Composites from southern pine juvenile wood. Part 2. Durability and dimensional stability

Anton D. Pugel
Eddie W. Price
Chung Y. Hse

Abstract

Southern pine juvenile and mature wood were processed into three composites: flakeboard, particleboard, and fiberboard. The durability of these composites was assessed by subjecting specimens to an ovendry-vacuum-pressure-soak (ODVPS) treatment, and then evaluated for modulus of elasticity, modulus of rupture, and internal bond. Overall, juvenile wood composites had values equivalent to or better than the mature wood composites. The dimensional stability of the composites was assessed by measuring the thickness swell and linear expansion of specimens subjected to an ODVPS treatment and specimens exposed to a single cycle of 30 to 90 percent relative humidity. Juvenile wood composites had significantly greater linear expansion than mature wood composites. Thickness swell was also greater for the juvenile wood composites after the ODVPS treatment. Of the three composite types evaluated, fiberboard properties were least affected by differences between the mature and juvenile wood furnishes.

The properties of composites made from juvenile wood furnishes are important for two reasons. First, juvenile wood furnishes can cause problems for other forest products such as lumber, plywood, etc. Therefore, the effect of juvenile wood on composites should be evaluated not only in terms of problems but in terms of the potential for using this type of furnish to produce economical, effective, and possibly, new products. Second, whether juvenile wood harms or enhances the performance of composites, more of it is being used in composites through the harvesting of fast-grown trees and whole-tree utilization.

The purpose of this study was to evaluate different sources of juvenile wood furnish for use in particle-type composites. Four different sources of southern pine juvenile wood were sampled: fast-grown trees, the inner core of older trees, branches, and tops. Along with a mature wood sample, the juvenile wood types were processed into flakeboard, particleboard, and fiberboard at two panel densities. The panel fabrication details and initial mechanical properties of these panels have been previously reported in Part 1 (4). The second part, reported herein, describes the durability and dimensional stability of juvenile wood composites. A third part will report the properties of composites made from known mixtures of juvenile and mature furnishes (5).

In this paper, durability was evaluated in terms of modulus of elasticity (MOE), modulus of rupture (MOR), and internal bond (IB) after specimens were subjected to an ovendry-vacuum-pressure-soak (ODVPS) treatment. Dimensional stability was measured as thickness swell and linear expansion of a set of specimens subjected to an ODVPS treatment and another set exposed to a single 30 to 90 percent relative humidity (RH) cycle. The results of all the tests are assessed by comparison to the mature wood composite properties.

Procedure

A full discussion of the materials and methods used to make the composites is provided in Part 1 (4) — a brief overview is provided here. Four sources of southern pine

The authors are, respectively, Assistant Professor of Forest Products, Dept. of Forestry, Univ. of Illinois, 110 Mumford Hall, Urbana, IL 61801; Manager, Wood Prod. Serv., Georgia-Pacific Corp., 2883 Miller Rd., Decatur, GA 30035; and Principal Wood Scientist, USDA Forest Serv., Southern Forest Expt. Sta., P.O. Box 5500, Pineville, LA 71360. The authors would like to express their appreciation for Cooperative Agreement 19-87-016, USDA Forest Serv., Southern Forest Expt. Sta., Pineville, La., and to the Agri. Expt. Sta., College of Agriculture, Univ. of Illinois at Urbana-Champaign. This paper was received for publication in June 1988.

Forest Prod. J. 40(3):57-61.

(*Pinus taeda* L.) juvenile wood were collected: 1) fast-grown trees (8 yr. old, 7 in. DBH); 2) an inner core (the first 10 yr. of growth of 40- to 50-yr.-old trees); 3) branches; and 4) tops (4 to 6 in. diameter at the large end). A sample of mature wood was obtained from the outer growth increments of 40- to 50-year-old trees. The specific gravities (ovendry weight/12% moisture content (MC) volume) were determined from flakes to be: fast-grown = 0.38; core = 0.42; branches = 0.44; tops = 0.42; and mature wood = 0.46. All material was debarked prior to comminution. Portions of each wood type were processed into flakes, particles, and fibers. These terms are used to describe relative sizes of the particles and are not indicative of commercial production processes. All panels were made under identical blending and pressing conditions including: 5 percent (by ovendry wood weight) liquid phenolic resin content, random orientation of particles, 7/16-inch panel thickness, and two target panel densities (40 and 44 pounds per cubic foot (pcf)). The actual panel densities after pressing were: flakeboards — 40.6 and 44.6 pcf; particleboards — 38.3 and 41.8 pcf; and fiberboards — 37.0 and 40.8 pcf. Specimens were conditioned at 70°F, 66 percent RH prior to the determination of initial physical and mechanical properties.

Two different accelerated-aging treatments were used to evaluate the composites. The specimens for the ODVPS treatment were 3 inches wide and 17 inches long. Nine specimens were randomly selected for each wood type, particle type, and panel density combination. Specimens were ovendried, then weighed and measured for thickness swell and linear expansion. Thickness was measured at three marked points to 0.001-inch accuracy using dial calipers. For linear expansion, the distance (approximately 10 in.) between surgical stainless steel pins inserted in the midportion of the specimen was measured with an optical-digital indicator to an accuracy of 0.0001 inch. After these initial measurements were made, specimens were immersed in room-temperature water, a vacuum of 27 inches of mercury was applied for 1 hour, then 75 pounds per square inch (psi) pressure was applied for 2 hours. Specimens were removed from the water and allowed to drain for 5 minutes before weighing and remeasuring as previ-

TABLE 1. — *The mechanical properties of southern pine mature and juvenile wood composites after an ODVPS treatment.*

Density level/ wood type	Property							
	Density[a]	Density retained[b]	MOE[a]	MOE retained[b]	MOR[a]	MOR retained[b]	IB	IB retained[b]
Flakeboard								
40 pcf[c]								
Mature	34.8	87	406,000	54	3,200	69	67	59
Fast-grown	31.2	76	233,000	45	2,700	55	60	51
Core	34.3	84	375,000	52	3,100	62	63	48
Branches	35.0	87	329,000	61	2,600	63	83	61
Tops	33.9	83	341,000	53	2,700	62	60	51
44 pcf[c]								
Mature	36.5	82	419,000	51	3,100	56	66	49
Fast-grown	32.5	72	248,000	41	3,100	54	70	55
Core	36.2	81	402,000	66	3,400	59	59	42
Branches	36.9	83	368,000	61	3,500	78	79	48
Tops	36.0	81	406,000	58	3,100	63	59	45
Particleboard								
40 pcf[c]								
Mature	31.4	83	157,000	38	900	44	36	29
Fast-grown	29.7	79	164,000	42	1,300	50	83	65
Core	31.8	82	192,000	42	1,300	52	62	36
Branches	31.4	81	166,000	45	1,300	53	71	60
Tops	31.0	81	157,000	39	1,000	47	44	39
44 pcf[c]								
Mature	34.1	82	189,000	38	1,200	45	46	28
Fast-grown	32.2	76	190,000	39	1,500	47	86	60
Core	33.7	80	210,000	40	1,500	48	63	34
Branches	33.0	79	176,000	41	1,500	50	69	47
Tops	33.2	79	186,000	39	1,200	46	47	36
Fiberboard								
40 pcf[c]								
Mature	31.5	85	88,000	35	700	48	59	66
Fast-grown	29.6	79	106,000	37	1,000	49	74	46
Core	30.2	82	105,000	39	900	48	67	70
Branches	30.7	83	97,000	38	900	47	66	63
Tops	31.2	84	99,000	39	800	52	59	39
44 pcf[c]								
Mature	34.0	83	113,000	36	1,000	52	72	77
Fast-grown	32.8	80	140,000	40	1,300	54	77	39
Core	32.7	80	132,000	39	1,100	48	71	49
Branches	32.6	80	119,000	37	1,100	48	84	47
Tops	33.6	82	133,000	40	1,000	49	77	45

[a] Based on dimensions at time of test.
[b] The ratio of the ODVPS value to the initial value (from Part 1 (4)) expressed as a percentage.
[c] Initial panel target densities.

TABLE 2. — *Significantly different means of the mechanical properties of southern pine mature and juvenile wood composites after an ODVPS treatment.*[a]

Density level/ wood type	Flakeboard			Particleboard			Fiberboard		
	MOE	MOR	IB	MOE	MOR	IB	MOE	MOR	IB
40 pcf [b]									
Mature	A	A	B	A	B	C	B	B	A
Fast-grown	C	A	B	A	A	A	A	A	A
Core	AB	A	B	A	A	B	A	AB	A
Branches	B	A	A	A	A	AB	AB	AB	A
Tops	AB	A	B	A	B	C	AB	AB	A
44 pcf [b]									
Mature	A	A	AB	A	B	C	B	B	A
Fast-grown	B	A	AB	A	A	A	A	A	A
Core	A	A	B	A	AB	B	AB	AB	A
Branches	A	A	A	A	AB	B	AB	B	A
Tops	A	A	B	A	B	C	AB	B	A

[a] Within each density level and composite type, properties with the same capital letter are not significantly different. Significant differences were determined at the 5 percent level using Scheffé's test. The letters have been assigned in descending order according to the relative magnitude of the means.

[b] These density levels refer to target panel density levels of the original panels.

ously described. The specimens were then reconditioned at 72°F, 66 percent RH until a constant weight was achieved. Subsequently, specimens were evaluated according to ASTM 1037-87 (1) for MOE, MOR, and IB.

The other set of specimens was exposed to a single cycle of 30 to 90 percent RH. The specimens were 2 inches wide and 17 inches long. The specimens were conditioned to constant weight at 72°F, 30 percent RH. The thickness swell and linear expansion measurements were made using the same techniques as previously described for the ODVPS specimens. Subsequently, the specimens were conditioned to constant weight at 72°F, 90 percent RH and remeasured. Finally, specimens were ovendried to permit calculation of equilibrium moisture content (EMC) at each of the humidity exposures.

Results

Durability

The average mechanical properties after ODVPS treatment for each type of composite are listed in Table 1. The statistically significant differences within panel density and particle type are presented in Table 2. The MOE and MOR calculations were based on the dimensions at time of test. With the exception of MOE of specimens from fast-grown trees, flakeboards made from each wood type performed similarly, i.e., there were few significant differences in MOE and IB, and no significant differences in MOR between wood types. Branchwood produced the highest flakeboard IB values after ODVPS treatment and also had the highest initial values. All wood types retained about the same percentage of the initial values for a given property and composite type. There was no significant difference in particleboard MOE values. Tops and mature wood produced the lowest MOR and IB values in particleboard. There were no significant differences in IB between wood types for fiberboard. Fiberboard and particleboard made from fast-grown wood exhibited the highest average values for the properties tested. Fiberboard made from mature wood exhibited the lowest MOE and MOR values.

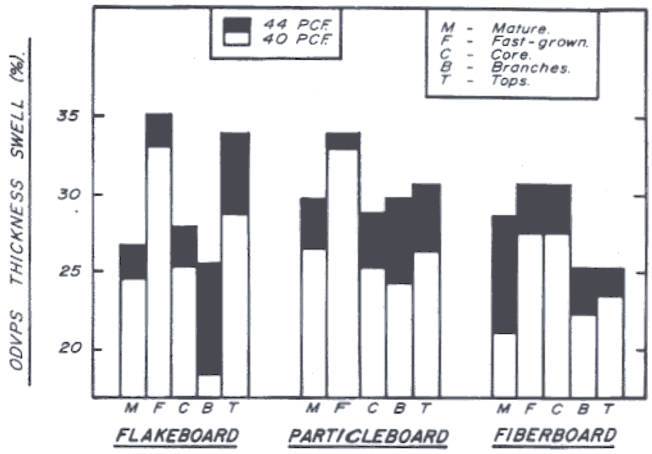

Figure 1. — Thickness swell of composites made from southern pine mature and juvenile wood after ODVPS treatment.

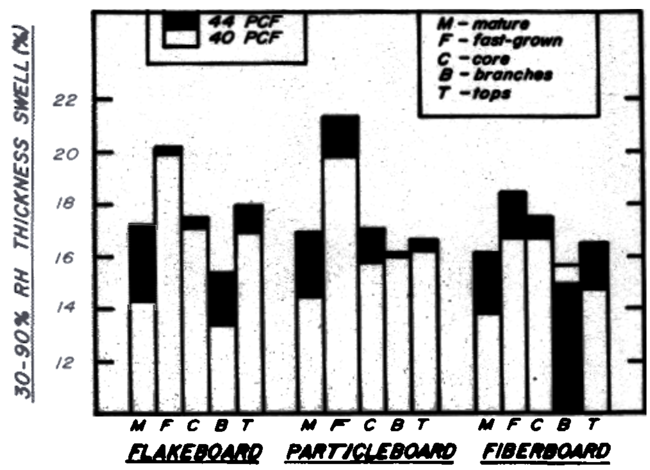

Figure 2. — Thickness swell of composites made from southern pine mature and juvenile wood after 30 to 90 percent RH exposure.

As was expected, panel properties decreased with decreasing particle size, except for IB. And as was also expected, the higher panel density was responsible for higher panel mechanical properties. The percentages of retained values were nearly the same for both density levels. Smaller particle size also decreased the significant differences in properties between wood types, to the point where juvenile wood fiberboard performed as well as the mature wood fiberboard. Fast-grown trees produced panels that had significantly higher fiberboard values. In comparing differences between wood types before (Table 3 of Part 1 (4)) and after (Table 2) accelerated aging, there is a decrease in the number of significantly different means.

Dimensional stability

The average thickness swell values for the southern pine composites are displayed in Figures 1 and 2, for ODVPS and 30 to 90 percent RH, respectively. Average linear expansion values are presented in Figures 3 and 4. Statistically significant differences in dimensional stability are presented in Table 3.

In general, there was little difference between wood types in the MCs attained at the two exposure conditions. However, there were some differences between composite types in the MCs attained following the ODVPS treatment: flakeboards — 100 percent MC; particleboards — 120 percent MC; and fiberboards — 130 percent MC. The 30 to 90 percent RH exposure produced uniform response in all panels with the lower humidity exposure producing an EMC of 5 percent, and the higher an EMC of 15.5 percent.

After ODVPS treatment, the composites made from fast-grown trees swelled significantly more than the mature wood composites. For flakeboard and particleboard, the fast-grown material also swelled more than the other juvenile wood types. Branchwood produced the lowest thickness swell at the lower density level for all composite types. ODVPS thickness swell values were greater for all composite types at the higher density level. As was the case with other properties, differences tended to dissipate as the particle size was reduced from flake to fiber. The 30 to 90 percent RH exposure produced no significant differences at either density level. However, composites made from fast-grown trees always had the highest average values. In almost all cases, the higher density panels produced more thickness swell.

After ODVPS treatment, composites made from fast-grown trees and branchwood produced the greatest linear expansion. Mature wood composites always produced significantly lower values than fast-grown tree composites. Panel density had a slight effect on linear expansion values. Linear expansion tended to be greater as particle size decreased but differences between wood types tended to be less. The 30 to 90 percent RH exposure also produced differences in linear expansion by wood type. As was the case for the ODVPS treatment, fast-grown and branchwood produced the greatest linear expansion; mature wood produced the lowest. The differences between wood types were least for particleboard. Although the linear expansion values were twice as great for the ODVPS treatment, both treatments produced similar results. For linear expansion, mature wood consistently produced lower values and fast-grown and branchwood produced the highest values.

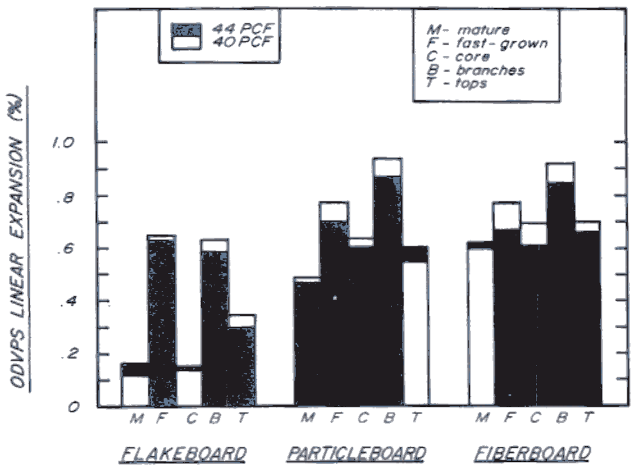

Figure 3. — Linear expansion of composites made from southern pine mature and juvenile wood after ODVPS treatment.

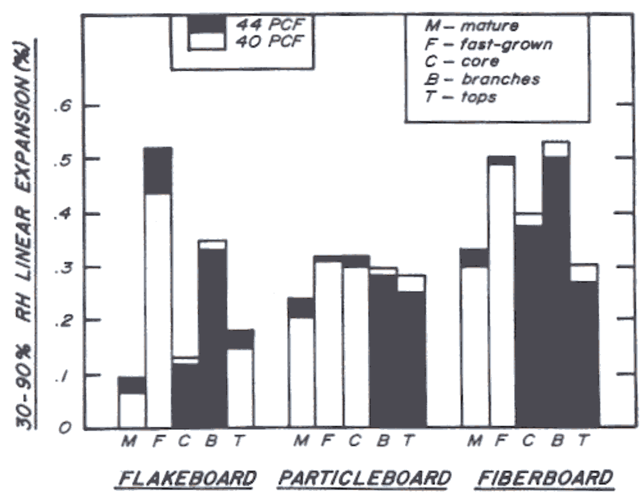

Figure 4. — Linear expansion of composites made from southern pine mature and juvenile wood after 30 to 90 percent RH exposure.

Discussion

Compaction ratio plays an important role in the properties of juvenile wood composites. It is, however, a two-edged sword — high compaction ratios produced durable juvenile wood composites but also contribute to greater

TABLE 3. — *Significantly different means of thickness swell and linear expansion for southern pine mature and juvenile wood composites after ODVPS and 30 to 90 percent relative humidity treatments.*[a]

Density level/ wood type	Composite type/property					
	Flakeboard		Particleboard		Fiberboard	
	ODVPS	30 to 90	ODVPS	30 to 90	ODVPS	30 to 90
Thickness swell						
40 pcf[b]						
Mature	B	A	B	A	B	A
Fast-grown	A	A	A	A	A	A
Core	B	A	B	A	A	A
Branches	C	A	B	A	AB	A
Tops	AB	A	B	A	AB	A
44 pcf[b]						
Mature	B	A	B	A	AB	A
Fast-grown	A	A	A	A	A	A
Core	B	A	B	A	A	A
Branches	B	A	B	A	B	A
Tops	A	A	B	A	B	A
Linear expansion						
40 pcf[b]						
Mature	C	D	D	B	C	C
Fast-grown	A	A	B	A	B	A
Core	C	C	C	A	B	B
Branches	A	B	A	A	A	A
Tops	B	C	D	A	B	A
44 pcf[b]						
Mature	C	D	D	B	B	B
Fast-grown	A	A	B	A	B	A
Core	C	D	C	A	B	B
Branches	A	B	A	B	A	A
Tops	B	C	C	B	B	A

[a] Within each density level and composite type, properties with the same capital letter are not significantly different. Significant differences were determined at the 5 percent level using Scheffé's test. The letters have been assigned in descending order according to the relative magnitude of the means.

[b] These density levels refer to target panel density levels of the original panels.

thickness swell (6). To roughly compare the composites at the same compaction ratio, one can examine the 44 pcf mature wood values in relation to the 40 pcf juvenile wood values. In comparing durability, the mature wood composites have higher MOE values, predominantly greater MOR, and little difference in IB. The dimensional stability comparisons do not change much when comparing 44 pcf mature wood to 40 pcf juvenile wood, although in all comparisons, fast-grown trees produced the highest values. This may be caused by the very high compaction ratios used for the fast-grown tree composites, which are not fully accounted for even when comparing 40 pcf to 44 pcf values. As noted previously (4), a market niche for juvenile wood composites may be in low density panels. For example, a 29 pcf panel can be produced at 1.3:1 compaction ratio using furnish from fast-grown trees. A panel of this density made from mature wood would have a compaction ratio of less than one. The properties of such a panel remain to be investigated for strength, durability, and dimensional stability.

Wasniewski (7) has presented some results regarding juvenile wood (comparable to the core material of this study) of Douglas-fir. He reports that this material in flakeboard was adequate to meet standards for strength, durability, and dimensional stability. However, juvenile wood always had the highest linear expansion and lowest MOE values. The juvenile Douglas-fir produced panels that had linear expansion values twice as great as panels made from 35-year-old and older material. The juvenile flakeboard had low thickness swell in 24-hour water-soak, but this short-term exposure test may be influenced by the high compaction ratio of the juvenile material. Greater densification may restrict moisture entry into the panel, thereby producing low swelling values (3). Howard (2) made flakeboard panels from the root wood of slash pine. Root wood was described as being anatomically close to juvenile wood. The results were very similar to the data of this study. Adequate strength and durability can be developed (except for low MOE) using root wood but the dimensional stability is less than that of mature wood flakeboard.

The results from our study indicate that juvenile wood sources can produce composites that have adequate initial properties and durability, but inadequate dimensional stability when compared to mature wood composites. These comparisons assume that the mature wood composite values meet commercial standards. It may be that, even though the juvenile wood values are less than the mature wood values, they can still meet commercial standards. It also must be stressed that all the composites were made under identical processing and pressing conditions. While this offers a straightforward comparison of the wood types, it does not take advantage of any special properties of the different wood types, which might be optimized in a composite. Accordingly, other than specific gravity, no attempt was made in this study to rigorously characterize the wood types. Information such as grain deviation, microfibril angle, and mechanical, physical, and chemical properties would lend much to understanding the impact of juvenile wood on composite performance. Finally, industrial processing techniques will introduce more variability into the results due to nonuniformity of particle sizes and particle damage during drying and blending. It is not known whether these processes have a greater or lesser effect on the juvenile wood types. Also, it should be reemphasized that the particleboard and fiberboard composites manufactured in this study were made like flakeboard with small particles. The effects of using higher panel densities, urea-formaldehyde adhesive, and commercial forming techniques will likely alter some results. For these products, other properties, such as screwholding, surface texture, and gluability, will also be important.

Conclusions

This study suggests that composites manufactured from southern pine juvenile wood sources may be able to compete with mature wood composites on the basis of durability, assessed from accelerated-aging tests. The composites made from juvenile wood, however, exhibited less dimensional stability. Greater thickness swell and linear expansion may cause problems in certain applications, especially if fast-grown material is used. Of the three composite types evaluated, fiberboard produced the fewest differences in properties between mature and juvenile wood furnishes.

It will be important to consider other manufacturing parameters, such as resin content and type, wax content, density profile, particle geometry, etc., when evaluating the effect of the use of southern pine juvenile wood furnish in commercial applications. Also, it is not known to what degree the physical properties of the furnish, such as chemical composition, grain angle, and microfibril angle, affected the results of this research. Further work in all these areas is recommended.

Literature cited

1. American Society for Testing and Materials (ASTM). 1988. Standard methods of evaluating the properties of wood-base fiber and particle panel properties. *In:* Annual Book of Standards. Vol. 04.09: Wood. ASTM D 1037-87. ASTM, Philadelphia, Pa.
2. Howard, E.T. 1974. Slash pine rootwood in flakeboard. Forest Prod. J. 24(6):29-35.
3. Kelly, M.W. 1977. Critical literature review of relationships between processing parameters and physical properties of particleboard. Gen. Tech. Rept. FPL-10. USDA Forest Serv., Forest Prod. Lab., Madison, Wis.
4. Pugel, A.D., E.W. Price, and C.Y. Hse. 1989. Composites from southern pine juvenile wood. Part 1. Panel fabrication and initial properties. Forest Prod. J. 40(1):29-33.
5. ________. 1990. Composites from southern pine juvenile wood. Part 3. Juvenile and mature wood furnish mixtures. Submitted to Forest Prod. J.
6. Suchsland, O. and H. Xu. 1989. A simulation of the horizontal density distribution in a flakeboard. Forest Prod. J. 39(5):29-33.
7. Wasniewski, J.L. 1989. Evaluation of juvenile wood and its effects on Douglas-fir structural composite panels. Proc. 23rd Washington State Univ. Inter. Particleboard/Composite Materials Symp. T.M. Maloney, ed. Pullman, Wash. pp. 159-173.