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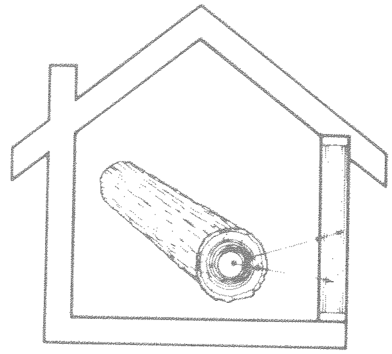

COM-PLY® REPORT 16

STRUCTURAL PERFORMANCE OF COM-PLY STUDS MADE WITH HARDWOOD VENEERS

COOPERATIVE RESEARCH

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STRUCTURAL PERFORMANCE OF COM-PLY STUDS MADE WITH HARDWOOD VENEERS

by

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Cooperative Research by
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and
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and Standards

PREFACE

This report is one of a series on the possibilities of producing house framing and structural panels with particleboard cores and veneer facings. These COM-PLY or composite materials were designed to be used interchangeably with conventional lumber and plywood in homes. Research on structural framing was initially limited to COM-PLY studs but has now been extended to include larger members such as floor joists.

In 1973, the home-building industry faced a shortage of lumber and plywood and consequent rising prices. Both industry and government recognized that this situation was not a temporary problem, and that long-range plans for better using the Nation's available forest resources would be necessary.

The Forest Service of the U.S. Department of Agriculture and the U.S. Department of Housing and Urban Development accelerated cooperative research on ways to utilize the whole tree. They concentrated on composite wood products made with particleboard and veneer as a way of using not only more of the tree stem, but also using less desirable trees and a greater variety of tree species than would conventional wood products. The particleboard which comprises a large portion of COM-PLY studs and joists is made from chipped-up wood that comes from forest residues, mill residues, or low-quality timber. Thus, such composites could greatly increase the amount of lumber and plywood available for residential construction, our major use of wood, without eroding the Nation's timber supply.

Research on composite wall and floor framing was performed by the Wood Products Research Unit, Southeastern Forest Experiment Station, Athens, Georgia. The American Plywood Association cooperated in these studies by designing and testing composite panel products that are interchangeable with plywood. Both types of products have been incorporated in demonstration houses.

Included in this series will be reports on structural properties, durability, dimensional stability, strength, and stiffness of composite studs and joists. Other reports will describe the overall project, compare the strength of composite and solid wood lumber, suggest performance standards for composite lumber, and provide construction details on houses incorporating such lumber. Still others will explore the economic feasibility of manufacturing composite lumber and panels and estimate the amount and quality of veneer available from southern pines. These reports, called the COM-PLY series, will be available from the Southeastern Forest Experiment Station and the U.S. Department of Housing and Urban Development.

CONTENTS

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STRUCTURAL PERFORMANCE OF COM-PLY STUDS MADE WITH HARDWOOD VENEERS

ABSTRACT.—COM-PLY 2 x 4 studs made with veneers of yellow-poplar, sweetgum, and white oak were tested for strength and stiffness, nail-holding properties, modulus of elasticity of component parts, static bending, and compression parallel and perpendicular to the grain. All tests were conducted according to performance standards for composite studs used in exterior walls or ASTM standards. Results indicated that the tested properties of COM-PLY 2 × 4's with any of the three hardwood veneers are comparable to those of COM-PLY 2 × 4's with southern pine veneers and to 2 × 4's of solid wood.

KEYWORDS: Modulus of elasticity, strength, stiffness, bending, compression, nail-holding ability, veneer, particleboard.

The Forest Service, U.S. Department of Agriculture, the Department of Housing and Urban Development, and several manufacturers of forest products have cooperated in developing a new composite lumber product. This product, the COM-PLY stud, is a structural sandwich with a particleboard core placed between layers of solid wood veneer.

The major use of forest products is in residential and commercial construction. Almost all of the wood products used in construction are softwoods. This dependence on softwoods is based on their availability, ease of drying and nailing, and generally lighter weight in comparison with hardwoods. Projections indicate that the future demand for softwood products will exceed supply.

Forested land in the United States is predominantly in hardwoods. If future demands for forest products are to be satisfied, methods must be found to use more of our hardwood resource. Select hardwood lumber and veneer have always had a ready market for use in furniture, cabinets, and paneling. For centuries, the hardwood forests have been selectively cut—the high-value trees have been taken and the culls and less desirable species have been left. Consequently, the residual hardwood stands would require more money to harvest and prepare for restocking than would accrue from selling the harvested timber for conventional processing.

The COM-PLY approach to manufacturing composite lumber and panels is ideally suited to the efficient use of hardwood stands. Composite products reduce or eliminate the major problems with hardwood utilization—long drying times, poor dimensional stability, and the difficulty of obtaining large sizes and long lengths of lumber. Since 60 to 80 percent of a COM-PLY product consists of the particleboard core, such products can utilize low-quality forest or manufacturing residues.

There is an abundant supply of several species of hardwoods that are not being used. Consequently, potential manufacturers and users of COM-PLY studs need to know about the structural performance of COM-PLY studs made with hardwood veneers. COM-PLY studs might be used for blocking, posts, headers, beams, or plates. Engineers and building code officials need to know whether COM-PLY studs made from hardwood veneers have sufficient structural strength for these uses.

The strength properties of greatest interest are (1) suitability for use as studs as measured by a performance test of strength and stiffness; (2) working stresses for extreme fiber in bending as measured by a static bending test; (3) axial load-bearing capacity, or strength in compression parallel to the grain; (4) bearing, or strength in compression perpendicular to the grain of the face plies; and (5) nail-holding ability.

This report, directed principally to designers and engineers, describes how the above strength and mechanical properties were determined for COM-PLY studs made with three species of hardwood veneers. This report is closely related to COM-PLY Report 12, "Structural Properties of COM-PLY Studs," which discusses the characteristics of COM-PLY studs made with softwood veneers (McAlister 1978).

MATERIALS

Yellow-poplar (*Liriodendron tulipifera* L.), sweetgum (*Liquidambar styraciflua* L.), and white oak (*Quercus alba* L.) make up over 50 percent of the volume of hardwood stands in the Piedmont of the Southeastern United States. We selected these three species for testing as the veneer components of COM-PLY studs.

The test studs were fabricated with 1/6-inch-thick veneers which were available from a veneer grade-yield study. Performance standards for composite studs (Blomquist and others 1976) specify that a sample of 10 studs be used to test performance. We decided on the basis of previous tests that a sample of five studs would be sufficient to determine structural properties. Thus, for our series of tests, 15 COM-PLY studs were needed for each hardwood species, or 45 COM-PLY studs in all.

To relate modulus of elasticity (MOE) of the stud components to the physical properties of the assembled COM-PLY studs, we had to determine the MOE of the components before the studs were fabricated. We randomly selected 64 strips of veneer of each species to represent all veneer cut from tree diameter classes of 12 to 20 inches. All strips were 1.5 inches wide, 96 inches long, and nominally 1/6 inch thick. All of the veneer had been conditioned to equilibrium moisture content at 70°F and 40 percent relative humidity.

We used the stress-wave method of determining dynamic modulus of elasticity (MOE_d) for each strip. This method has been described by Koch and Woodson (1968).

The veneer strips were then laminated together into pairs with a phenol-resorcinol adhesive according to the procedures of Vick (1977). The strips were laminated together in predetermined order (strip 1 to strip 2, . . . strip 63 to strip 64) so that the MOE of each component strip was known. After laminating, the MOE_d of each laminate was determined by the stress-wave technique.

The core material used in this study was a phenolic-bonded particleboard 1½ inches thick. The particleboard had an average density of 40 lb/ft^3, an internal bond of 75 lb/in^2, an MOE (in plane of panel) of 300,000 lb/in^2, and contained 8 percent phenolic resin binder throughout the three layers.

Cores for COM-PLY studs were ripped to a width of 2.83 inches. We determined the MOE of the core as a beam 1.5 inches wide and 2.83 inches deep by center-loading as a simple beam over a span of 90 inches. Deflections at midspan were measured to the nearest 0.001 inch for loads of 10, 20, and 30 pounds. We used a dial gage mounted on a yoke to measure the deflections. To calculate the MOE in bending (MOE_b), we subtracted the deflection at 10 pounds of load from the deflection at 30 pounds of load and determined the slope of the load/deflection curve for this 20-pound increment. The MOE_d of the veneer strips and the MOE_b of the particleboard core were used in all calculations.

The two-ply strips were laminated to the cores with the odd-numbered strips to the outside of the assembled stud. Thus, the position of each ply in each stud was known. The gluing procedures used in fabricating the COM-PLY studs had proved satisfactory in previous studies (Vick 1977).

After fabrication, 10 studs from each species group were selected at random for the performance testing. The remaining five studs were cut into segments for the strength tests, as shown in figure 1.

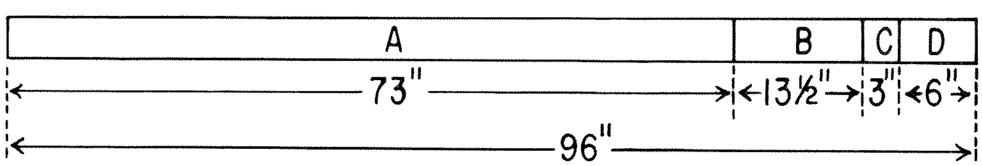

Figure 1.—Location of stud segments for the three strength tests: A, static bending; B, compression parallel to the grain; C, not used; D, compression perpendicular to the grain.

Properties of transformed sections were calculated for all studs according to the method found satisfactory in a previous study (McAlister 1978). Transformed sections were used to calculate all allowable strength properties except static bending.

PERFORMANCE TESTS

METHODS

We conducted the performance tests according to the procedures outlined in "Performance Standards for Composite Studs Used in Exterior Walls" (Blomquist and others 1976). In addition to the combined axial and transverse loading specified, all studs were first tested on edge in static bending under limited load. We used quarter-point loading over a 90-inch span to a maximum load of 250 pounds to determine the bending stiffness factor or EI. To calculate the EI of the COM-PLY studs, we subtracted the deflection under 100 pounds of load from the deflection at 200 pounds of load and calculated the slope of the load/deflection curve for the resulting 100-pound load increment.

RESULTS

The results of the performance tests and the static bending tests under limited load for COM-PLY studs made from yellow-poplar, sweetgum, and white oak veneer are shown in table 1.

The predicted EI was higher than the actual EI for the yellow-poplar and sweetgum studs and lower than the actual EI for the white oak studs. The predicted EI values averaged within 7 percent of the actual EI values. Somewhat closer predictions could be made if the dynamic MOE of the veneers were corrected to tensile MOE. Note that the transformed moment of inertia, I_t, is a little more than half the geometric I of a 1.5-inch-wide by 3.5-inch-deep beam section.

The performance standards for composite studs (Blomquist and others 1976) specify test methods and the methods of calculating allowable loads and allowable deflection. Applying these procedures to the average deflections and maximum loads given in table 1 yields the results shown in table 2. COM-PLY studs with veneers of yellow-poplar, sweetgum, and white oak met the performance criteria. The values are comparable to the performance values of COM-PLY studs made with southern pine veneers.

We plotted load/deflection curves for each of the studs for the static bending and the combined loading tests (axial load of 1,190 pounds plus bending load). A typical plot of the two curves is shown in figure 2. Note that axial loading increases the stiffness of the COM-PLY studs because of the reaction moment at the fixed reaction block in this test.

STATIC BENDING

METHODS

We performed structural static bending tests according to the methods outlined in ASTM D 198-76 (ASTM 1978c). The test span was 69 inches with loads applied at one-third points by a universal testing machine. Head speed was maintained at 0.25 inch per minute. Height and width of the test segments were recorded to the nearest 0.001 inch. Deflections under load were determined by using a dial gage mounted on a yoke, and readings were taken to the nearest 0.001 inch at 100-pound load increments until the deflection was at least 0.500 inch. The gage and yoke were removed and the test was continued until failure. We recorded the time required to load the specimen to failure, the method of failure, and the maximum load.

We calculated the bending stiffness, EI_b, of the COM-PLY studs by subtracting the deflection at 100 pounds of load from the deflection at 300 pounds of load and determining the slope of the load/deflection curve for the resulting 200-pound increment.

RESULTS

The results of the structural static bending tests for the COM-PLY studs made with the three species of hardwood veneers are shown in table 3. The transformed moment of inertia (I_t) for the COM-PLY studs

Table 1.—Component MOE values, stiffness factors, and performance test results for COM-PLY studs made with three species of hardwood veneers

Veneer species	Stud No.	Component MOE			Transformed moment of inertia (I_t)	Bending stiffness (EI)		Performance values		
		Core MOE_b	Average strip MOE_d	Average laminate MOE_d		Predicted	Actual static bending	Deflection at 225 lb	Ultimate load	Ultimate load per foot of span (w)
		. . . . . . *Million lb/in²*			*In⁴*	*Million lb/in²*		*In*	*Lb*	*Lb/ft*
White oak	3	0.284	1.82	1.84	2.97	5.41	5.71	0.348	1,040	138.7
	4	.284	1.82	1.84	2.97	5.41	6.74	.232	1,340	178.7
	6	.285	1.98	2.09	2.93	5.80	5.93	.297	930	124.0
	7	.290	2.01	1.95	2.93	5.89	6.37	.268	1,210	161.3
	8	.259	2.26	2.28	2.85	6.44	6.74	.235	1,200	160.0
	9	.276	2.16	2.14	2.88	6.22	5.93	.314	1,000	133.3
	10	.281	2.10	2.11	2.91	6.11	6.41	.302	975	130.0
	11	.296	2.30	2.20	2.89	6.65	6.96	.298	1,310	174.7
	12	.290	2.07	2.16	2.91	6.02	6.61	.300	1,035	138.0
	14	.281	2.51	2.49	2.84	7.13	7.91	.248	1,150	153.3
	Avg.				2.91	6.11	6.53	.284	1,119	149.2
	SD					.0537	.6339	.0374	143.39	19.13
Yellow-poplar	16	.248	1.90	1.84	2.90	5.51	5.61	.385	800	106.7
	17	.274	1.98	1.99	2.92	5.78	5.35	.303	946	126.1
	18	.255	1.94	1.99	2.90	5.63	5.47	.376	824	109.9
	19	.294	2.22	2.14	2.90	6.44	6.29	.288	1,152	153.6
	20	.276	1.71	1.61	2.98	5.10	4.33	.436	560	74.7
	21	.307	1.94	1.87	2.97	5.76	5.74	.330	981	130.8
	22	.281	1.87	1.75	2.95	5.52	5.41	.337	912	121.6
	23	.272	2.18	2.06	2.88	6.28	5.74	.355	884	117.9
	25	.299	2.04	1.92	2.94	6.00	5.02	.342	885	118.0
	26	.289	2.01	1.90	2.93	5.89	5.27	.372	829	110.5
	Avg.				2.92	5.79	5.42	.352	877	116.98
	SD					.3908	.5138	.0427	150.58	20.07

Table 1.—Component MOE values, stiffness factors, and performance test results for COM-PLY studs made with three species of hardwood veneers—continued

Veneer species	Stud No.	Component MOE			Transformed moment of inertia (I_t)	Bending stiffness (EI)		Performance values		
		Core MOE_b	Average strip MOE_d	Average laminate MOE_d		Predicted	Actual static bending	Deflection at 225 lb	Ultimate load	Ultimate load per foot of span (w)
		..... *Million lb/in²*	......		*In⁴*	*Million lb/in²*		*In*	*Lb*	*Lb/ft*
Sweetgum	31	.298	1.76	1.70	3.01	5.30	5.07	.350	988	131.7
	32	.302	1.90	1.92	2.98	5.66	5.19	.350	973	129.7
	33	.285	1.86	1.79	2.96	5.51	5.17	.335	990	132.0
	34	.282	1.52	1.48	3.05	4.64	4.77	.354	912	121.6
	35	.252	1.72	1.66	2.94	5.06	4.72	.370	898	119.7
	36	.268	1.70	1.88	2.97	5.05	4.83	.397	835	111.3
	37	.255	1.83	1.82	2.92	5.34	5.17	.347	903	120.4
	39	.252	1.95	1.93	2.89	5.64	5.71	.308	910	121.3
	43	.306	1.82	1.78	3.00	5.46	5.25	.330	983	131.1
	45	.322	1.85	1.92	3.02	5.59	5.55	.310	956	127.5
	Avg.				2.98	5.32	5.14	.345	935	124.6
	SD					.3255	.3203	.0266	51.17	6.83

Table 2.—Summary of performance values for COM-PLY studs made with three species of hardwood veneers

Veneer species	Adjusted load (W*)	Adjusted midspan deflection (D**)
	Lb/ft	*In*
Yellow-poplar	44.6	0.377
Sweetgum	70.3	.360
White oak	67	.306

*W must be greater than 40 to pass performance standard.

**D must be less than 0.412 to pass performance standard.

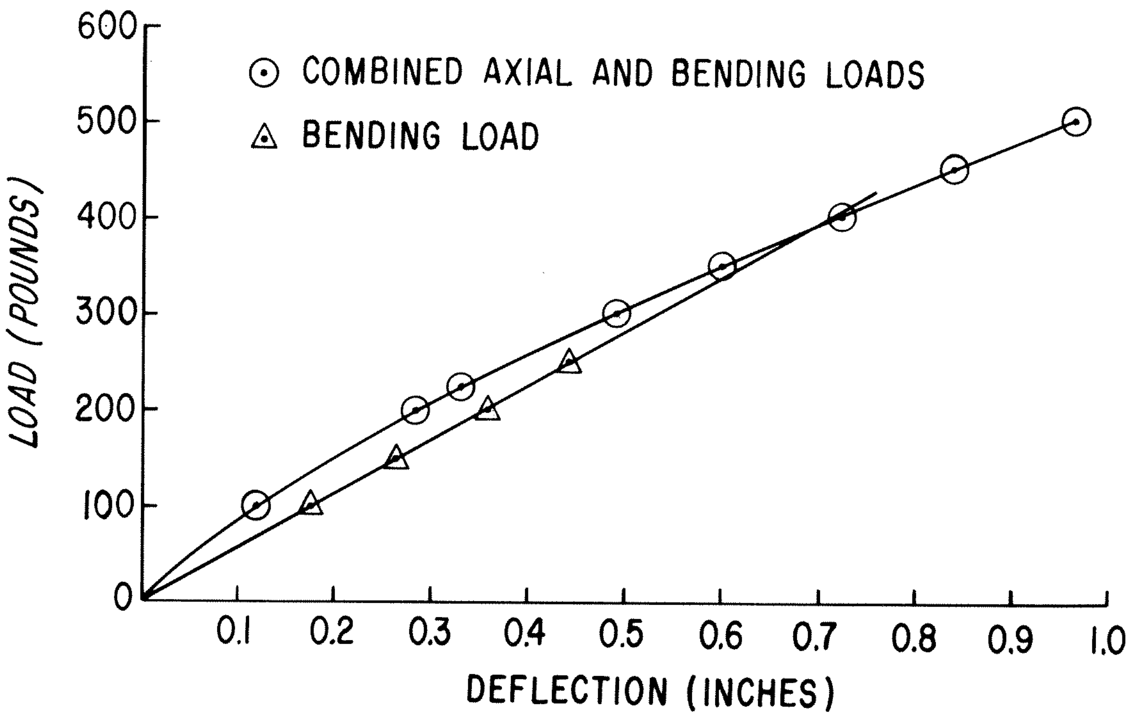

Figure 2.—Typical load/deflection curves for two methods of loading COM-PLY studs.

Table 3.—Results of structural static bending tests on COM-PLY studs made with three species of hardwood veneer as based on transformed section analysis

Veneer species	Stud No.	Average veneer MOE_d	Core MOE_b	Properties of transformed sections: Moment of inertia* (I_t)	Section modulus (S_t)	Area (A_t)	Bending stiffness (EI): Actual (EI_b)	Predicted** $(EI_b)_p$	Ultimate load	Maximum moment	Maximum fiber stress (MOR†)
		Million lb/in²		*In⁴*	*In³*	*In²*	*Million lb/in²*		*Lb*	*In-lb*	*Lb/in²*
White oak	1	2.02	0.280	3.33	1.49	1.72	6.37	6.73	1,653	19,010	5,871
	2	2.19	.311	3.48	1.55	1.78	6.66	7.62	1,675	19,262	5,870
	5	2.65	.301	3.30	1.46	1.63	5.89	8.74	1,470	16,905	5,132
	13	2.27	.283	3.38	1.50	1.69	6.78	7.67	1,375	15,812	4,825
	15	2.04	.237	3.20	1.42	1.61	5.95	6.53	1,450	16,675	5,207
	Avg.	2.23	.282	3.34	1.49	1.69	6.33	7.46	1,525	17,533	5,381
	SD	.255	.028	.101	.047	.069	.404	.881	132	1,522	469
Yellow-poplar	24	2.03	.285	3.19	1.44	1.68	5.45	6.48	1,365	15,698	4,970
	27	1.74	.274	3.17	1.45	1.73	5.35	5.52	1,160	13,340	4,229
	28	2.17	.285	3.26	1.46	1.68	6.41	7.07	1,560	17,940	5,564
	29	2.05	.319	3.34	1.52	1.78	5.50	6.85	845	9,718	3,017
	30	1.83	.276	3.44	1.55	1.80	5.14	6.29	1,285	14,778	4,481
	Avg.	1.96	.289	3.28	1.48	1.74	5.57	6.44	1,243	14,295	4,452
	SD	.175	.018	.113	.046	.057	.489	.599	266	3,056	950
Sweetgum	38	1.96	.252	3.12	1.41	1.63	5.14	6.12	990	11,385	3,537
	40	1.87	.258	3.14	1.42	1.66	4.96	5.87	1,215	13,972	4,427
	41	1.67	.312	3.33	1.54	1.88	4.88	5.56	1,160	13,340	4,218
	42	1.70	.319	3.30	1.53	1.88	4.48	5.61	875	10,062	3,165
	44	1.91	.316	3.20	1.47	1.77	5.03	6.11	1,245	14,318	4,508
	Avg.	1.82	.291	3.22	1.47	1.76	4.90	5.85	1,097	12,615	3,971
	SD	.129	.033	.091	.059	.118	.249	.266	158	1,823	591

*Transformed to average veneer MOE_d base.
**$(EI_b)_p$ = (Average veneer MOE_d) x (I_t).
†MOR calculated by using section modulus for 1.5-inch x 3.5-inch section.

averaged between 3.22 in^4 and 3.43 in^4. These values are somewhat greater than the 2.75 in^4 value found for COM-PLY studs made from slash pine veneer. Part of the difference is due to the generally lower MOE_d of the hardwood veneers in comparison with that of slash pine and also to the slightly greater depth (0.067 inch) of the studs made with the hardwood veneers.

The best predictor of actual bending stiffness (EI_b) for the COM-PLY studs was the average MOE_d of the four plies of veneer. There were species differences in the linear regression equations, as follows (all moduli in million lb/in^2):

Veneer species	Regression	Coefficient of determination
		r^2
Yellow-poplar	$EI_b = 1.299 + 2.175 \times$ (average veneer MOE_d)	0.61
Sweetgum	$EI_b = 2.135 + 1.516 \times$ (average veneer MOE_d)	.62
White oak	$EI_b = 7.330 - 0.447 \times$ (average veneer MOE_d)	.08
Slash pine	$EI_b = 2.43 + 1.53 \times$ (average veneer MOE_d)	.74

The regressions for yellow-poplar and sweetgum are quite similar, but there appears to be no linear relationship for the studs made from white oak veneers. The significant result is that the bending stiffness of COM-PLY studs made from yellow-poplar and sweetgum can be predicted with a good degree of accuracy.

There was little linear correlation between modulus of rupture (MOR) and average veneer MOE_d for COM-PLY studs made from hardwood veneers. This lack of correlation was surprising because there was a close correlation ($r^2 = 0.73$) found for this relationship in COM-PLY studs made from slash pine veneer.

The allowable bending stress based on rectangular section modulus and safe resisting moment in bending were calculated by a formula proposed in ASTM D 245-74 (ASTM 1978a):

$$\text{Allowable strength property} = \frac{\text{Average ultimate strength} - t_{0.05}\,(\text{SD, standard deviation})}{2.1}$$

where $t_{0.05} = 2.132$ for 4 degrees of freedom. A more conservative approach to establishing allowable stresses can be found in ASTM D 2915-74 (ASTM 1978b). The allowable stresses presented below apply only to COM-PLY studs made from materials with properties similar to those used in this study:

Veneer species	Average EI	Allowable fiber stress	Safe resisting moment
	.... *Lb/in²*	....	*In/lb*
Yellow-poplar	5.57×10^6	1,156	3,704
Sweetgum	4.90×10^6	1,291	4,156
White oak	6.33×10^6	2,086	6,804

A larger sample would tend to increase these allowable design values for COM-PLY studs made with hardwood veneers by decreasing the $t_{0.05}$ value and standard deviation.

The COM-PLY studs made from yellow-poplar and sweetgum have about half the allowable fiber stress value found for COM-PLY studs made from slash pine veneer. However, the values for studs made from yellow-poplar and sweetgum are higher than the 850 lb/in^2 allowable for stud-grade, kiln-dried studs of southern pine (NFPA 1977a).

TESTS OF COMPRESSION PARALLEL TO GRAIN

METHODS

A strength property of interest to engineers and designers is compression strength parallel to the long axis of the stud. Axial loading simulates the use of the stud as a column carrying compressive loads.

The procedure we used to test compression parallel to the veneer grain was based on the recommendation in ASTM D 198-76 (ASTM 1978c). Load was applied through a spherical loading head on a universal testing machine. We recorded deflections over a 6-inch gage length (to the nearest 0.0001 inch) for each 1,000-pound load increment until the COM-PLY column failed.

The load/deflection curve for each COM-PLY column was plotted so that the load at the proportional limit could be determined. A typical load/deflection curve is shown in figure 3. For each column we recorded ultimate load, the time needed to apply that load, and the weight of the section. All dimensions were measured and recorded to the nearest 0.001 inch.

RESULTS

The results of the compressive-load tests are shown in table 4. The average compressive strength (ultimate stress) for the short columns made from COM-PLY studs varied according to wood species, with

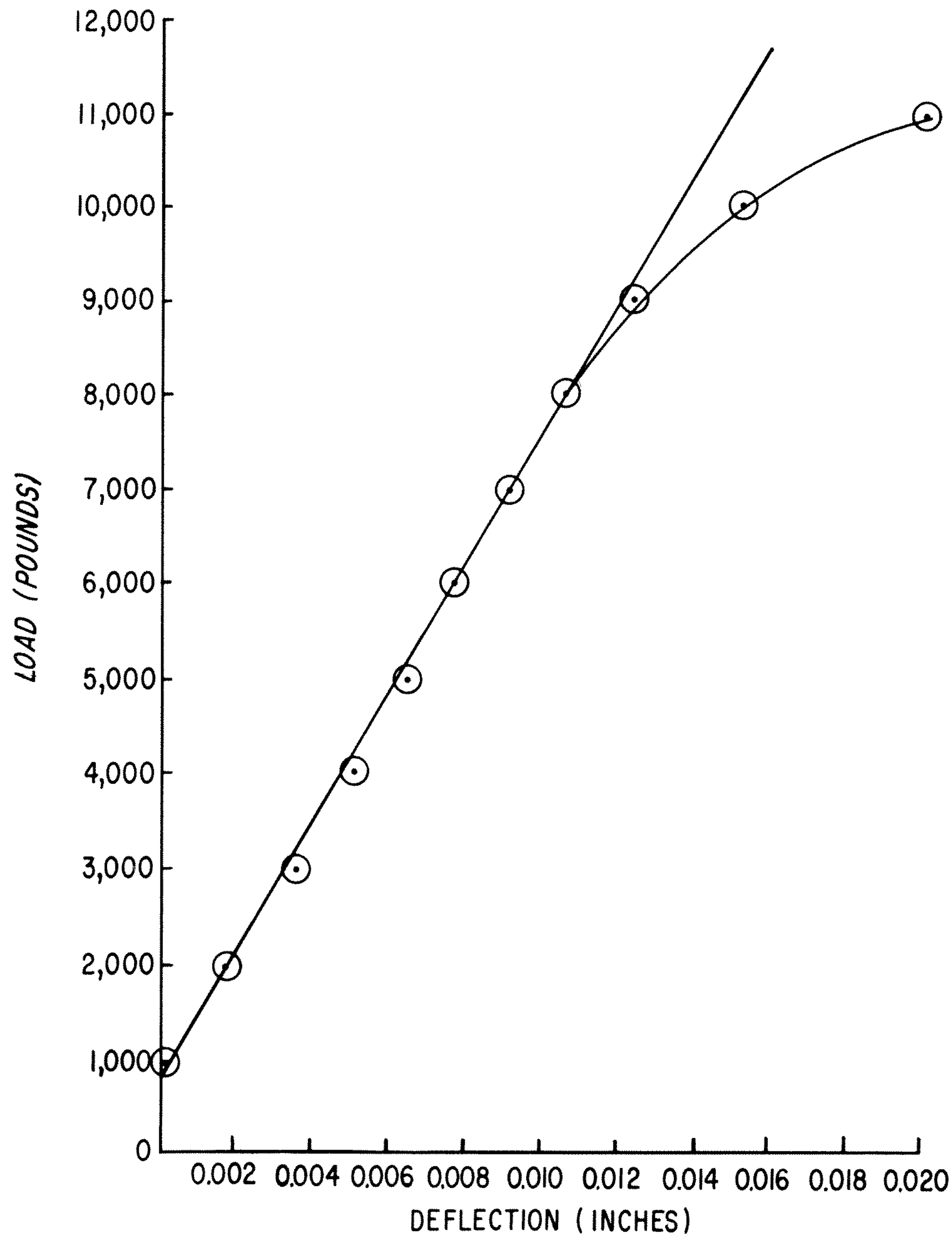

Figure 3.—Typical load/deflection curve for compression parallel to grain of COM-PLY studs made with hardwood veneers.

Table 4.—Values of compressive-load strength and stiffness for COM-PLY studs made with hardwood veneers as based on transformed areas

Veneer species		Stud No.	Load to proportional limit	Ultimate load	Stress at proportional limit	Ultimate stress	Transformed area (A_t)	Compressive MOE
			. . . . *Lb*	. . . .	. . . . . *Lb/in²*	. . . . .	*In²*	*Million lb/in²*
White oak		1	9,000	12,440	5,223	7,233	1.72	3.48
		2	11,000	14,540	6,183	8,168	1.78	4.82
		5	8,000	13,140	4,897	8,061	1.63	3.34
		13	6,000	14,000	3,545	8,284	1.69	3.54
		15	7,000	11,280	4,357	7,006	1.61	2.49
	Avg.		8,200	13,080	4,841	7,750	1.67	3.53
	SD		1,924	1,288	983	587	.069	.834
Yellow-poplar		24	9,000	13,040	5,351	7,762	1.68	4.46
		27	8,000	11,840	4,613	6,844	1.73	3.14
		28	9,000	12,740	5,367	7,583	1.68	2.98
		29	9,000	14,040	5,045	7,888	1.78	4.80
		30	9,000	12,300	4,996	6,833	1.80	2.56
	Avg.		8,800	12,792	5,074	7,382	1.74	3.59
	SD		447	832	309	508	.057	.982
Sweetgum		38	7,000	11,300	4,299	6,932	1.63	3.68
		40	7,000	11,520	4,217	6,940	1.66	2.41
		41	8,000	12,560	4,252	6,681	1.88	2.28
		42	8,000	12,860	4,261	6,840	1.88	2.66
		44	8,000	12,120	4,511	6,847	1.77	3.08
	Avg.		7,600	12,072	4,308	6,848	1.76	2.82
	SD		548	664	117	104	.118	.570

white oak being the strongest and sweetgum the weakest.

The allowable compressive stresses (f_c) based on transformed section area for COM-PLY studs made with the three species of hardwood veneer, as calculated by the same basic formula (ASTM 1978a) used for bending stresses, were as follows:

Veneer species	Average compressive ultimate stress	Allowable compressive stress
	.... *Lb/in²*	....
Yellow-poplar	7,382	2,999
Sweetgum	6,848	3,155
White oak	7,750	3,094

The f_c values for COM-PLY studs made with the three species of hardwood veneer compare favorably with the allowable f_c of 3,432 lb/in² found for COM-PLY studs made with slash pine veneers and with the allowable f_c of 675 lb/in² for stud-grade, kiln-dried 2 × 4's of southern pine (NFPA 1977a).

The compressive MOE's based on transformed section areas of the COM-PLY studs made with hardwood veneers were quite high, with yellow-poplar and white oak studs averaging over 3.5 million lb/in² and sweetgum studs averaging over 2.8 million lb/in² (table 4).

Surprisingly, there was no correlation found between the compressive MOE and the bending stiffness and modulus of rupture for COM-PLY studs made with hardwood veneers. Reasonably good correlations for these relationships were found for COM-PLY studs made with slash pine veneers.

TESTS OF COMPRESSION PERPENDICULAR TO GRAIN

METHODS

The test for compression perpendicular to the veneer grain measures a stud's ability to resist crushing or bearing loads. Our test of this property was based on the procedures outlined in ASTM D 143-52 (ASTM 1978d). Only the 1½-inch-wide veneer edge was tested because the veneer plies in the 3½-inch face were not perfectly aligned with the core. Removing enough core and veneer material to provide flat, parallel surfaces would have caused erroneous test results.

The tests were made on a universal testing machine with a capacity of 10,000 pounds. Head speed was 0.01 inch per minute. We measured the deflection of the 2-inch-wide loading block (to the nearest 0.0001 inch) for each 200-pound load increment until the total deflection reached 0.10 inch. We considered that the 0.10-inch deflection constituted failure. This load was recorded as the maximum load.

The load/deflection curve was plotted so that the load at the proportional limit could be determined. A typical load/deflection curve is shown in figure 4. For each test segment we recorded the weight, all dimensions to the nearest 0.001 inch, the identification number of the outer veneer ply under the loading block, and the time required to reach a deflection of 0.10 inch.

RESULTS

Results of these tests are shown in table 5. The average fiber stress at proportional limit for all species was considerably higher than for COM-PLY studs made from slash pine veneer. The allowable bearing stresses calculated by the same basic formula (ASTM 1978a) would be:

$$\text{Allowable bearing stress} = \frac{\text{Average stress at proportional limit} - t_{0.05}\,(\text{SD})}{1.5}$$

Such calculations would yield the following results for COM-PLY studs made with the three species of hardwood veneer:

Veneer species	Allowable bearing stress
	Lb/in²
Yellow-poplar	432
Sweetgum	547
White oak	601

These allowable stresses in bearing are greater than the 405 lb/in² allowable (NFPA 1977a) for stud-grade, kiln-dried 2 × 4's of southern pine and the 227 lb/in² allowable for COM-PLY studs made with slash pine veneers (McAlister 1978).

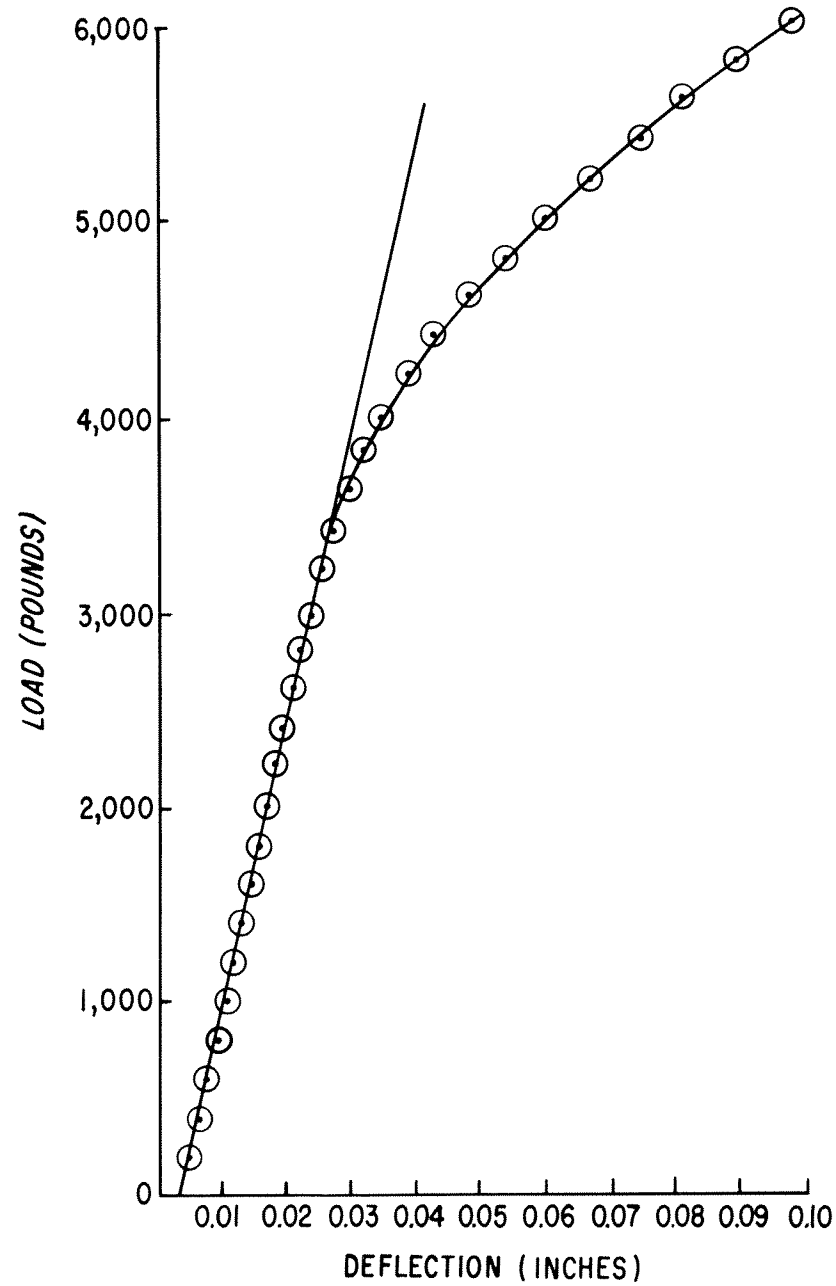

Figure 4.—Typical load/deflection curve for compression perpendicular to grain of COM-PLY studs made with hardwood veneers.

Table 5.—Values of compression perpendicular to the veneer face for COM-PLY studs made with three species of hardwood veneers

Veneer species		Stud No.	Core MOE_b	Average veneer MOE_d	Load at proportional limit	Load at 0.10-inch compression	Stress at proportional limit	Stress at maximum load
			Million lb/in^2		...... *Lb*		..... *Lb/in*^{2}	
White oak		1	0.280	2.02	3,000	5,480	1,003	1,832
		2	.311	2.19	3,400	7,100	1,130	2,359
		5	.301	2.65	3,600	6,330	1,200	2,110
		13	.283	2.27	3,400	5,580	1,127	1,850
		15	.237	2.04	3,000	5,320	995	1,765
	Avg.		.282	2.23	3,280	5,962	1,091	1,983
	SD		.028	.255	268	745	89	248
Yellow-poplar		24	.285	2.03	2,400	5,450	805	1,829
		27	.274	1.74	2,400	5,380	797	1,786
		28	.285	2.17	2,400	4,670	803	1,563
		29	.319	2.05	3,000	6,000	1,000	2,000
		30	.276	1.83	3,000	5,640	1,000	1,880
	Avg.		.289	1.96	2,640	5,428	881	1,812
	SD		.018	.175	329	487	109	160
Sweetgum		38	.252	1.96	3,000	4,910	996	1,630
		40	.258	1.87	2,800	5,260	932	1,751
		41	.312	1.67	2,600	5,380	854	1,766
		42	.319	1.70	2,800	5,320	931	1,769
		44	.316	1.91	2,800	5,480	933	1,827
	Avg.		.291	1.82	2,800	5,270	929	1,749
	SD		.033	.129	141	217	51	72

NAILING TESTS OF COM-PLY STUDS

METHODS

Nailing tests were performed on the unbroken sections of COM-PLY studs used for performance testing. We tested lateral load on joints between plywood wall facings and the veneer faces of studs and direct nail withdrawal from the narrow faces of studs according to procedures described by Walker (1977). We did not perform tests involving the stud-to-plate joint because these values are primarily a function of the nailing characteristics of the particleboard core. The results for COM-PLY stud-to-plate joints with this core material have been published (Walker 1977).

RESULTS

The results of the lateral load tests of plywood-to-stud joints are shown in table 6. Specifications issued by the National Forest Products Association (NFPA 1977b) set the allowable lateral design load for this type of joint at 51 pounds when spruce studs are used. COM-PLY studs made with yellow-poplar, sweetgum, and white oak exceeded this minimum requirement. The same specifications give the allowable lateral design loads for Group I woods (ash, beech, maple, and oak) at 78 pounds for the kind of joints used in this test. Both sweetgum and white oak COM-PLY studs exceeded this value, and the yellow-poplar studs almost equaled it.

The results of the direct nail withdrawal tests are shown in table 7. There are no specifications for this type of test. However, the resistance to direct withdrawal of all nail types tested with COM-PLY studs made with hardwood veneers equaled or exceeded the comparable values for spruce studs in previous tests (Walker 1977).

CONCLUSIONS

COM-PLY studs made with yellow-poplar, sweetgum, and white oak veneers met the performance criteria for composite studs used in exterior walls. Thus, potential manufacturers of COM-PLY studs can use these readily available hardwood veneers to produce studs.

The engineering properties of COM-PLY studs made with yellow-poplar, sweetgum, and white oak veneers are comparable to the values for kiln-dried, stud-grade lumber of southern pine and compare favorably with COM-PLY studs made with high-quality veneer of slash pine.

COM-PLY studs made with the three tested species of veneer can be used with standard fasteners in common applications. Allowable load values per nail equal or exceed values found for spruce studs.

Table 6.—Values from lateral load test of plywood-to-stud joints for COM-PLY studs made with three species of hardwood veneers

Veneer species	Average ultimate load	Standard deviation	Adjusted load
	Lb		
Yellow-poplar	287	61	75
Sweetgum	319	45	113
White oak	269	34	101

Table 7.—Loads resulting from testing direct withdrawal of nails fastened to the narrow faces of COM-PLY studs made with three species of hardwood veneers

Veneer species	Nail type	Average ultimate load	Standard deviation	Adjusted load
		.... *Lb*		
Yellow-poplar	drywall	156	36	37
	8d common	258	42	84
	16d box	236	39	76
Sweetgum	drywall	177	11	81
	8d common	289	46	96
	16d box	291	34	112
White oak	drywall	180	25	64
	8d common	266	32	102
	16d box	214	29	77

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COM-PLY 2 × 4 studs made with veneers of yellow-poplar, sweetgum, and white oak were tested for strength and stiffness, nail-holding properties, modulus of elasticity of component parts, static bending, and compression parallel and perpendicular to the grain. All tests were conducted according to performance standards for composite studs used in exterior walls or ASTM standards. Results indicated that the tested properties of COM-PLY 2 × 4's with any of the three hardwood veneers are comparable to those of COM-PLY 2 × 4's with southern pine veneers and to 2 × 4's of solid wood.

KEYWORDS: Modulus of elasticity, strength, stiffness, bending, compression, nail-holding ability, veneer, particleboard.

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