MODELING THE LINEAR EXPANSION OF WOOD COMPOSITES

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ABSTRACT

A model is presented that allows the prediction of the LE of a wood composite based on the properties of the raw material. The model disregards the effects of layer discontinuity but takes into account the inelastic behavior of wood in compression across the grain. The model predicts LE values that correspond to minimal values achieved by commercial particleboard but which are exceeded by most. This discrepancy is attributed to the effects of layer discontinuity. The LE requirement of the commercial standard for particleboard is discussed.

INTRODUCTION

The translation under conditions of restraint into sizable buckling and warping deformations of the relatively small linear expansion (LE) of wood composites (Suchsland 1990a, b) and the difficulty of relating these dimensional changes to controllable raw material and process variables have been of considerable concern to both manufacturers and users.

Modeling LE, i.e. trying to express in quantitative terms the gross behavior of the composite in terms of the measurable behavior of the raw materials, is complicated by the unique spatial arrangement in the composite of the individual elements (Fig. 1). Of the two organizational characteristics—randomization of grain direction and discontinuity of the laminas—we will attempt to model the effect of randomization, and will then ascribe the remaining error to the much more elusive effect of the discontinuity.

THE MODEL

Our model for the random composite is a multilayered "star plywood" in which the face and back veneers are arranged at a grain angle of 90°, and in which the grain direction of additional inner plies subdivides the 90° angle into equal segments (Fig. 2). The expansion of this model is identical in the two principal directions, a consequence of randomization. It can be calculated using the following equation, which is based on the assumption of elastic behavior of the veneer layers (Norris 1964; Suchsland and McNatt 1985):

$$\Delta D_{res} = \frac{\sum \frac{E_i \cdot T_i \cdot \Delta D_i}{1 + \Delta D_i}}{\sum \frac{E_i \cdot T_i}{1 + \Delta D_i}} \qquad \text{(a)}$$

$$\Delta D_{res} = \left(\frac{E_1 \cdot T_1 \cdot \Delta D_1}{1 + \Delta D_1} + \frac{E_2 \cdot T_2 \cdot \Delta D_2}{1 + \Delta D_2} + \frac{E_3 \cdot T_3 \cdot \Delta D_3}{1 + \Delta D_3}\right) \div \left(\frac{E_1 \cdot T_1}{1 + \Delta D_1} + \frac{E_2 \cdot T_2}{1 + \Delta D_2} + \frac{E_3 \cdot T_3}{1 + \Delta D_3}\right) \quad \text{(b)} \qquad (1)$$

where

E = layer modulus of elasticity, psi
T = layer thickness, in.
ΔD = layer dimensional change, in./in.

Equation (1a) represents the general case, Eq. (1b) the three-layer laminate. Inputs for the three-layer case are shown below (Douglas fir, relative humidity change from 50 to 80% which corresponds to a moisture content change of 6.8%):

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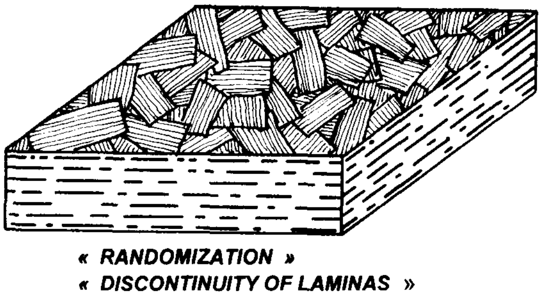

FIG. 1. Organizational characteristics of wood composites.

$$E_1 = E_{long} \quad \text{(at 80\% RH)}$$
$$E_2 = E_{45\,deg} \quad \text{(at 80\% RH)}$$
$$E_3 = E_{(perp.)av} = (E_{tan} + E_{rad})/2 \quad \text{(at 80\% RH)}$$
$$\Delta D_1 = c_{long} \cdot \Delta MC = 0.00007 \cdot 6.8 = 0.0005 \text{ in./in.}$$
$$\Delta D_2 = c_{45\,deg} \cdot \Delta MC$$
$$\Delta D_3 = c_{(perp.)av} = ((c_{tan} + c_{rad})/2) \cdot \Delta MC = ((0.00253 + 0.00160)/2) \cdot 6.8 = 0.0141 \text{ in./in.} \quad (2)$$

where

c = expansion coefficient in./in. %
$\cdot \Delta D$ and E as above

Note that the tangential and radial values are averaged for the "perpendicular" input in order to account for the variability of grain orientation in the elements of a composite.

The expansion of other configurations can be similarly calculated (Fig. 3, upper curve). The shape of this curve demonstrates that the addition of inner plies reduces the strong mutual restraint of face and back veneers until this effect diminishes at about 37 layers and the LE stabilizes at a little over 0.003 in./in. or 0.3%. In a ¾-in. board, this threshold is reached with a veneer thickness of about 0.020 in.

Similar results of earlier studies (Bryan 1962; Xu and Suchsland 1997) had been accepted as validation of the model since they agreed with average LE values of commercial particleboards. The mechanics of plywood expansion, however, is not entirely elastic. Only about 25% of the compression deformation

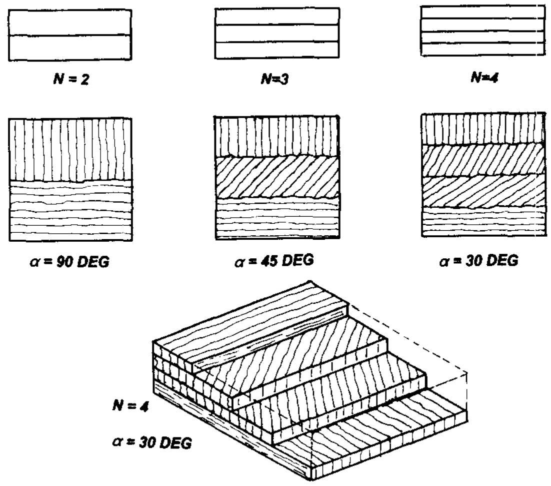

FIG. 2. Star-plywood concept.

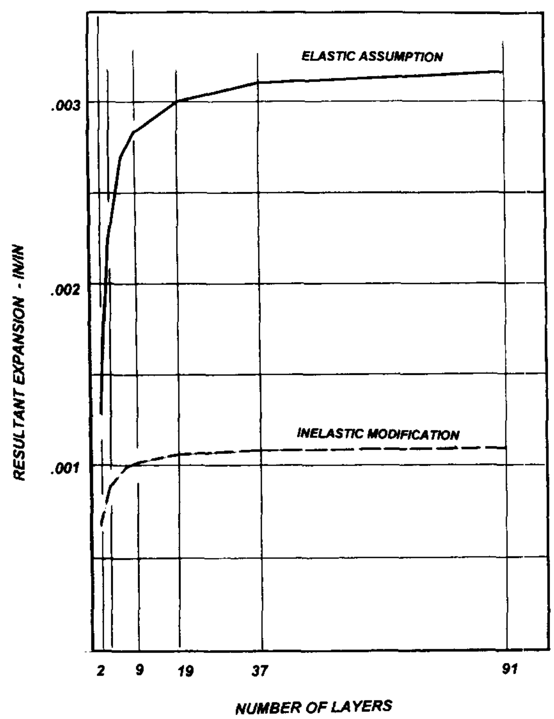

FIG. 3. Resultant expansion of Douglas fir star-plywood as function of number of layers.

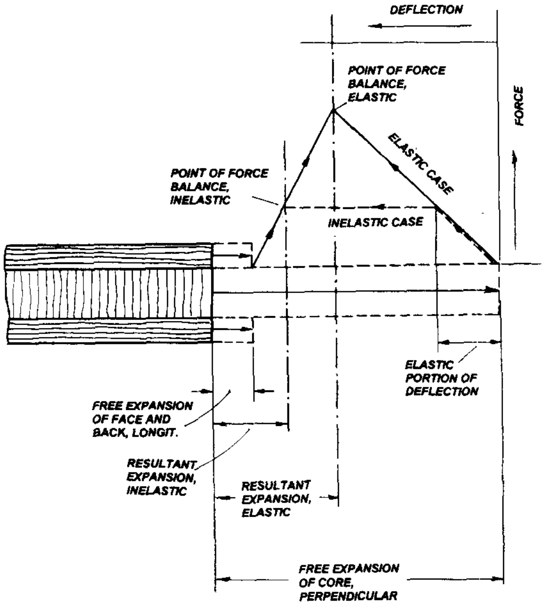

FIG. 4. Schematic illustration of the mechanics of the resultant expansion of a three-ply plywood. Unequal free expansions of core and faces and the presence of the glue line result in a resultant expansion where the compression and tensile forces are in balance. Reducing the elastic compression response of the core shifts the force balance and the resultant expansion to the left.

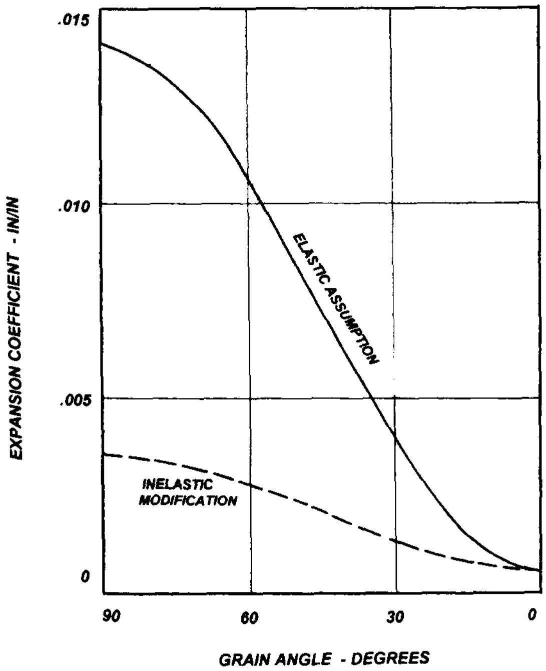

FIG. 5. Reduction of the expansion coefficient to adjust for the reduced elastic response of wood in compression across the grain.

across the grain is elastic strain (Xu and Suchsland 1994). This reduction causes the force balance of the expanding plywood to shift towards smaller expansion values (Fig. 4). Reducing the input (Eq. 1) for the expansion across the grain to ¼ of the full value yields results that fairly predict the actual measured expansion of plywood. No other adjustments are necessary. Figure 5 illustrates this adjustment for Douglas fir. The curves again represent averages of the radial and tangential expansions.

With this modification, Eq. (1) yields the lower curve in Fig. 3 (inelastic modification). This curve levels off at about 0.001 in./in. or 0.1% LE, about ⅓ of the elastic value.

RESULTS AND CONCLUSIONS

The model was applied to three species using both the elastic approach and the inelastic modification. The results are summarized in

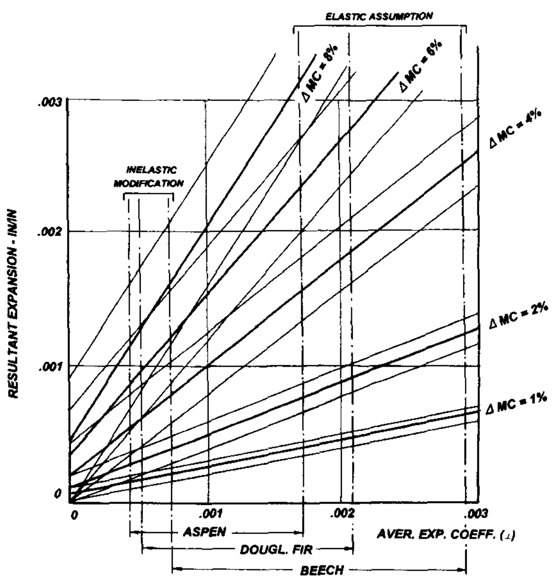

FIG. 6. Resultant expansion of star-plywood (91 layers) of three species and for several moisture content changes.

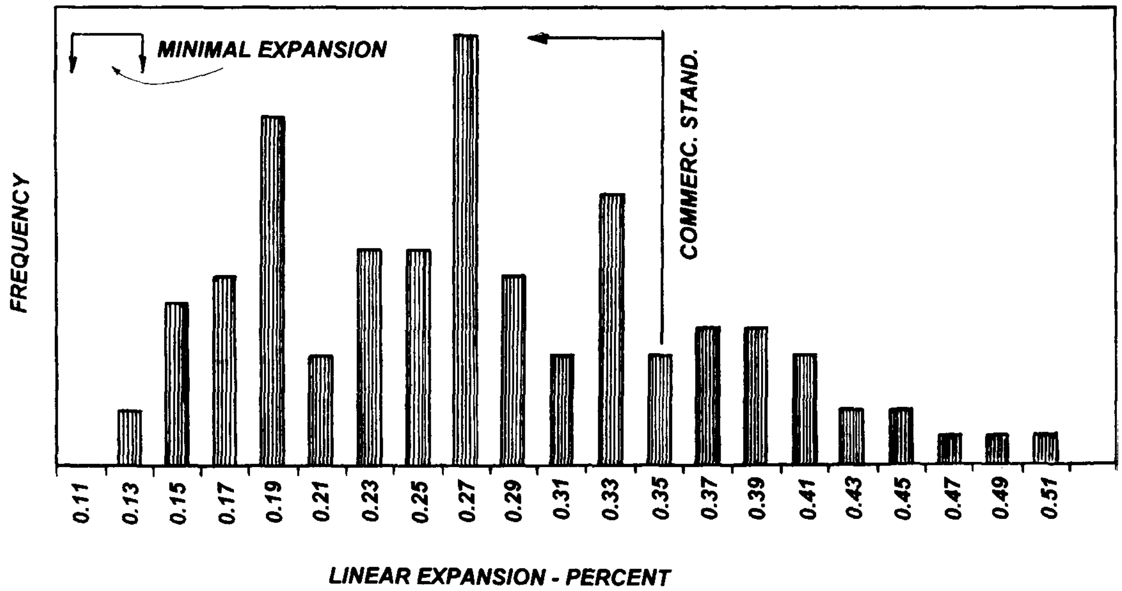

FIG. 7. Linear expansion of industrial grade particleboard in percent (8). Relative humidity interval: 50 to 80%.

Fig. 6. The abscissa shows the average expansion coefficient across the gain. At the right limit of each species range is the true coefficient, at the left limit the adjusted value (25%). The expansion of the star-plywood (91 layers) is shown for a number of moisture content changes. The range around each ΔMC-line indicates the effect of the longitudinal expansion coefficient. This coefficient is equal to zero for the lower line and 0.00014 in./in. for the upper line. For the heavy line, it is 0.00007 in./in. an average value for all species. The effect of the longitudinal expansion on the expansion of the star-plywood is rather insignificant.

For a moisture content change of 6.8% (equivalent to a relative humidity change from 50 to 80%), the expansion for the three species can be estimated to range from 0.0010 to 0.0013 in./in. or 0.10 to 0.13% LE. The expansion coefficient across the grain appears to be the dominant variable. Thus, high density species that have larger expansion coefficients across the grain would result in boards with larger LE values. It must be remembered that the model accounts only for the randomization of the grain direction and not for the discontinuity of the laminas.

Figure 7 shows the results of an industry-wide study conducted by the Composite Panel Association in 1996–97 of the linear expansion of commercial particleboards (Composite Panel Assoc. 1996–97). The calculated expansion of randomized plywood is at the low end of the spectrum. This would suggest that for the boards at the low end, the discontinuity effect is minimal and that their behavior is plywood-like. The much larger expansion values of the bulk of the commercial particleboards are, at least in part, a manifestation of significant layer discontinuities. The severity of these discontinuities, and therefore the departure of the product from the star-plywood model must to a large degree be a matter of particle geometry, and to a lesser degree of species.

This suggests that the manufacturer of a particleboard with large LE (right end of spectrum), in order to substantially improve this property, would have to switch to the species and the particle geometry used by a manufacturer of boards at the left end of the spectrum. But LE is not the only important board property. By changing species and particle geometry in order to improve LE, other important characteristics may be lost, because they may not be achievable in boards that possess the structural prerequisites for low LE.

The commercial standard requirement of 0.35% linear expansion, therefore, appears arbitrary and impractical. It leaves a painfully large group of boards outside of compliance, boards that may be superior in certain aspects to those that are in compliance.

A better policy would be to divide the range of linear expansion into three or four subranges and to identify these subranges in the grade stamp. This would allow that user to whom the linear expansion is critical a choice that he now does not have. And it would eliminate the awkwardness of a standard that is unrealistic and not enforced.

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