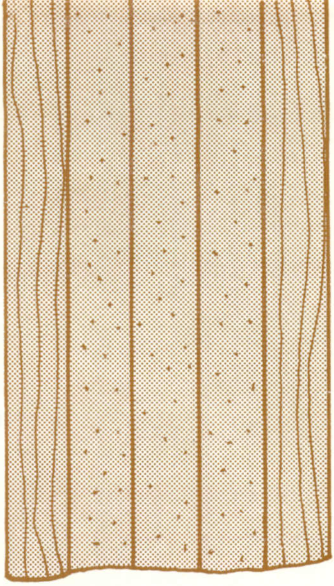
CIRCULAR 210
DECEMBER 1973



Comparison of FLEXURAL PROPERTIES and DIMENSIONAL STABILITIES of two constructions of 5/8-inch, 5-ply SOUTHERN PINE PLYWOOD

Agricultural Experiment Station
AUBURN UNIVERSITY
R. Dennis Rouse, *Director*   Auburn, Alabama

CONTENTS

FIRST PRINTING 3M, DECEMBER 1973

Comparison of Flexural Properties and Dimensional Stabilities Of Two Constructions of 5/8 Inch, 5-Ply Southern Pine Plywood

YEN MING CHIU and EVANGELOS J. BIBLIS[1]

PLYWOOD is generally defined as a laminated wood panel construction with an odd number of plies, where the grain of each ply is at right angles to the grain of adjacent plies and to the ends or edges of the panel. Presently more than 85 per cent of the total output of ½-inch southern pine plywood is manufactured as 4-ply construction. The construction of 4-ply plywood differs from the conventional concept of plywood construction in that an even number of plies is used, with the two inner plies parallel to each other to form a laminated center layer.

The American Plywood Association has recognized the structural feasibility of the new 4-ply plywood. New specifications for parallel laminated layers and revisions of panel constructions have been included in the proposed new revision of Product Standard PS-1-66 for softwood plywood *(1)*. In the revised specification, panel construction is stated in terms of layers instead of plies. Each layer may be composed of one or more parallel plies. The proposed new product specification allows greater flexibility for plywood construction and veneer combinations. Most panel grades up to ¾ inch thick can be manufactured with a minimum of three layers and with a minimum number of either three or four plies. Parallel laminated outer layers could consist of veneers 1/10 inch or thicker in any thickness combination up to a maximum layer thickness of ¼ inch. Parallel laminated inner layers could consist of veneers 1/16 inch or thicker in any thickness combination up to a total layer thickness of 3/8 inch. The proportion of veneers or layers with grain orientation perpendicular

[1] Research Associate, and Professor, Department of Forestry.

to face grain is specified to be between ⅓ and ⅔ of the total thickness. However, for panels with 4 or more plies, the combined thickness of all inner layers should not be less than ½ of the total panel thickness.

Studies concerning certain properties of ½-inch, 4-ply southern pine plywood construction were published in a previous report *(2)*. In this paper, the flexural properties and dimensional stability of two constructions of ⅝ inch, 5-ply southern pine plywood are compared. One is a new construction in that the middle three plies are laminated parallel to each other to form a middle layer with layer grain direction perpendicular to that of face plies. The other is the conventional 5-ply construction with grain directions of faces and core parallel to each other and grain direction of crossbands perpendicular to that of faces and core.

THEORETICAL CONSIDERATION

The flexural properties of plywood can be estimated from the properties of component plies and of the plywood construction as suggested and verified by the Forest Product Laboratory *(3)*. For example, the modulus of elasticity (MOE) of a plywood strip with long span is given by the following formula:

$$E = \frac{1}{I} \sum_{i=1}^{n} E_i I_i \qquad (1)$$

where I is the moment of inertia of the entire cross section about the neutral axis, E_i is modulus of elasticity of the *ith* ply and I_i is the moment of inertia of the *ith* ply about the neutral axis of the plywood strip. For 5-ply plywood of conventional construction (cross section shown in Figure 1):

$$E_{//} = \frac{E_L}{125}\left(26\frac{E_T}{E_L} + 99\right)$$

$$E_{\perp} = \frac{E_L}{125}\left(26 + 99\frac{E_T}{E_L}\right) \qquad (3)$$

For 5-ply plywood constructed with parallel laminated inner layer (cross section shown in Figure 2):

$$E_{//} = \frac{E_L}{125}\left(27\frac{E_T}{E_L} + 98\right) \qquad (4)$$

$$E_{\perp} = \frac{E_L}{125}\left(27 + 98\frac{E_T}{E_L}\right) \qquad (5)$$

where $E_{//}$ and $E_{\perp}$ are MOE of plywood strips with face grain orientation parallel and perpendicular to span respectively; E_L and E_T are MOE of rotary cut veneer parallel and perpendicular to grain direction respectively.

Assuming that E_L and E_T values of all plies are the same and that the ratio E_T/E_L is 0.04, the calculated $E_{//}$ of 5-ply plywood construction with parallel laminated inner layer is only 0.9 per cent smaller than $E_{//}$ of the conventional construction. The calculated $E_{\perp}$ of the construction with a parallel laminated inner layer is about 3 per cent higher. Therefore, the effect of grain orientation of the core ply of 5-plywood on stiffness appears to be insignificant. This is attributed to the fact that stiffness of plywood depends largely on the stiffness of faces. Maximum horizontal shear stresses, however, develop in the neutral plane of a strip. When the span/depth ratio of a plywood strip is less than 48, shear deflection begins to influence the stiffness. At low span/depth ratios, percentage of shear deflection becomes a significant part of the total deflection. Therefore, the orientations of inner-plies may be important when plywood is to be used in small span/depth ratios.

EXPERIMENTAL PROCEDURE

Three groups of 5/8 inch, 5-ply southern pine plywood panels (4 x 8 feet) were constructed in a plywood mill with rotary cut veneer all 1/8 inch thick, and bonded with a commercial extended phenolic adhesive. Each group consisted of four panels. The first group of panels was made with all select veneer, free of visible defects, in conventional construction (faces, crossbands, and core). The second group also was made with all select veneer, but was constructed with the three inner plies parallel to each other and perpendicular to the faces. The third group was of conventional construction, but with selected veneer in the faces only, while veneer of inner plies were grade-D with large knots, knot holes and other defects.

All panels were conditioned at 65 per cent R.H. and 74°F prior to testing. Panels were first tested nondestructively as full size panels over a 6-foot span for their MOE values. Two MOE values were obtained for each panel from two tests on the same panel, but loaded on the opposite sides. After the nondestructive test, each full size panel was cut into six smaller panels 15 inches in width and 48 inches in length. Half of the smaller panels were cut with face grain direction parallel to the length and the other half with face grain direction perpendicular to the length.

One small panel with face grain parallel to length was selected randomly from each of the first and second groups of panels and cut into seven 2-inch strip specimens. These strips were tested nondestructively in flexure at the following six span-to-depth ratios: 48, 32, 24, 18, 12, 8. From these tests, the effects of horizontal shear on the flexural stiffness of the two constructions were established. Pure modulus of elasticity (MOE) and modu-

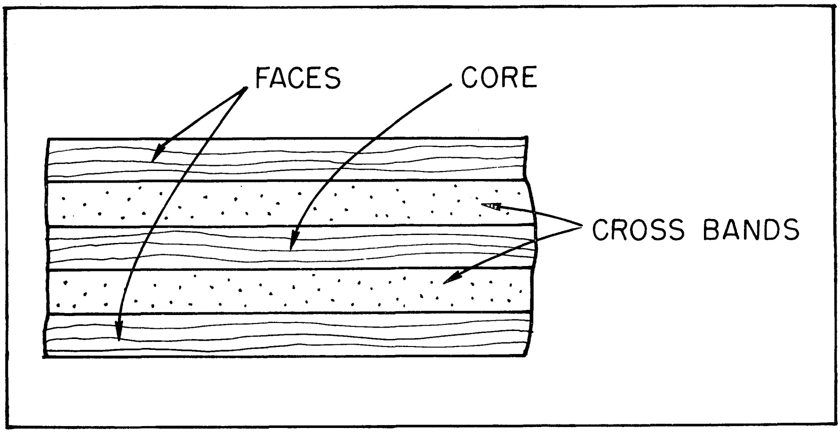


FIG. 1 5-ply plywood of conventional construction.

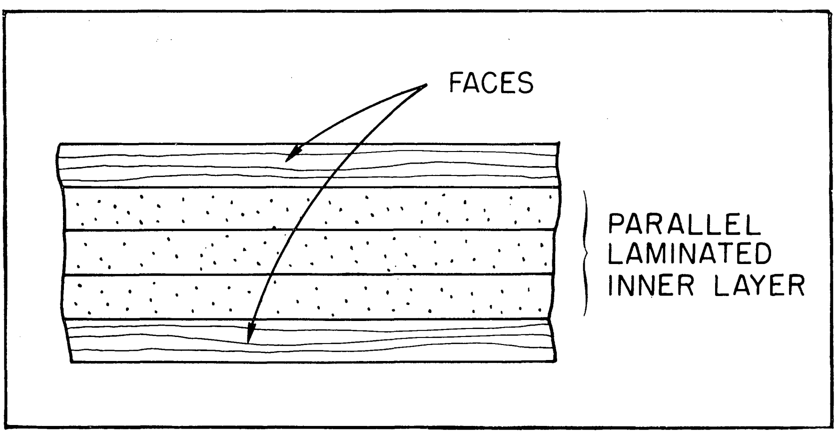


FIG. 2 5-ply plywood constructed with parallel laminated inner layer.

lus of rigidity (G) for each construction were determined according to a method used previously by the authors *(4,5)*. All other panels with parallel face grain and with perpendicular face grain were loaded on full width at midspan and tested destructively in flexure at 42½-inch span and 36-inch span respectively. MOE, MOR (modulus of rupture), and FSPL (fiber stresses at proportional limit) of each group of panels were obtained.

Twelve square panel specimens, 14½ x 14½ inches in size, were cut from the undamaged portions of some of the tested panels of the first and second groups for dimensional stability tests. Initial thickness, length (sides parallel to face grain orientation), and width (sides perpendicular to face grain orientation), and flatness (cupping and twisting) of each square panel were measured at equilibrium at 74°F and 65 per cent R.H. Then, the specimens were soaked in water for 48 hours and their dimensional changes and extent of warping were measured. The same specimens were reconditioned at 74°F and 65 per cent R.H. for 6 weeks to regain their initial equilibrium moisture level and the irreversible dimensional changes were measured.

RESULTS AND DISCUSSION

Results of nondestructive flexural tests of full size panels are shown in Table 1. The results show that Group 3 panels (conventional, grade-D inner plies) had the highest MOE value, followed by Group 1 panels (conventional, all select veneer) and Group 2 panels (parallel inner plies, all select veneer). However, statistical analyses of the results indicated that there was no significant difference between MOE values of Group 1 and Group 2 panels ($t = 1.555$, and d.f. $= 14$) and between MOE values of Group 1 and Group 3 panels ($t = 1.236$, and d.f. $= 14$). Stiffness of plywood parallel to face grain depends primarily on the stiffness of face plies which are subjected to most of the bending stresses. Stiffness was not significantly affected by either orientation or grade of inner plies.

Test results of small flexure panels of 15-inch width are shown in Table 2. Statistical comparisons of the results are shown in Table 3. Average value of MOE parallel to grain for each group was almost the same as value shown in Table 1 for corresponding groups. It is reasonable to expect that test results of small samples from a large panel will represent closely the property of the panel.

TABLE 1. FLEXURAL PROPERTIES OF FULL SIZE SOUTHERN PINE PLYWOOD PANELS (4 x 8 FT.) LOADED ON FULL WIDTH AT CENTER OF 6-FT. SPAN PARALLEL TO FACE GRAIN

Panel Group	Plywood construction	Panel I.D.	Modulus of elasticity		
			Side A	Side B	Average
			P.S.I.	*P.S.I.*	*P.S.I.*
1	5-ply, regular construction; all plies select veneer	1	2,111,030	2,061,940	
		2	1,803,890	2,193,920	
		3	2,138,780	2,339,290	2,118,600
		4	2,122,150	2,178,000	
2	5-ply, constructed with parallel laminated inner layer; all plies select veneer	1	2,132,180	2,184,180	
		2	1,620,110	1,563,260	
		3	2,029,190	2,078,690	1,963,600
		4	2,109,870	2,009,400	
3	5-ply, regular construction; face plies select veneer, inner plies D-grade veneer	1	2,306,180	2,121,680	
		2	2,355,560	2,001,590	
		3	2,087,340	2,180,110	2,207,700
		4	2,217,220	2,392,260	

TABLE 2. FLEXURAL PROPERTIES OF SOUTHERN PINE PLYWOOD PANELS OF 15-INCH WIDTH WITH SPANS OF 42.5 INCHES PARALLEL TO FACE GRAIN AND SPANS OF 36.0 INCHES PERPENDICULAR TO FACE GRAIN

Panel group	Plywood construction	Specific gravity (o.d.b.)	Orientation of face grain to span		MOE	MOR	FSPL
					P.S.I.	*P.S.I.*	*P.S.I.*
1	5-ply, regular construction; all plies selected veneer	.630	//	Av.	2,109,970	9,100	8,340
				$S_{\bar{x}}$[1]	61,190	445	445
			⊥	Av.	506,640	5,330	3,020
				$S_{\bar{x}}$	32,220	329	148
2	5-ply, constructed with parallel laminated inner layer; all plies select veneer	.620	//	Av.	1,964,900	8,050	7,020
				$S_{\bar{x}}$	39,145	360	429
			⊥	Av.	607,150	5,840	3,650
				$S_{\bar{x}}$	15,430	419	258
3	5-ply, regular construction; face plies select veneer, inner plies D-grade veneer	.624	//	Av.	2,177,710	10,590	7,960
				$S_{\bar{x}}$	105,260	320	534
			⊥	Av.	378,250	2,140	1,440
				$S_{\bar{x}}$	20,690	207	168

[1] $S_{\bar{x}}$ designates sample standard error of mean.

TABLE 3. COMPARISONS OF FLEXURAL PROPERTIES BETWEEN PLYWOOD GROUPS SHOWN IN TABLE 2 WITH "t"—TEST

Comparisons	Face grain orientation	Degree of freedom	Calculated "t"—values		
			MOE	MOR	FSPL
Group 1 vs. Group 2	//	14	1.77 n.s.	2.22*	2.03 n.s.
Group 1 vs. Group 3	//	15	—0.56 n.s.	—2.73*	0.54 n.s.
Group 2 vs Group 3	//	15	—1.59 n.s.	—5.18**	—1.26 n.s.
Group 1 vs. Group 2	⊥	16	—2.70*	—0.96 n.s.	—2.20*
Group 1 vs. Group 3	⊥	16	8.28**	8.21**	7.06**
Group 2 vs. Group 3	⊥	16	8.68**	8.19**	7.35**

n.s. Not significant.
* Significant at 5% probability level.
** Significant at 1% probability level.

The analysis of test results of the panels with face grain parallel to span indicated that values of MOE and FSPL of each group were not significantly different. Again this indicates that stiffness and elasticity of the panels, when loaded with face grain parallel to span, are not affected significantly by the quality and orientation of inner plies. MOR values of Group 1 panels were higher than those of Group 2 panels but lower than those of Group 3 panels. The lower MOR values of Group 2 may be explained by the effect of grain orientation of the parallel laminated inner layer. The high MOR values of Group 3, however, can be attributed only to the possibly higher strength of the face veneers. Thus, effect of face veneer properties on the strength of panels appeared to be greater than the effect of grade and construction of inner plies.

The analysis of test results of panels with face grain perpendicular to span indicates that all strength and stiffness properties of the panels were significantly different from one another except for MOR values between Group 1 and Group 2 panels. In panels with face grain perpendicular to span, face veneers contribute insignificantly to strength or stiffness. Panels of Group 2, with all three inner plies parallel to span, exhibited higher stiffness properties than Group panels with regular construction, but no significant difference between MOR values was found. Strength and stiffness properties of Group 3 panels were extremely low compared to Group 1 or Group 2 panels. It is apparent that the grade-D inner plies with many defects had a very significantly adverse effect on the perpendicular properties of Group 3 panels.

Results of 2-inch strips of Group 1 and Group 2 panels tested at six span/depth ratios with face grain parallel to span are shown in Figure 3. Pure MOE (stiffness free of shear) of Group 1 and Group 2 strips were 2,124,000 psi and 2,093,000 psi respectively. Moduli of rigidity (G) were 14,640 psi and 12,460 psi for Group 1 and Group 2 respectively. The MOE values were not significantly different, whereas the G value of strips of conventional construction was about 18 per cent greater than that of strips with a parallel laminated inner layer. Effective moduli of elasticity of both constructions decreased considerably at short spans compared to the MOE at a span/depth ratio of 48. How-

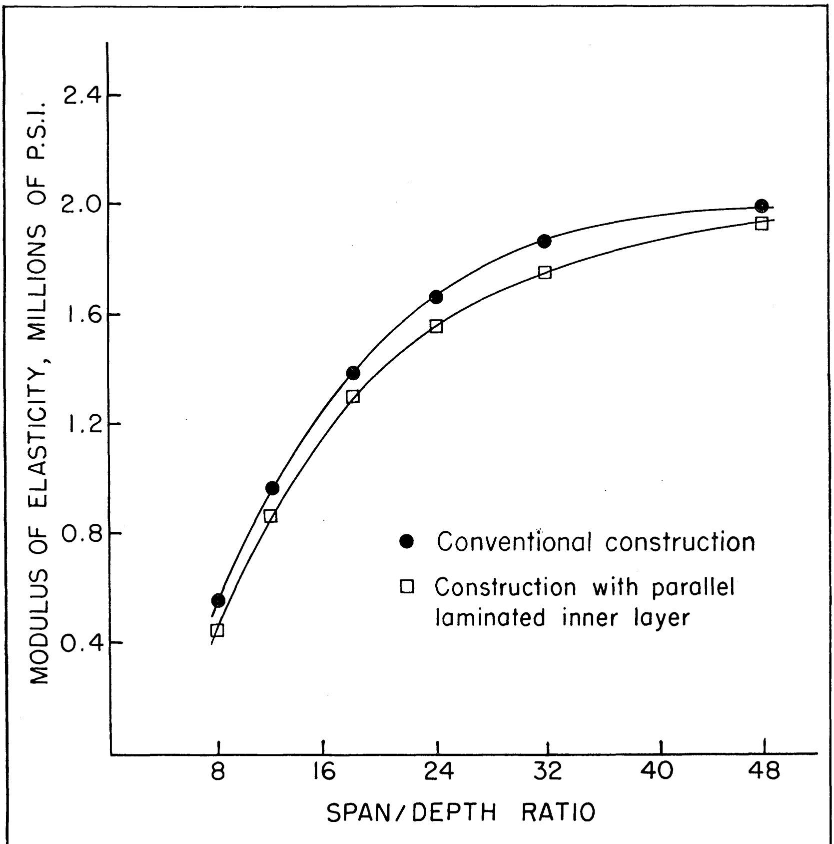


FIG. 3 Results of 2-inch strips of Group 1 and Group 2 panels tested at six span/depth ratios with face grain parallel to span.

TABLE 4. DIMENSIONAL CHANGES OF TWO TYPES OF 5/8", 5-PLY SOUTHERN PINE PLYWOOD PANELS (14.5" x 14.5") FROM EQUILIBRIUM CONDITION AT 65 PER CENT R.H. AND 74°F TO WET CONDITION

Panel group	Percentage of swelling[1]			Warping of panels[2]				
				Twisting at 4th corner	Cupping at middle-edge points			
	Thickness	Length	Width		A1	A2	B1	B2
				In.	*In.*	*In.*	*In.*	*In.*
1	8.79	0.26	0.45	0.078	0.055	0.023	0.023	0.018
2	8.31	0.47	0.40	0.083	0.005	0.010	0.094	0.027

[1] Length and width designate the directions parallel to and perpendicular to face grain respectively.
[2] Middle-edge points A1 and A2 lay on panel edges which are perpendicular to face grain direction. Middle-edge points B1 and B2 lay on panel edges which are parallel to face grain direction. The 4th corner is formed by edges A1 and B1 with the other three corners lay on a flat plane.

TABLE 5. IRREVERSIBLE DIMENSIONAL CHANGES OF TWO TYPES OF ⅝", 5-PLY SOUTHERN PINE PLYWOOD PANELS (14.5" x 14.5") RECONDITIONED FROM WET TO ORIGINAL EQUILIBRIUM CONDITION AT 65 PER CENT R.H. AND 74°F

Panel group	Percentage of swelling[1]			Warping of panels[2]				
				Twisting at 4th corner	Cupping at middle-edge points			
	Thickness	Length	Width		A1	A2	B1	B2
				In.	*In.*	*In.*	*In.*	*In.*
1	2.98	0.04	0.08	0.026	0.028	0.015	0.013	0.010
2	3.08	0.09	0.06	0.021	0.016	0.023	0.010	0.016

[1] Length and width designate the directions parallel to and perpendicular to face grain respectively.
[2] Middle-edge points A1 and A2 lay on panel edges which are perpendicular to face grain direction. Middle-edge points B1 and B2 lay on panel edges which are parallel to face grain direction. The 4th corner is formed by edges A1 and B1 with the other three corners lay on a plane.

ever, statistical comparisons did not show any significant difference between the stiffness of the two types of construction at each span.

Comparisons of dimensional stabilities of Group 1 and Group 2 panels after 48-hours soaking in water are shown in Table 4. Irreversible dimensional changes of the panels, after reconditioning to approximately 12 per cent M.C., are shown in Table 5. Results did not show any appreciable differences between the two constructions with respect to linear expansions and flatness of the panels, except that swelling along face grain direction of Group 1 was somewhat less than that of Group 2 panels. This slight advantage of Group 1 panels is due to the crossbands and core construction that offer greater restraint between adjacent plies. Whereas for Group 2 panels, there was little or no restraint among the parallel laminated inner plies.

SUMMARY AND CONCLUSIONS

Flexural properties and dimensional stability of two constructions of 5/8 inch, 5-ply southern pine plywood panels were compared. One construction was a new 5-ply construction with a parallel laminated inner layer. The other construction was the conventional 5-ply construction with crossbands and core. Both groups were made of all select veneer that was free of defects. In addition to the above two groups a third group of conventional construction, but with D-grade inner plies was made and it's flexural properties were compared with the above two groups.

Results showed that stiffness and elasticity of panels tested with face grain orientation parallel to span were not affected significantly by the construction or quality of inner plies. Effect of variation in face veneer properties on the strength of panels appeared to be greater than the effect of construction and grade of inner plies, as indicated by the highest MOR-value of panels with grade-D inner plies. There was no significant difference of the effect of horizontal shear on effective stiffness at any span between panels of conventional construction and panels constructed with a parallel laminated inner layer.

Face veneer did not contribute significantly to strength or stiffness in panels with face grain perpendicular to span. Panels with D-grade inner plies had much lower MOE and MOR values than the other two groups. Panels with a parallel laminated inner layer exhibited higher stiffness than conventional panels, but there was no significant difference between their MOR-values.

Dimensional stabilities of the two types of constructions were similar, although the conventional construction showed slightly less linear expansion along face grain direction.

For all practical purpose, little or no difference in the flexural properties and dimensional stabilities between the two types of 5-ply plywood constructions can be expected when the natural variability of veneer properties in actual manufacturing is taken into account.

LITERATURE CITED

(1) American Plywood Association. Jan. 1972. Fifth Draft of Proposed Revision of Product Standard PS 1-66 for Softwood Plywood, Construction and Industrial. Tacoma, Washington.

(2) Biblis, E. J., S-T Hsu, and Y-M Chiu. 1972. Comparison of Certain Structural Properties among 3-ply, 4-ply and 5-ply, ½-in Southern Pine Plywood Sheathing. Wood and Fiber 4(1): 13-19.

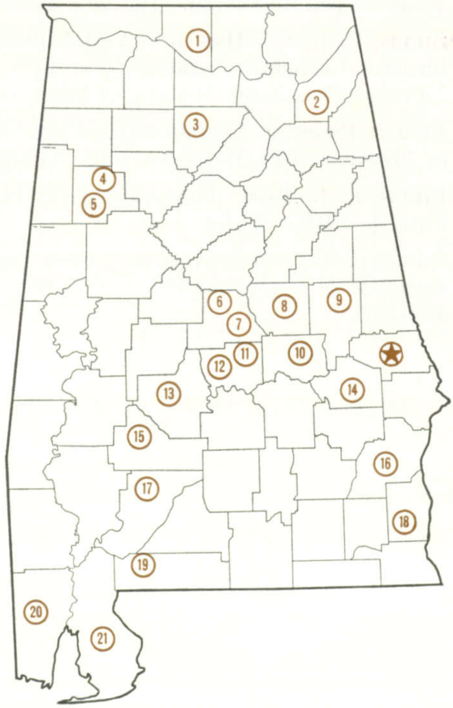
(3) Forest Product Laboratory. 1964. Bending Strength and Stiffness of Plywood. FPL-Rept. No. 059. Madison, Wis.

(4) Biblis, E. J. 1969. Flexural Rigidity of Southern Pine Plywood. For. Prod. J. 19(6): 47-54.

(5) Biblis, E. J. and Y-M Chiu. 1969. An Analysis of Flexural Elastic Behavior of 3-ply Southern Pine Plywood. Wood and Fiber 1(2): 154-161.

AGRICULTURAL EXPERIMENT STATION SYSTEM OF ALABAMA'S LAND-GRANT UNIVERSITY

With an agricultural research unit in every major soil area, Auburn University serves the needs of field crop, livestock, forestry, and horticultural producers in each region in Alabama. Every citizen of the State has a stake in this research program, since any advantage from new and more economical ways of producing and handling farm products directly benefits the consuming public.



Research Unit Identification

★ Main Agricultural Experiment Station, Auburn.

1. Tennessee Valley Substation, Belle Mina.
2. Sand Mountain Substation, Crossville.
3. North Alabama Horticulture Substation, Cullman.
4. Upper Coastal Plain Substation, Winfield.
5. Forestry Unit, Fayette County.
6. Thorsby Foundation Seed Stocks Farm, Thorsby.
7. Chilton Area Horticulture Substation, Clanton.
8. Forestry Unit, Coosa County.
9. Piedmont Substation, Camp Hill.
10. Plant Breeding Unit, Tallassee.
11. Forestry Unit, Autauga County.
12. Prattville Experiment Field, Prattville.
13. Black Belt Substation, Marion Junction.
14. Tuskegee Experiment Field, Tuskegee.
15. Lower Coastal Plain Substation, Camden.
16. Forestry Unit, Barbour County.
17. Monroeville Experiment Field, Monroeville.
18. Wiregrass Substation, Headland.
19. Brewton Experiment Field, Brewton.
20. Ornamental Horticulture Field Station, Spring Hill.
21. Gulf Coast Substation, Fairhope.