COMPARISON OF CERTAIN STRUCTURAL PROPERTIES AMONG 3-PLY, 4-PLY AND 5-PLY, ½-INCH SOUTHERN PINE PLYWOOD SHEATHING[1]

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ABSTRACT

An evaluation of three constructions 3-ply, 4-ply and 5-ply, ½-inch-thick southern yellow pine plywood sheathing as subfloor and roof was made. The evaluation considered only flexural properties, panel shear properties and dimensional stability in relation to panel cost, though other properties are recognized as being important too.

Among the three constructions considered, the 3-ply can support higher flexural loads and deflect less as subflooring than can the 4-ply and 5-ply constructions when panels used with face grain orientation parallel to span (perpendicular to the direction of joists). Specifically, at 16-inch spans, flexural strength and stiffness of 3-ply panels are approximately 8% higher than those of 4-ply panels while the manufacturing cost of 3-ply plywood is approximately 5–8% less than the manufacturing cost of 4-ply.

Although the 3-ply construction exhibits significantly larger dimensional changes than the two other constructions, it appears that would not create any trouble if used as subflooring, since changes of moisture conditions in modern housing are not large enough to produce appreciable internal stresses.

Wood floor systems for residential housing in the U. S. A. have undergone substantial changes within the last twenty years and there are certain indications that even more changes will take place in the future. Originally, floors consisted of a two-layer system that later changed, to some degree, to a one-layer system. Recently a new two-layer floor system, plus the finish flooring, has become popular.

The original two-layered floor consisted of a subfloor of 1-inch × 6-inch wood boards, usually placed diagonally to the joists, with a second layer flooring or finish flooring placed on the subfloor but laid crosswise to the floor joists (Anderson 1967; Anderson and Heyer 1955). This second layer usually was hardwood strip flooring, which was available in a variety of widths and thicknesses.

The introduction and almost general acceptance of "wall to wall" carpeting resulted in a substantial reduction of hardwood finish flooring. The new floor systems associated with a carpeted finish floor also caused a substantial reduction in wood board subfloors. Such systems were also two-layered, but made of plywood consisting of (a) standard ½-inch plywood as a subfloor, and (b) plywood underlayment, ⅜-inch thick. Plywood subfloors with an advantage of reduced installation cost replaced most of the solid wood board subfloors. Plywood underlayment and a cover of flexible tile or carpet replaced most of hardwood finish floor.

The two-layered plywood floor eventually was replaced by one-layered plywood floor, ¾-inch or ⅝-inch thick. However, the one-layered plywood floor did not provide full customer satisfaction, apparently because of the significant reduction in total thickness. Thus, the currently most acceptable flooring system is a new two-layered system combining both plywood and particleboard. This latest two-layered floor consists of (a) a plywood subfloor,

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½-inch thick, and (b) a particleboard underlayment, ⅝-inch thick, for a total thickness of 1⅛-inch.

The objective of this paper is to present an evaluation of three constructions of ½-inch-thick southern yellow pine plywood sheathing as subfloor in a two-layered floor, and as roof sheathing. The evaluation considers only flexural properties, panel shear properties, and dimensional stability in relation to panel cost, though other properties, such as heat and sound insulation, and dynamic frequency characteristics are recognized as being important.

Construction of ½-inch-thick southern yellow pine sheathing has been manufactured in the past mostly as 5-ply, with all plies ⅒-inch in thickness. A small percentage was and still is manufactured as 3-ply, with all plies ⅙-inch in thickness. Presently, however, more than 80% of the total production output is manufactured as 4-ply, with all plies ⅛-inch in thickness. This construction of 4-ply plywood is basically the same as that of 3-ply, since the grain orientation of the two middle plies is parallel to one another, but perpendicular to that of the faces. Manufacturers of 4-ply southern yellow pine plywood claim that 4-ply panels remain flatter. It is also claimed that manufacturing 4-ply ½-inch sheathing results in fewer hot delaminations (blowups) after release from the hot press.

In view of the ever-increasing demand for wood in housing construction and for other wood products while timber supplies are limited, designs for efficient utilization of wood in every product should be made. Furthermore, consumers of wood products demand assurance of end-use performance at a minimum inplace cost. Therefore, a comparison of end-use performance among the three constructions of ½-inch-thick southern yellow pine plywood sheathing for subfloor and roof in relation to their cost is justified. A similar comparison between 3-ply and 5-ply constructions of ½-inch western softwood plywood made in the past clearly illustrated the advantages of the 3-ply construction to both producer and consumer (Whyte 1962).

USE REQUIREMENTS OF PLYWOOD PANELS FOR SUBFLOOR AND ROOF SHEATHING

Primarily, panels must support uniform and concentrated loads applied perpendicular to the panel's plane with face grain orientation parallel to the span of support. Panels also must remain dimensionally stable, retain their original flat form under a normal range of relative humidity and temperature fluctuations, and thus remain firmly in place. Of structural importance, particularly for roof plywood panels, is the ability to support lateral shear loads in the plane of the panel.

There are additional important requirements that have not been investigated in this study, such as the ability to withstand impact loads, to hold various types of fasteners, and to provide some heat and sound insulation.

Consideration of the flexural characteristics of the three constructions

Flexural strength and stiffness of plywood utilized with face grain orientation parallel to the span[2], as in the case of subfloor and roof sheathing, depend largely on the relative thickness of the plies with a grain orientation parallel to span and on the location of these plies relative to the neutral axis. Thus, the ratio of the moment of inertia of the plies with grain parallel to span to the moment of inertia of the entire section is very important. The larger this ratio is, the greater are the flexural properties. In the 3-ply construction (all plies ⅙-inch thickness), this ratio of moments of inertia is larger than a similar ratio in the 4-ply (all ⅛-inch) and 5-ply (all ⅒-inch) constructions. Similarly, this ratio of inertias is larger in the 4-ply than in the 5-ply construction. Therefore, flexural strength and stiffness parallel to the face grain orientation are expected to

[2] That is, the direction of face grain, along the 8-ft panel length, is oriented perpendicular to the direction of supporting joists.

be higher in the 3-ply, intermediate in the 4-ply, and lowest in the 5-ply construction.

On the other hand, the production cost of each of the three constructions varies, since the 5-ply has 4 glue lines, the 4-ply has 3 glue lines, and the 3-ply has only 2 glue lines. Also other manufacturing costs, such as for veneer peeling, veneer sorting, assembling, and curing increase with decreasing veneer thickness. It has been estimated by several manufacturers of southern pine plywood that overall manufacturing costs of 3-ply construction are approximately 15% lower than those of 5-ply, and 8% lower than those of 4-ply construction. A similar study concerned with properties and costs of 3-ply and 5-ply, ½-inch-thick plywood sheathing of western softwoods reported that manufacturing cost of the 3-ply construction was approximately 10% below that of the 5-ply (Whyte 1962).

Consideration of the dimensional stability of the three constructions

Shrinkage or swelling of plywood, parallel and perpendicular to face grain orientation, depends on (a) the ratios of ply thickness in the two directions and (b) on the number of plies. It is therefore expected that the difference in shrinkage or swelling per cent in the two directions of 5-ply, ½-inch-thick plywood would be less than those of the 4-ply and 3-ply constructions. Similarly, difference in directional changes of 4-ply would be smaller than that of 3-ply construction.

Plywood panel twisting could be a serious utilization problem. Twisting is primarily caused by grain deviation among parallel plies. In 5-ply construction, grain deviation of crossbands (nonparallelism among crossbands) is usually the cause of twisting. In 3-ply construction, grain deviation of faces (nonparallelism of faces) is the usual cause of twisting. Generally, plywood construction with a larger number of plies minimizes twisting because of the effect of additional glue lines and the averaging out of grain deviations (F. P. L.-0136, 1966; F. P. L.-064, 1964). Thus panels of 5-ply constructions are expected to be flatter than those of the 4-ply and 3-ply constructions under the same moisture content changes. Similarly panels of the 4-ply construction are expected to be flatter than those of the 3-ply.

Consideration of panel shear strength and shear modulus

Structural plywood components, including roof panels, resist shear stresses acting in planes perpendicular to the panel (through the thickness) or in the plane of the panel (edgewise shear) as a result of shear forces applied to the panel's edges. There is no information available related to panel shear properties of southern pine plywood (edgewise and perpendicular to the plane of panel) particularly on the effect of the number of plies, while information exists on panel shear properties of other species (Norris, Werren, and McKinnon 1961; Post 1968).

EXPERIMENTAL DATA

a) Plywood construction

Nine panels 4 × 8 ft, ½-inch-thick of southern yellow pine plywood were constructed in a plywood mill. All veneer was peeled from a single tree of loblolly pine (*Pinus taeda,* L.). The first log (nearest the tree base) was rotary cut into ⅒-inch-thick veneer from which three 5-ply panels were constructed. The second log was rotary cut into ⅙-inch-thick veneer from which three 3-ply panels were constructed. The third log (from the ground) was cut into ⅛-inch-thick veneer from which three 4-ply panels were made.[3] All veneer used for the construction of all panels (faces, cores, and cross bands) was selected so as to be of equal quality, free from all visible defects. A commercial extended phenolic resin was used with 90 lb. spread per MDGL (1,000 square feet of double glue line) for bonding all panels. Panels

[3] This compounding of veneer thickness with log position was necessary because it was impractical to change knife setting while peeling the same log.

TABLE 1. *Average[1] flexural strength and stiffness values of ½-inch-thick plywood strips tested with face grain orientation parallel to span at a 48:1 span-to-depth ratio*

Plywood construction		Specific gravity (O.D.B.)	Moisture content %	Modulus of elasticity (psi)	Modulus of rupture (psi)
3-ply	Av.	0.61	8.5	1,945,300	11,480
	Sx[2]			90,990	219
4-ply	Av.	0.62	8.4	1,856,700	10,800
	Sx			31,800	286
5-ply	Av.	0.68	8.6	1,575,800	10,430
	Sx			21,500	286

[1] Each value represents average of 30 specimens.
[2] Sx designates the sample standard error.

were prepressed at room temperature with 160 psi. for 3 min and then hot pressed with 200 psi. at 285 F for 6½ min. Cured panels were cooled under pressure and then stored in a conditioned room at 50% RH and 73 F until testing.

b) *Flexural properties*

Ten plywood specimens were cut from each panel (3 panels × 3 constructions × 10 = 90 specimens altogether) and tested to failure in static bending with face grain orientation parallel to span, according to ASTM Standards D805–63. Flexural stiffness and strength at a 48:1 span-to-depth ratio were calculated for each specimen. Average values for each property and for each construction are shown in Table 1.

In addition, five other specimens were cut from each panel (3 panels × 3 constructions × 5 = 45 specimens altogether) for another series of static bending tests with face grain parallel to span. From these series of tests, the stiffness of each plywood construction was determined at the following span-to-depth ratios: 48, 32, 24, 14, 11 and 8, shown in Fig. 1. From the same series of tests, the moduli of rigidity for each construction were determined according to a method used previously by Biblis (1969).

Test results (Table 1) show that the 3-ply plywood over a 24-inch span, a span-to-depth ratio of 48:1, is 4.8% stiffer and 6.3% stronger than 4-ply plywood. Over the same span, the 3-ply construction is 23.4% stiffer and 10% stronger than 5-ply plywood construction. Over a 16-inch span, a span-to-depth ratio of 32:1 that plywood sheathing is commonly used in residential housing, the 3-ply construction is approximately 8 and 23% stiffer than 4-ply and 5-ply construction, respectively (Fig. 1).

It is therefore shown that, considering just the flexural requirements of ½-inch-thick structural plywood for subfloor and roof sheathing, the 3-ply construction is the most suitable. This is because it can

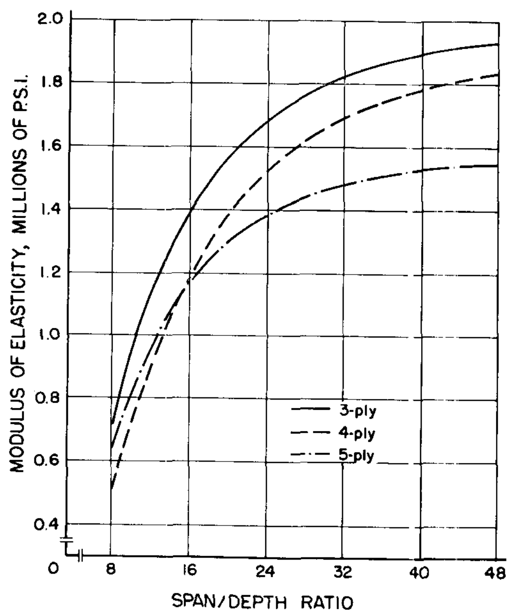

FIG. 1. Effective module of elasticity of 3-ply, 4-ply, and 5-ply, ½-inch-thick southern pine plywood flexure specimens with face grain parallel to span.

TABLE 2. *Dimensional changes of ½-inch-thick 15 inch × 15 inch southern yellow pine plywood panels changing from 12% MC to 24% MC*

	Percentage of swelling			Warping of panels				
				Twisting	Cupping at middle-edge points[1]			
Plywood construction	Thickness	Length	Width	At 4th corner[2] (inches)	A_1 (inches)	A_2 (inches)	B_1 (inches)	B_2 (inches)
3-ply	5.10	0.058	0.446	0.5260	0.3298	0.0382	0.2275	0.0122
4-ply	7.17	0.023	0.162	0.1059	0.0746	0.0086	0.0612	0.0173
5-ply	7.62	0.045	0.134	0.0180	0.0157	0.0179	0.0157	0.0102

[1] Middle-edge points A_1 and A_2 lay on panel edges which are perpendicular to face grain direction.
[2] The 4th corner formed by edges A_1 and B_1.

support higher loads, will deflect less, and costs less than 4-ply and 5-ply constructions of the same thickness.

c) *Dimensional stability*

Ten 15-inch × 15-inch panel specimens, with face grain orientation parallel to two opposite edges, were cut from panels of each plywood construction. These panels were used to determine dimensional stability as well as for panel shear tests (described below) at two moisture conditions; the original being 12% MC and the final 24% MC. Thus, the evaluation of dimensional stability of the three types of construction was made between the above moisture content limits. Percentages of swelling in thickness, in length (parallel to face grain orientation) and in width (perpendicular to face grain orientation) for each construction are shown in Table 2.

Generally, the results show no significant difference in per cent shrinkage between the 4-ply and 5-ply construction. This fact suggests that the 4-ply construction in this respect is more efficient since it costs less than the 5-ply construction. Per cent shrinkage of the 3-ply construction is significantly higher than that of the other two constructions.

In Table 2 are also shown results of panel warping for each plywood construction caused by same changes in moisture conditions. It should be noted that all test panels had small unavoidable grain deviations, but were of the same magnitude in all three constructions. Twisting is indicated by the deviation of the fourth corner from the plane defined by the other three corners of the panel. Edge cupping is indicated by the deviation of middle-edge point from the three corner plane. Results indicate that the 5-ply construction is almost free of twisting and cupping. The 3-ply construction developed a significant amount of twisting (fourth corner deviation more than ½ inch) and considerable edge cupping. The 4-ply construction developed a small amount of twisting and edge cupping that can be characterized as stable construction. Results indicate here again that panels with 4-ply construction can perform in service just as well as the 5-ply. The amount of twisting of the 3-ply construction, however, should cause some concern, particularly for its utilization as roof sheathing. This degree of twisting indicates that installed 3-ply roof panels could develop internal stresses that may have an effect on the roof. However, an increase in the number of nails to restrain the twisting forces might be more economical than the extra cost of the 4-ply construction.

For utilization as subflooring, the dimensional changes of the 3-ply construction should not cause any particular problem for the following reasons: (a) in modern housing, variations in moisture conditions are not so large as to cause the same dimensional changes and internal stresses as those in the test; (b) subfloor panels in modern housing are additionally restrained by the underlayment and adhesive used in modern installation of subflooring.

TABLE 3. *Average value of edgewise shear properties and interply shear modulus of ½-inch-thick plywood of three constructions*

Plywood construction		Specific gravity (O.D.B.)	Edgewise shear: Shear strength: Parallel to grain (psi)	Edgewise shear: Shear strength: Perpendicular to grain (psi)	Edgewise shear: Modulus of rigidity (psi)	Interply modulus of rigidity (psi)
3-ply	Av.	0.61	979	977	94,120	20,860
	Sx		23	10	2,200	—
4-ply	Av.	0.62	930	928	93,680	13,430
	Sx		18	13	1,450	—
5-ply	Av.	0.68	1007	1035	105,380	20,320
	Sx		24	30	1,610	—

Panel shear properties

For the evaluation of panel shear properties, three types of specimens were prepared and tested. One group of specimens was used to test edgewise shear strength, and the other two groups were used to test moduli of rigidity, each for different shear plane. Edgewise shear strength was evaluated by the rail shear test specimens (shear through panel thickness) for each of the three constructions. Specimen size and shape, as well as test procedures, were chosen to correspond with those used at the U. S. Forest Products Lab. (McNatt 1969). Thirty edgewise shear test specimens were cut from each of the three plywood constructions. One-half were tested with face grain orientation parallel, the other half perpendicular to the load direction. All specimens were tested at approximately 12% moisture content.

Results of the test shown in Table 3 indicate that edgewise shear strength is essentially the same whether the face grain orientation is parallel or perpendicular to the direction of shear load. However, shear strength differences among the three constructions were found. Shear strength of the 5-ply is 9.6 and 4.3% greater than that of 4-ply and 3-ply, respectively. The higher shear strength of 5-ply construction is probably attributed to its higher specific gravity. Shear strength of the 3-ply is approximately 5% larger than that of 4-ply construction. Thus, the results indicate that the 3-ply construction could satisfy edgewise shear design requirements for ½-inch-thick panel at a lower cost.

Edgewise shear modulus (rigidity) for each construction was evaluated by the plate shear test according to ASTM Standards D805–63. Ten square panel specimens from each construction (the same specimens used for dimensional stability test) were tested at approximately 12% moisture content. Results from this test, shown in Table 3, indicate that edgewise shear modulus for the 5-ply construction is approximately 12 and 12.5% higher than that of the 3-ply and 4-ply constructions, respectively. It is also indicated that 3-ply construction can provide equal edgewise shear rigidity at lower cost than can the 4-ply construction.

Finally, the shear modulus (rigidity) of interply shear[4] for each construction was evaluated according to a method used previously by Biblis (1969). This method requires the determination of the effective flexure moduli of elasticity at various short span-to-depth ratios. Fifteen specimens from each construction were tested at five spans, at approximately 8.5% moisture content. Results from these tests, shown in Table 3, indicate that interply shear moduli (rigidity) for 3-ply and 5-ply constructions are approximately 36 and 34% higher,

[4] Shear within the entire thickness of panel, with shear plane oriented perpendicular to panel's plane.

respectively, than for the 4-ply construction. The results also indicated that the 3-ply construction has approximately 3% higher interply shear modulus (rigidity) than does the 5-ply construction.

SUMMARY AND CONCLUSIONS

It appears that among the three plywood constructions (3-ply, 4-ply, and 5-ply) of ½-inch-thick southern yellow pine plywood considered the 3-ply construction is the most efficient for subflooring. That is, the 3-ply plywood construction would perform better at a lower cost. Among the three constructions, the 3-ply can support higher flexural loads and deflect less as subflooring than can the 4-ply and 5-ply constructions when panels are used with face grain orientation paralled to span (perpendicular to the direction of joists). Specificially, at 16-inch spans, flexural strength and stiffness of 3-ply panels are approximately 8% higher than those of 4-ply panels while the manufacturing cost of 3-ply plywood is approximately 5–8% less than the manufacturing cost of 4-ply.

Similarly, results indicate that the 5-ply construction is inefficient for subflooring when compared to the manufacturing cost and the flexural properties of either 3-ply or 4-ply constructions. Flexural strength and stiffness (with face grain orientation parallel to span) of 5-ply construction over 16-inch spans are 10 and 21% lower, respectively, than corresponding properties of 3-ply plywood, while the manufacturing cost of 5-ply is approximately 10–15% higher than the cost of the 3-ply.

Although the 3-ply construction exhibits significantly larger dimensional changes than the two other constructions, it appears that would not create any trouble if used as subflooring, since changes of moisture conditions in modern housing are not large enough to produce appreciable internal stresses.

For utilization as roof sheathing, where moisture changes are not controlled as well as subflooring, dimensional changes of the 3-ply construction could cause some trouble, and therefore the 4-ply construction becomes more desirable and very competitive. Development of internal stresses in the 3-ply construction when used as roof sheathing could be restrained by additional nailing. This, however, increases installation cost. The question therefore remains whether the cost of additional nailing of 3-ply roof sheathing exceeds the difference in cost between 3-ply and 4-ply construction.

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