Composites from southern pine juvenile wood. Part 3. Juvenile and mature wood furnish mixtures

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Abstract

Composite panels made from mixtures of mature and juvenile southern pine (*Pinus taeda* L.) were evaluated for initial mechanical properties and dimensional stability. The effect that the proportion of juvenile wood had on panel properties was analyzed by regression and rule-of-mixtures models. The mixed furnish data: 1) highlighted the degree to which juvenile wood types can affect specific panel properties; 2) substantiated significant and non-significant differences found in parts 1 and 2 of the study for homogeneous panels; and 3) showed the rule-of-mixtures to be a good model for property changes due to changes in the proportion of juvenile wood in the furnish.

Material containing a large proportion of juvenile wood from southern pine plantations and logging residues may be an abundant and low-cost furnish for composites. Conversely, this material may adversely affect strength and dimensional stability, causing manufacturing problems and consumer complaints. Since most commercial panels are or will be produced from a mixture of mature and juvenile wood, it is important to evaluate if and how much juvenile wood can be used without jeopardizing the minimum panel properties that must be met.

The overall project was designed to evaluate the effects of juvenile wood, defined herein as wood formed in the first 10 years of growth, on particle-type composites of southern pine (*Pinus taeda* L.). Juvenile wood was collected from four sources: 1) fast-grown trees; 2) the inner core of large-diameter trees; 3) branches from logging residue; and 4) tops from logging residue. The juvenile wood types and a mature wood sample were processed into flakes, particles, and fibers. Panels were fabricated from homogeneous and mixed furnishes at two densities, 40 and 44 pounds per cubic feet (pcf). They were evaluated for the initial mechanical properties and dimensional stability. Modulus of elasticity (MOE), modulus of rupture (MOR), and internal bond (IB) of homogeneous panels have been previously reported in Part 1 (Pugel et al. 1989). The effects of accelerated aging on the mechanical properties and dimensional stability have been reported for homogeneous panels in Part 2 (Pugel et al. 1990). The properties of the panels made from mixtures of mature and juvenile wood is presented herein.

Materials and methods

A full discussion of the materials and methods used to make and evaluate the composites is provided in Parts 1 and 2 of this study. A brief overview is provided here. Four sources of southern pine (*Pinus taeda* L.) juvenile wood were collected: 1) fast-grown trees (8 yr. old, 7 in. diameter at breast height [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

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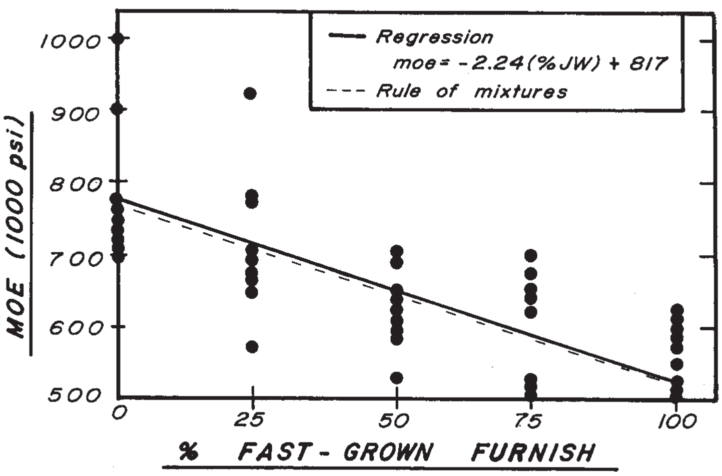

Figure 1. — Modulus of elasticity of 44-pcf flakeboard made from mixtures of juvenile (fast-grown) and mature southern pine furnish.

Table 1. — Regression equations and statistical comparisons with the rule of mixtures for flakeboard made from mixtures of southern pine juvenile and mature wood furnishes.

					Significance tests[a]		
Property	Mixture	Intercept	Slope	r^2	Slope	$a = a_o$	$b = b_o$
40 pcf							
MOE	Fast-grown	755	-2.27	.370	*	NS	NS
	Branches	759	-2.28	.336	*	NS	NS
	Tops	768	-1.26	.138	*	NS	NS
IB	Core	100	.239	.128	*	*	NS
	Branches	106	.268	.232	*	NS	NS
44 pcf							
MOE	Fast-grown	817	-2.24	.533	*	NS	NS
	Branches	830	-1.98	.367	*	NS	NS
	Tops	863	-1.44	.239	*	NS	NS
MOR	Branches	5530	-9.66	.142	*	NS	NS
IB	Fast-grown	138	-.125	.071	NS	NS	NS
	Core	121	.094	.026	NS	*	NS
	Branches	131	.243	.196	*	NS	NS
40 pcf							
TS	Fast-grown	25.9	.773	.169	*	NS	NS
	Branches	26.2	-.0629	.234	*	NS	NS
	Tops	26.0	.0173	.012	NS	NS	NS
LE	Fast-grown	.0327	.00337	.722	*	*	NS
	Branches	.193	.00519	.808	*	NS	NS
	Tops	.250	.00211	.535	*	NS	NS
44 pcf							
TS	Fast-grown	27.7	.0954	.0269	*	NS	NS
	Tops	26.7	.0714	.0137	*	NS	NS
LE	Fast-grown	.191	.00499	.749	*	*	NS
	Branches	.218	.00438	.739	*	*	NS
	Tops	.289	.00123	.196	*	NS	NS

[a] Significance determined by t-test. * = significant difference at the 95 percent confidence level; NS = no significant difference; Slope refers to a test of whether the regression slope is equal to zero; $a = a_o$ refers to a test of whether the regression and rule-of-mixtures intercepts are equal; $b = b_o$ refers to a test of whether the regression and rule-of-mixtures slopes are equal. If a particular mixture for a specific property was not significant for all three significance tests, the results are not presented.

wood was obtained from the outer growth increments of 40- to 50-year-old trees. The specific gravities (ovendry weight/12% moisture content 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 further processing. 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, a size analysis is presented in Part 1 (Pugel et al. 1989). Each of the four juvenile wood types was mixed with mature wood on a weight basis. Mixtures of 25 percent juvenile wood/50 percent mature wood, 50 percent juvenile wood/50 percent mature wood, 75 percent juvenile wood/25 percent mature wood, and 100 percent juvenile wood furnish were used to manufacture panels. A single set of 100 percent mature wood samples was manufactured for comparison. 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, a panel thickness of 7/16 inch, and two target panel densities after pressing were, for flakeboards, 40.6 pcf and 44.6 pcf. Specimens were conditioned at 70°F, 66 percent relative humidity, prior to the determination of physical and mechanical properties.

Nine specimens per mixture type and density level were evaluated for MOE, MOR, and IB. One set of specimens were evaluated for both thickness swell (TS) and linear expansion (LE) after the specimens were subjected to an ovendry-vacuum-pressure-soak (ODVPS) treatment .

Results

The combination of mixtures and properties just outlined provides information for 120 regressions of 45 data points each. The full raw data set is on file at the USDA Forest Serv., Southern Res. Sta., Pineville, Louisiana.

Effect of mixtures

The simple linear regression equations, coefficients of determination, and significance test results are presented in **Tables 1** to **3** for flakeboard, particleboard, and fiberboard, respectively. The regression equations were of the form:

$$y = a + b \times x \qquad [1]$$

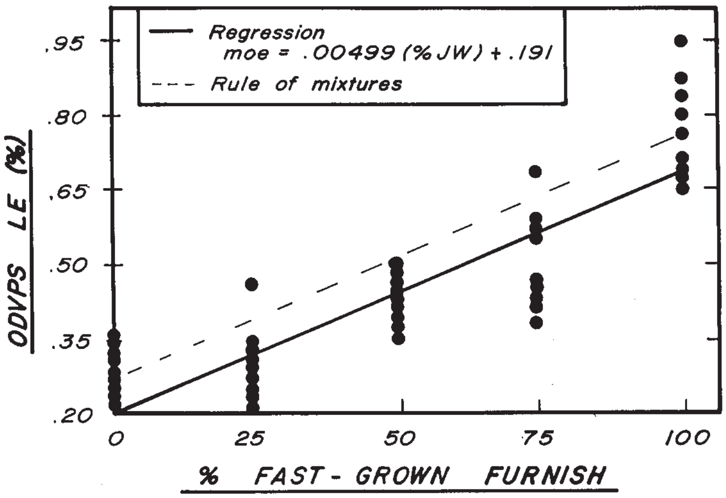

Figure 2. — Linear expansion after ODVPS exposure of 44-pcf flakeboard made from mixtures of juvenile (fast-grown) and mature southern pine furnish.

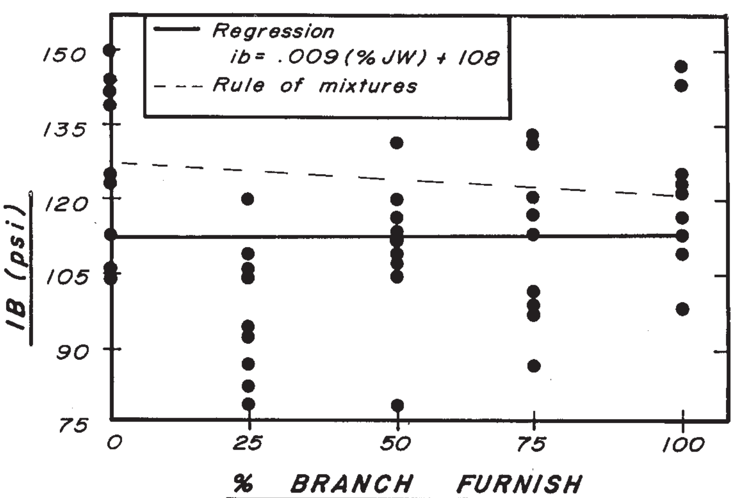

Figure 3. — Internal bond of 40-pcf particleboard made from mixtures of juvenile (branches) and mature southern pine furnish.

where:

y = property value of mixed panel
a = intercept from regression analysis
b = slope from regression analysis
x = percentage of juvenile wood in furnish

The addition of juvenile wood to mature wood furnish will have three effects on panel properties: property values will improve, they will suffer, or they will not be changed. It cannot be generally stated that a positive or negative slope means that the property has improved or suffered, but it can be said that the property has increased (significant, positive slope) or decreased (significant, negative slope). For example, **Figure 1** illustrates a case where the slope is negative and significantly different from zero, and indeed the MOE of flakeboard has decreased from increased percentage of fast-grown (juvenile) wood in the furnish. However, while **Figure 2** illustrates a significant positive slope, the increased percentage of fast-grown furnish increased the amount of LE, this is a detrimental effect of proportion of juvenile wood on the panel properties. Properties that do not change are reflected in **Tables 1** to **3**, under the heading "Slope" and denoted by "NS." An example of this effect is shown in **Figure 3**.

In terms of the juvenile wood types studied, fast-grown material has an especially detrimental effect on the particle and flake composites, but improves the mechanical properties. The proportion of core juvenile wood has negligible impact on panel properties except for LE. And in general, inclusion of any juvenile wood has an adverse impact on LE, irregardless of density and particle type. One of the more interesting and unexplained results is the fiberboard MOR increase with the juvenile wood content.

Homogeneous panel results

The results of the mixed furnish data also support the results from the homogeneous panel tests of Part 1 (Pugel et al. 1989), Part 2 (Pugel et al. 1990), and Shupe et al. (1999). For example, pure fast-grown flakeboard panels were simultaneously slightly higher in bending strength and much lower in bending stiffness than the pure mature wood panels. While not explaining this result, the mixed data certainly support this finding with a significant negative slope for MOE and a nonsignificant positive slope for MOR. In general, none of the mixed furnish results refuted the significant differences found between homogeneous panels and also supported cases where no significant differences were found.

Regression versus rule of mixtures

The rule of mixtures is introduced for comparison with the regression results. The rule allows calculation of mixed panel properties from the homogeneous pure panel properties, determined in Part 1 (Pugel et al. 1989) and Part 2 (Pugel et al. 1990), and the mixture proportions. Each furnish contributes to the final property value in proportion to its percentage of furnish by weight:

$$y = x \times c + z \times d \qquad [2]$$

where:

y = panel property
x = percentage juvenile wood by weight
c = pure juvenile wood panel property

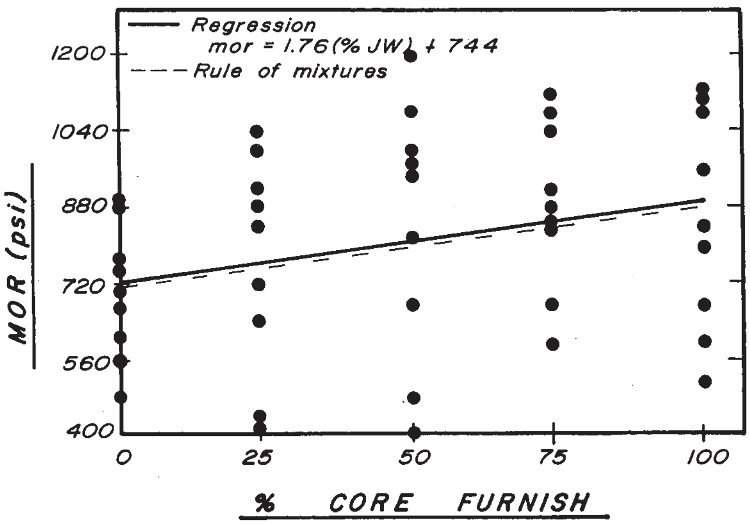

Figure 4. — Modulus of rupture after ODVPS exposure of 40-pcf fiberboard made from mixtures of juvenile (core) and mature southern pine furnish.

Table 2. — Regression equations and statistical comparisons with the rule of mixtures for particleboard made from mixtures of southern pine juvenile and mature wood furnishes.

					Significance tests[a]		
Property	Mixture	Intercept	Slope	r^2	Slope	$a = a_o$	$b = b_o$
40 pcf							
MOE	Core	396	.546	.130	*	NS	NS
MOR	Fast-grown	2020	6.67	.353	*	NS	NS
	Core	1950	6.62	.282	*	NS	NS
IB	Fast-grown	106	.091	.028	NS	*	NS
	Core	98	.638	.357	*	*	NS
	Branches	108	.009	.000	NS	*	NS
44 pcf							
MOE	Branches	487	-.679	.151	*	NS	NS
MOR	Core	2730	3.95	.126	*	NS	NS
IB	Fast-grown	139	-.079	.015	NS	*	NS
	Core	133	.248	.067	NS	*	NS
	Branches	139	-.093	.015	NS	*	NS
	Tops	148	-.232	.096	*	*	*
40 pcf							
TS	Fast-grown	26.0	.0614	.345	*	NS	NS
LE	Fast-grown	.611	.0032	.728	*	NS	NS
	Core	.611	.0017	.505	*	NS	NS
	Branches	.618	.0048	.761	*	NS	NS
44 pcf							
TS	Fast-grown	28.6	.0467	.200	*	NS	NS
LE	Fast-grown	.618	.0020	.451	*	NS	NS
	Core	.639	.0011	.220	*	NS	NS
	Branches	.600	.0047	.831	*	NS	NS
	Tops	.609	.0010	.211	*	NS	NS

[a] Significance determined by t-test. * = significant difference at the 95 percent confidence level; NS = no significant difference; Slope refers to a test of whether the regression slope is equal to zero; $a = a_o$ refers to a test of whether the regression and rule-of-mixtures intercepts are equal; $b = b_o$ refers to a test of whether the regression and rule-of-mixtures slopes are equal. If a particular mixture for a specific property was not significant for all three significance tests, the results are not presented.

z = percentage mature wood by weight

d = pure mature wood panel property

A test for significant differences between the parameters of the regression and rule-of-mixtures models can be made by standardizing the forms of the two models. Substituting (100-x) for z in Eq. [**2**] and rearranging,

$$y = 100 \times d + (c - d) \times x \qquad [3]$$

and comparing to the terms from Equation [**1**]:

$$a = 100 \times d \qquad [4]$$

$$b = c - d \qquad [5]$$

The last two columns in **Tables 1** to **3** present the results of t-test comparisons between the intercept ($a = a_o$) and slope ($b = b_o$) parameters of the two models. There were no significant differences between the slope parameters generated by each model and very few cases where the intercepts differed significantly.

Figures 1 to **4** present visual examples of the model-fitting results of the parameter analysis. **Figure 1** illustrates the case where the slope is significantly different from zero, but differences between rule and regression parameters are not. **Figure 2** illustrates the case where the slope is significantly different between the rule and the regression. **Figure 3** illustrates the situation where the slope is not significantly different for the two models. Finally, **Figure 4** illustrates the case where the slope is not significantly different than zero and there are no differences between the parameters of the two models.

Discussion

Use of the results

The reasoned use of the results of this study will include balancing properties and economics. If juvenile wood furnish can be produced at a lower cost and the mixture proportion can be adjusted to give the minimum panel properties required, then it would be prudent to use a higher proportion of juvenile wood in the furnish. There will be many tradeoffs in panel properties because, for example, adding fast-grown particle furnish will increase MOR and it will also increase LE. On the other hand, if certain properties do not meet accepted standards, it may be possible to limit the proportion of juvenile wood in the furnish. For example, for almost all types of juvenile wood, panel density, and composite type, reducing the percentage of juvenile wood will decrease LE.

Rule of mixtures

The rule of mixtures model appears to be a reasonable method to estimate the effect of juvenile wood furnish proportion on composite panel properties. This model greatly simplifies the preparation of the test panels and analysis of results. Yet, while a vast majority of the tests could be made on the homogeneous panels, it would still be wise to test a few mixed-furnish panels to validate the model.

Additional research

The results of this project are intimately tied to the raw material, processes, and products used. The raw material was not analyzed for quantifiable differences such as chemical content, microfibril angle, cell types, etc. For example, the core juvenile wood type performed very similarly to mature wood for most properties and products. It is possible that the juvenile zone of the logs sampled did not display typical softwood juvenile wood characteristics such as high microfibril and grain angle, low cellulose content, etc. Also, no attempts were made to adjust the manufacturing process to accommodate the individual characteristics of the furnishes. Some alternative strategies such as different particle sizes, separate blending and resin contents, particle stratification, and lower panel densities may improve the performance of the composites made from juvenile wood.

Future work on the role of juvenile wood in wood composites should proceed in two directions. Research is needed regarding the following: 1) commercial processing of juvenile wood furnish; and 2) blending and pressing of juvenile wood composites. There is also a need to develop relationships between physical properties of the furnish and the mechanical and durability properties and dimensional stability of the panels. It should be emphasized that no attempt has been made to optimize conditions for using juvenile wood nor to develop products that might capitalize on the unique properties of the juvenile wood.

Table 3. — Regression equations and statistical comparisons with the rule of mixtures for fiberboard made from mixtures of southern pine juvenile and mature wood furnishes.

					Significance Tests[a]		
Property	Mixture	Intercept	Slope	r^2	Slope	$a = a_o$	$b = b_o$
40 pcf							
MOE	Fast-grown	255	.350	.121	*	NS	NS
MOR	Fast-grown	1570	4.77	.266	*	NS	NS
	Core	1520	4.13	.175	*	NS	NS
	Branches	1450	3.53	.117	*	NS	NS
IB	Fast-grown	93	.700	.591	*	NS	NS
	Branches	112	.256	.072	NS	*	NS
44 pcf							
MOE	Fast-grown	313	.405	.138	*	NS	NS
MOR	Fast-grown	1880	7.11	.445	*	NS	NS
	Core	2000	4.63	.141	*	NS	NS
	Branches	1890	3.90	.157	*	NS	NS
IB	Fast-grown	98	.872	.545	*	NS	NS
	Branches	114	.884	.500	*	*	NS
	Tops	93	.820	.610	*	NS	NS
44 pcf							
TS	Fast-grown	25.3	.0368	.160	*	NS	NS
LE	Fast-grown	.740	.0016	.378	*	NS	NS
	Core	.662	.0014	.212	*	*	NS
	Branches	.729	.0032	.765	*	NS	NS
	Tops	.730	.0011	.183	*	NS	NS
44 pcf							
TS	Fast-grown	28.1	.0280	.100	*	NS	NS
	Branches	28.8	.0329	.147	*	NS	NS
LE	Branches	.757	.0022	.369	*	NS	NS

[a] Significance determined by t-test. * = significant difference at the 95 percent confidence level; NS = no significant difference; Slope refers to a test of whether the regression slope is equal to zero; $a = a_o$ refers to a test of whether the regression and rule-of-mixtures intercepts are equal; $b = b_o$ refers to a test of whether the regression and the rule-of-mixtures slopes are equal. If a particular mixture for a specific property was not significant for all three significant tests, the results are not presented.

Conclusions

The juvenile-mature wood furnish mixture data serve three important functions. First, the proportion and type of juvenile wood had varying, yet in some cases, substantial influence on composite panel performance. Second, the trends of the mixture's data support the results from the tests on homogeneous juvenile and mature wood panels of the first two parts of the study. Third, the rule of mixtures provides a good model for estimating the effect of mixed juvenile and adult furnish on panel performance. In general, the mixtures analysis provides insight into the effects a manufacturer might anticipate by using mixtures of mature and juvenile wood for composite products.

Comprehensive conclusions

As this is the last of a three-part series that has investigated composite properties from southern pine juvenile wood, a comprehensive discussion of the major findings of the series is in order. Overall, the initial MOE, MOR, and IB of the juvenile wood composites were comparable to the mature wood composite values. However, the higher compaction ratios needed for the juvenile wood panels have implications and possibilities that may affect the commercial use of this furnish. Juvenile wood composites had values equivalent to or better than the mature wood composites. Juvenile wood also gave less favorable dimensional stability values, particularly for fiberboard.

Juvenile wood is the furnish of the present and likely the future for the wood-based composite industry. Although juvenile solid wood is clearly inferior to mature wood for most applications, the same is not necessarily true for most properties of most wood-based composite types. In short, it simply requires more juvenile wood furnish, and consequently higher compaction ratios, to produce panels with comparable properties. Advances in forest management and tree improvement have resulted in the ability of forest land managers to produce much greater volumes of fiber per unit of land. Plantation wood has high volumes of juvenile wood, but can also contain some mature wood as well, which is advantageous due to the rule of mixtures. These studies indicate that wood-based composite panels with favorable properties can be made from juvenile wood. The implication to the industry is that although there are some disadvantages to producing panels with a high percentage of juvenile wood, the properties are sufficient in most cases to satisfy grade requirements. A comprehensive economic analysis is necessary to fully evaluate the implications of using fast-grown wood for wood-based composites.

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