PAIRMATCHING AND PREDICTION MODELS: THEIR USE IN PREDICTING PARTICLEBOARD PROPERTIES[1]

Robert J. Tichy
Research Assistant, Materials Science and Engineering Dept.
Washington State University, Pullman, WA 99163

(Received 13 February 1976)

ABSTRACT

It is quite valuable for the research scientist to be able to predict accurately the strength properties of his treatment specimens. This is frequently done through the use of control or untreated test specimens.

This study explored several methods of predicting treatment specimen MOR's for two types of oriented particleboard, using side- and end-matched control specimens. The effect of control specimen positioning was investigated. Side-matching proved to be more accurate than end-matching. With the treatment specimen flanked on either side by control specimens, the average percent error was only 3.4% with a standard deviation of 2.8 when the prediction parameter was obtained by averaging the MOR's of the flanking control specimens. A freehand curve fit method was attempted with similar results.

The introduction of another material property (i.e., modulus of elasticity) into the prediction model was examined. Because of a low correlation of the parameters used (MOR and MOE), this method did nothing to improve prediction accurary.

Additional keywords: Statistical analysis, experimental design, modulus of rupture, modulus of elasticity, particleboard, prediction equations.

INTRODUCTION

In most experimental designs, the effects of specific variables or treatments are tested and evaluated on the basis of some "standard" condition. The standard usually is determined by the use of a matched control or untreated specimen whose properties are assumed to be characteristic of the matched material. This invariably leaves the question of just how accurate the prediction of the treatment specimen is. Because wood and wood products, like most biological materials, are inherently variable in their material properties, information about methods of accurately predicting those properties is of considerable interest.

Generally, when dealing with wood products, test specimens are either side- or end-matched. In both cases the principal axes are intended to be identical in the pairs. This study investigated the prediction accuracy of side- and end-matched specimens of oriented particleboard. The objectives of this study were to examine the effectiveness of pairmatching techniques on this material and to propose alternative methods of matching test specimens.

In a recent study by Gerhards (1976) several prediction models were proposed. Two models from his paper were selected for this study. The first model (Model I) simply entertains the philosophy that two adjacent specimens cut from a member will have the same properties. For example, if modulus of rupture (MOR) was being evaluated, the modulus of rupture for C1 (control specimen 1) is assumed to be that of treatment specimen T1.

The second model (Model II) introduces an additional parameter into the consideration (Model II here is Model IV in Gerhards' paper). This is usually some material parameter that can be or has been correlated to the property being investigated. Two such material properties commonly used are modulus of elasticity (MOE) and specific gravity. Mathematically, Model II can be expressed as

$$Y = f(X_i - X_m) \qquad [1]$$

---

[1] I would like to acknowledge the aid given by Professor Robert J. Hoyle, Jr. in suggesting the study and furnishing some experimental data and general guidance.

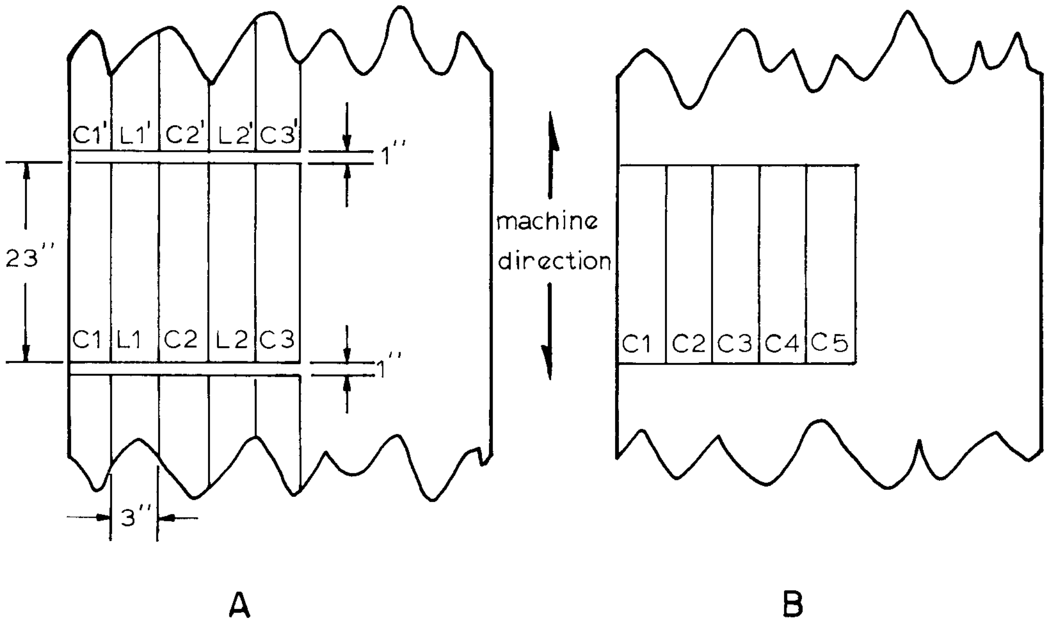

FIG. 1. Specimen cutting patterns; (A) 3-ply glued-laminated board; (B) 3-layer single mat formed board.

where Y = the predicted property (MOR in this case),
X_i = the material parameter used in the prediction equation (MOE in this case),
X_m = the nondestructively determined parameter of the matched specimen.

Frequently a regression equation relating two properties can be employed as the function.

ANALYTICAL DESIGN AND PROCEDURE

Data from two studies conducted at Washington State University on oriented particleboard were used for the analyses. The test material consisted of two types of particleboard, randomly selected from a manufacturer's pilot plant production of a commercial board. The orientation scheme of the particles of one type was similar to the principle of 3-ply plywood. The three-layered, glued-laminated board consisted of

TABLE 1. *Percent error for the end-matched test specimens, Model I (three-layered board)*

	Panel Number					
Specimen Number	1	2	3	4	5	6
1	4.8	0.2	21.3	4.0	-28.4	9.0
2	-7.1	-5.5	11.9	-0.2	-5.8	6.1
3	-7.1	5.0	-23.3	-12.7	-17.1	9.1
4	-10.8	-1.9	11.7	-8.3	-8.5	-13.0
5	8.8	-13.4	6.7	11.7	11.1	5.2
6	12.1	-10.5	-0.3	18.3	27.3	6.5

Tot. Ave. (algebraic) 0.5   S.D. (alg.) 12.4
Tot. Ave. (absolute) 10.1   S.D. (abs.) 6.9

TABLE 2. *Percent error for the end-matched test specimens, Model II (three-layered board)*

	Panel Number					
Specimen Number	1	2	3	4	5	6
1	-2.9	-4.0	24.4	2.9	-14.8	-13.5
2	-2.3	-1.7	21.3	-14.2	-4.3	3.1
3	10.9	3.1	-13.5	-13.3	-8.8	10.6
4	6.8	-8.2	2.9	-3.5	2.7	-9.3
5	19.8	-9.3	2.5	10.0	-16.5	12.9
6	6.0	-6.2	8.2	7.6	15.9	-1.5

Tot. Ave. (alg.) 0.7 S.D. (alg.) 10.8
Tot. Ave. (abs.) 8.9 S.D. (abs.) 6.0

TABLE 3. *Percent error for the side-matched specimens using Model I (three-layered board)*

	Panel Number					
Specimen Number	1	2	3	4	5	6
1	0.1	2.0	5.5	12.7	-32.0	19.3
2	-10.9	-3.5	-5.8	4.6	-17.5	14.5
3	-8.5	-12.0	5.6	-14.3	26.5	-1.7
4	-2.9	-	-0.4	6.4	-7.7	-7.9
5	10.6	-1.4	-15.5	-1.2	0.2	3.8
6	6.7	-7.1	18.0	2.9	8.2	-16.6
7	13.2	3.5	2.7	16.0	-8.0	14.8
8	3.2	-12.9	-11.8	12.3	18.8	-2.3
9	-10.3	-4.5	-7.5	-6.4	-9.3	9.3
10	-7.0	-1.9	-14.0	1.1	10.9	10.9
11	-1.7	-7.9	16.9	2.3	1.7	-
12	-8.4	-5.7	0.7	-23.1	1.0	-

Tot. Ave. (alg.) -0.3 S.D. (alg.) 11.0
Tot. Ave. (abs.) 8.6 S.D. (abs.) 6.7

TABLE 4. *Percent error for the side-matched specimens using Model II (three-layered board)*

	Panel Number					
Specimen Number	1	2	3	4	5	6
1	4.7	-1.7	6.6	12.7	-17.5	5.1
2	4.7	0.5	5.8	-8.0	-8.6	24.0
3	-	-12.0	10.0	-8.6	27.8	-10.2
4	-3.3	-	10.2	28.0	-0.1	-5.8
5	10.1	5.5	-10.0	6.7	-9.0	8.3
6	4.3	-5.7	7.7	4.0	3.9	-10.8
7	12.9	17.1	1.1	19.0	-1.9	5.8
8	2.0	-11.5	-18.7	47.2	17.4	0.1
9	3.5	3.1	-17.2	-6.1	-12.7	16.9
10	-20.4	5.3	-11.1	-9.9	16.7	2.2
11	-8.9	-4.8	10.1	0.8	-0.9	-
12	9.7	-4.7	3.7	-20.4	-11.3	-

Tot. Ave. (alg.) 1.7 S.D. (alg.) 12.5
Tot. Ave. (abs.) 9.7 S.D. (abs.) 8.0

TABLE 5. *MOR predicted using Model I and adjacent test specimens, percent error (single mat board)*

Ci predicts		Panel Number				
C(i+1)		1	2	3	4	5
C1	C2	2.5	-0.2	2.0	9.9	9.9
C2	C3	2.8	-3.3	9.0	-8.7	9.1
C3	C4	2.9	-7.5	-12.4	8.4	-11.7
C4	C5	-13.3	-14.0	-4.8	6.0	-3.2

Tot. Ave. (alg.) -0.9 S.D. (alg.) 8.3
Tot. Ave. (abs.) 7.1 S.D. (abs.) 4.2

two ⅛-inch-thick face panels, with their major axes aligned along the test span direction and a ¼-inch core with its major axis at ninety degrees to the face plies. The second type was a single mat-formed board similar in construction, with the exception that the cross-oriented layers of particles were pressed in a single operation. Both board types were ½-inch thick.

A load duration study of the three-layered board used groups of five specimens cut from panels as shown in Fig. 1A. In that study, the L1 and L2 specimens were treatment specimens, and the C1, C2, C3 specimens were controls. The information on the C1, C2, and C3 specimens, being readily available, has been analyzed for the effectiveness of side-matching. The information on C1 and C1′ specimens has been examined for end-matching effect. There were 70 side-matched pairs and 36 end-matched pairs. Specimen size was 23″ × 3″ × ½″.

The second experiment, dealing with the single mat-formed board, provided twenty-five specimens, also 23″ × 3″ × ½″. There were five specimens (C1 through C5) from each of five panels. These specimens were cut from locations immediately adjacent to one another, as seen in Fig. 1B, yielding four side-matched pairs per panel for a total of twenty distinct pairs. No end-matched pairs were obtained from this type of board.

Models I and II were applied to the three-layered board, with Model I and variations thereof applied to the data from the single mat-formed board.

Using Model II for the three-layered board, the adjustment was based on a previously determined regression equation (Hoyle and Adams 1975) correlating modulus of rupture and modulus of elasticity. This equation was developed from control data for the material under consideration and can be stated as:

$$\mathrm{MOR} = 0.00421(\mathrm{MOE}) + 897 \qquad [2]$$

with a coefficient of determination of 0.48.

To predict a treatment specimen MOR, a simple example best illustrates the technique. Assume MOR_1 will be used to predict MOR_2 using the regression equation.

$$\mathrm{MOR}_1 = 0.00421\ E_1 + 897 \qquad [3]$$

$$\mathrm{MOR}_2 = 0.00421\ E_2 + 897 \qquad [4]$$

TABLE 6. *MOR predicted using Model I and test specimens spaced 3″ apart, percent error (single mat board)*

Ci predicts		Panel Number				
C(i+2)		1	2	3	4	5
C1	C3	5.2	-3.6	10.8	2.0	18.1
C2	C4	5.6	-11.1	-2.5	0.0	-1.5
C3	C5	-10.1	-22.6	-17.7	13.6	-15.3

Tot. Ave. (alg.) -1.9 S.D. (alg.) 11.8
Tot. Ave. (abs.) 9.3 S.D. (abs.) 7.1

If Eq. [3] is subtracted from Eq. [4], the result can be written as:

$$MOR_2 = 0.00421(E_2 - E_1) + MOR_1 \quad [5]$$

The previously mentioned variables of Model I, as applied to the single mat-formed board, involved interpolating a predicted specimen MOR between the MOR's of the two adjacent specimens (controls), thus C2 strength from C1 and C3 strengths. Straight and freehand curve fit lines to the specimen properties were selected for the interpolation processes due to their direct application to the experimental data. In most cases, experiments using side- or end-matching can be designed to have controls on either side or either end of the treatment specimen. As seen in Fig. 1B, test specimens C1, C3, and C5 were used to predict C2 and C4.

All the test specimens were conditioned at 12% EMC until equilibrium was attained. The test specimen weights and dimensions were recorded. Destructive testing followed. This operation was carried out on a Reihle testing machine with third-point loading on an 18-inch span. Load versus deflection curves were recorded, and the modulus of rupture and modulus of elasticity were calculated.

RESULTS AND DISCUSSION

Analysis of the data consisted of comparing the percent error between actual and predicted moduli of rupture. Algebraic and absolute percent errors were computed. The algebraic percent error was defined as the percent difference ($MOR_{predicted} - MOR_{actual} / MOR_{actual}$) between the predicted modulus of rupture and the actual modulus of rupture of the prediction specimen. The absolute percent error was merely the absolute value of the algebraic percent error.

The algebraic percent errors are of interest when comparing the mean treatment effect to the mean untreated properties of a multi-specimen sample. The absolute percent errors are of interest when using the control specimens as a basis for applying treatment to their matched counterparts. In load duration studies, the applied stress (treatment) is a percentage of the predicted property and the interest is in fidelity of the prediction for the application of the proper treatment stress.

TABLE 7. *Predicted MOR's using the sample averaging and curve fit techniques (single mat board)*

Specimen Number	Panel Number	Technique Simple Average (% Error)	 Freehand Curve (% Error)
C2	1	-0.1	1.1
C4	1	7.5	-6.1
C2	2	1.5	-1.8
C4	2	3.4	-2.0
C2	3	-3.6	5.1
C4	3	-3.2	5.8
C2	4	9.0	-10.5
C4	4	1.4	-2.7
C2	5	1.0	2.8
C4	5	-3.7	7.0
Tot. Ave. (alg.)		1.3	-0.1
S.D. (alg.)		4.4	5.6
Tot. Ave. (abs.)		3.4	4.5
S.D. (abs.)		2.8	2.9

Three-layered oriented particleboard—end-matched

Both Models I and II were used in the analysis of the side- and end-matched specimens. Tables 1 and 2 are compilations of the percent error and their respective algebraic and absolute means and standard deviations for the end-matched specimens. The average percent error was 10.1, with a standard deviation of 6.9.

Three-layered oriented particleboard—side-matched

Tables 3 and 4 are compilations of the percent errors, total averages, and standard deviations for Models I and II, respectively, as applied to the side-matched specimens. For the end-matched specimens, use of the elastic modulus (Model II) did slightly improve one's prediction capability, while the reverse was observed for the side-matched specimens. Generally, however, differences between the two methods of prediction are small, as are differences between the matching techniques. It should

TABLE 8. *Summary of results*

Technique	Type of Board	Control Location	% Error			
			Absolute		Algebraic	
			Mean	S.D.	Mean	S.D.
Model I	3-layer	one end-matched control	10.1	6.9	0.5	12.4
Model I	3-layer	one side-matched control	8.6	6.7	-0.3	11.0
Model II*	3-layer	one end-matched control	8.9	6.0	0.7	10.8
Model II*	3-layer	one side-matched control	9.7	8.0	1.7	12.5
Simple Averaging	single mat	pair of side-matched controls	3.4	2.8	1.3	4.4
Property Trend**	single mat	pair of side-matched controls	4.5	2.9	-0.1	5.6
Model I	*single mat*	*one side-matched control:*				
		adjacent	7.1	4.2	-0.9	8.3
		3" removed	9.3	7.1	-1.9	11.8

* Using regression of MOR on MOE

** Using location parameter

be noted that the total averages tended to be less than 10%, with rather high standard deviations. The acceptability of the subsequent ranges in percent error of prediction are left to the reader.

It was also found that Model II, using test specimen weight as the relating property, did nothing to increase or decrease prediction accuracy over the levels previously described.

Single mat-formed particleboard—side-matched

It was felt that the proximity of the control specimens to the treatment specimens was important. For the single mat board, control specimens were located immediately adjacent to the prediction specimens (Fig. 1B) in anticipation that the percent error would decrease. Table 5 shows the results of twenty MOR predictions, total averages, and standard deviations. Table 6 gives the results of predictions made using the same data but with the test specimens separated by 3-inch intervals.

As expected, a comparison of Tables 5 and 6 showed that the test specimens located immediately adjacent produced significantly lower average percent errors and standard deviations.

Because of the increase in prediction accuracy by selecting adjoining specimens, it was felt that control specimens on either side could increase the power of prediction even further. Table 7 displays the effect of averaging the *two* neighboring control specimens and using that average as the prediction value. It can be seen that the prediction of the modulus of rupture is enhanced by this averaging technique. The total absolute average percent error was 3.4 with a standard deviation of only 2.8, as compared to 7.1 and 4.2 in Table 5.

The encouraging results of the averaging technique prompted a further refinement of the method by plotting a curve including three or more points to show property trends through the material. Figure 2 depicts a typical arrangement of MOR's plot-

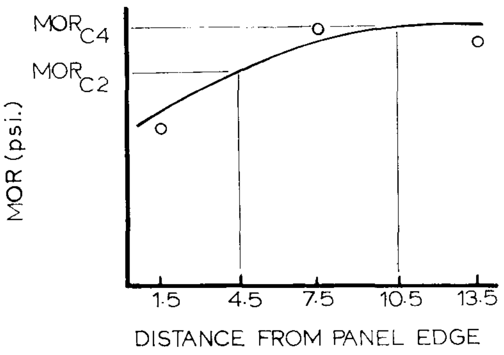

FIG. 2. Curve for specimen location effect.

ted against test specimen position in the panel.

The results of the application of this technique to the same data previously analyzed showed a 1.1% increase in the absolute percent error and a slight increase in the standard deviation (Table 7), indicating no noticeable improvement in prediction accuracy. As this method is quite subjective, a more sophisticated method of curve fitting or a larger number of plotted points could be advantageous. If, however, the variation in properties was a random feature of the material, no advantage would be expected.

CONCLUSION

The need for accurate material property prediction is well understood, but the methods are not. With an increase in the power of prediction, the reliability and confidence one may assume in his results can be greatly improved.

In this study, general techniques and models of prediction were evaluated. It was found that for this experiment on oriented particleboard the addition of another material property (Model II) did little to improve the overall prediction accuracy for either side- or end-matched specimens. Model II, using specimen weight, was considered; but the correlation was not good enough to suggest that it would improve prediction accuracy. No data on this evaluation are included in this report, as the coefficient of determination for MOR and specific gravity was only 0.47.

The relative locations of the control specimens and the treatment specimens did, however, significantly affect prediction accuracy. It seemed logical that the closer the two specimens were located in relation to one another, the better the prediction, as was illustrated by this study.

The most accurate method of prediction was found to be a simple averaging technique. When the treatment specimen was flanked by controls and the average of the two adjacent specimens was used as the prediction value, percent error was greatly reduced. The variations in those predicted values also were markedly reduced.

REFERENCES

GERHARDS, C. C. 1976. Pair matching and strength prediction of lumber. Wood Sci. 8(3):180–187.

HOYLE JR., R. J., AND R. D. ADAMS. 1975. Load duration characteristics of Strand Wood compared to clear Douglas-fir wood and Douglas-fir plywood. Research Report No. 75/57-10, College of Engineering Research Division, Washington State University, Pullman, WA.