and 44 percent larger than 5/8 inch and 7/8 inch plywood.

The 7/8 inch thick sandwich (5/8 inch core + 1/8 inch faces) can carry larger maximum loads than either of the other two sandwiches or the 5/8 inch or 7/8 inch thick plywoods. MOR values of these sandwich specimens have been predicted with reasonable accuracy by an approximate formula.

Values of E for sandwich specimens tested with face grain direction parallel to the span are slightly larger than values of equal thickness plywood.

The total midspan deflection of the sandwich specimen was predicted accurately at three span/depth ratios with an approximate method which was developed and applied for plywood by the authors. Total deflections predicted by this method for two of the sandwich constructions are in excellent agreement with actual deflection values from tests. Total midspan deflections at three spans of the third sandwich type were predicted with errors varying from 10.5 percent to 18.5 percent.

Edgewise shear moduli G_{xy} of the sandwich panels are approximately 30 percent larger than those of plywood. This is attributable to the larger edgewise shear modulus of the particleboard core that contributes substantially to shear stiffness of the sandwich panel. Edgewise shear modulus of each sandwich construction was predicted very accurately from shear properties and thickness of components. Edgewise shear strength of sandwich panels was found to be higher than for particleboard cores or face veneers. This can be attributed only to the variability of veneer properties and, perhaps, of the particleboard.

CONCLUSIONS

Flexural stiffness and strength of structural sandwich wood panels with grain orientation of face veneer parallel to span can be predicted with accuracy at any span by elementary methods from properties and thickness of particleboard core and face veneer.

Edgewise moduli of rigidity of these structural sandwich panels also can be predicted very accurately with an elementary method from the properties and thickness of the components.

Modulus of rupture and modulus of elasticity values of 5/8 inch and 7/8 inch thick sandwich panels with grain orientation of face veneer parallel to the span are larger than corresponding values of plywood of equal thickness and veneer quality.

Edgewise shear moduli of all sandwich panels are approximately 30 percent larger than plywood panels of the same veneer quality.

The most efficient structural sandwich wood panel of those investigated is the one with a 3/8 inch particleboard core faced with 1/6 inch veneers. The MOR value of this sandwich is 27 percent and 44 percent larger than that of 5/8 inch and 7/8 inch plywood, respectively.

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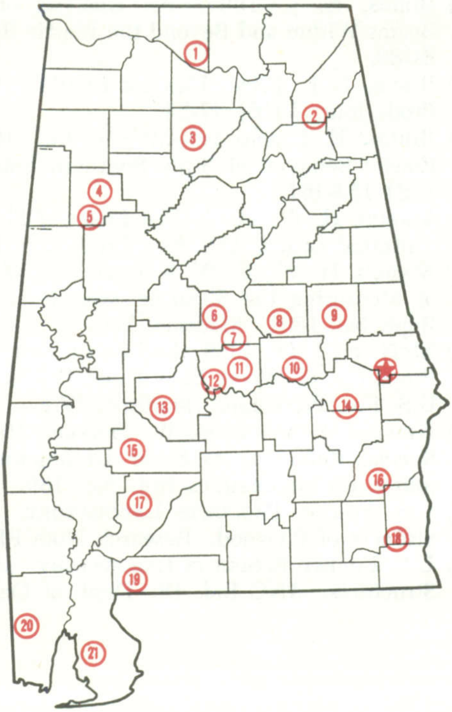

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