Extended Abstract **4-8**

Moisture Diffusion through a Corrugated Fiberboard under Compressive Loading: Its Deformation and Stiffness Response

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Abstract

This research develops a model using finite element to study the response of a panel made of a typical commercial corrugated fiberboard due to an induced moisture function at one side of the fiberboard. The model predicts how the moisture diffusion will permeate through the fiberboard's layers (medium and liners) providing information on moisture content at any given point throughout the structure. The short column is loaded by edgewise compression, all panel edges are simply supported. This is one type of boundary conditions; other boundary conditions can be investgated. The model predicts the deformation response, the loss of stiffness, and the swelling mechanism in all the layers of the fiberboard under the static compressive loading. The parameters studied include the moisture content at different location of the fiberboard's layers as described by the moisture diffusion law.

The Finite Element Model

The FE model as shown in the Figure 1 represents a typical C-fluted geometry of a corrugated panel, Rahman [1]. A 12 in. by 12 in. corrugated panel is subjected to a steady state moisture flow due to rise in relative humidity from 50% to 90% later a transient analysis is possible using a swept sine humidity function similar to the experimental set-up used at the U.S. Forest Products Laboratory in Madison, WI. Urbane [2]. The corrugated fiberboard modeled in this analysis consisted of two facings made from liner material, separated by a medium layer. The liner and the medium will be modeled as 8-node shell elements that allow for curved medium geometry. The liners and medium will be assigned orthotropic stress-strain functions (bilinear orthotropic curves), Saliklis [3] generated from experimental data under variable moisture contents namely 50% and 90% RH. The liner and medium materials are considered orthotropic; the major orthogonal directions are the machine direction (MD), the cross machine direction (CD), and the out-of-plane z-direction. The layers are assumed perfectly bonded at juncture lines. The flow of moisture is considered to propagate in one direction across the thickness of the board.

The compressive mechanical loading is considered first then coupled with the moisture flow and the load deformation curve of the fiberboard is generated. The results will be compared with a similar experimental set-up performed at the Forest Product Laboratory.

Theoretical

A derivation of two essential properties namely the coefficient of moisture conductivity D_w and the coefficient of moisture expansion a for the liner and the medium materials are needed to make the finite element analysis possible. These constants are not available in the literature for

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these materials. Therefore, FEA is used first to derive these constants. The research work by Margot Sehlstedt-Persson [4] is expanded to obtain the coefficient of moisture diffision per unit mass for a solid material such as paper.

$$\frac{D_w}{m} = \frac{100x}{tA\, r\, DM}$$ [m/(kg s^2)]. Where, D_w = vapor diffusion coefficient [m/s^2]

m = mass of water transported in time t [kg], x = sample thickness [m], t = time [s]

A = area [m^2], r = basic density (dry weight, raw volume) [kg/m^3], DM = moisture content difference[%].

Applying this expression to liner and medium material for the dimensions of the corrugated fiberboard. For liner material with basis weight = 0.203 kg/m^2, the $\frac{D_w}{m}$ = $4.69\text{x}10^{-10}$ m^2/(g-s), and $\frac{D_w}{m}$ = $9.24\text{x}10^{-10}$ m^2/(g-s) for medium material. These constant are used as input in a FE model. The determination of the coefficients of moisture expansion a for liner and medium materials are obtain by constructing A 12 in. by 12 in. plate and given the material properties of liner and medium one at a time. The plate was subjected to uniformly compressive loading. The actual stress strain diagram for the material is used as an input at 50% RH and the a coefficient is varied until the stress strain diagram at 90% RH is reached. The plate is subjected to moisture stress analysis coupled with mechanical stress analysis.

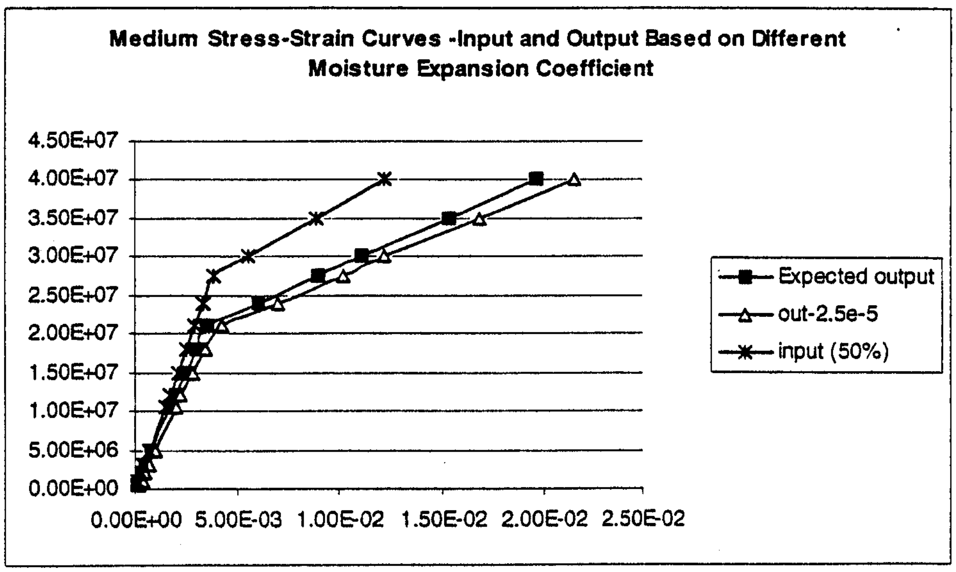

Figure 1: Medium stress-strain curves at 50%RH (upper) and at 90%RH (lower) for the targeted value of coefficient of moisture expansion.

Results

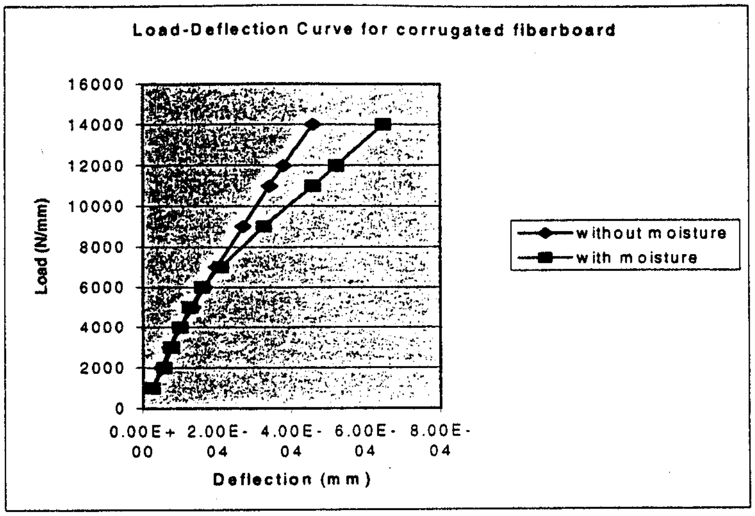

Figure 2: Loss of fiberboard strength due to moisture diffusion (50%RH to 90%RH)

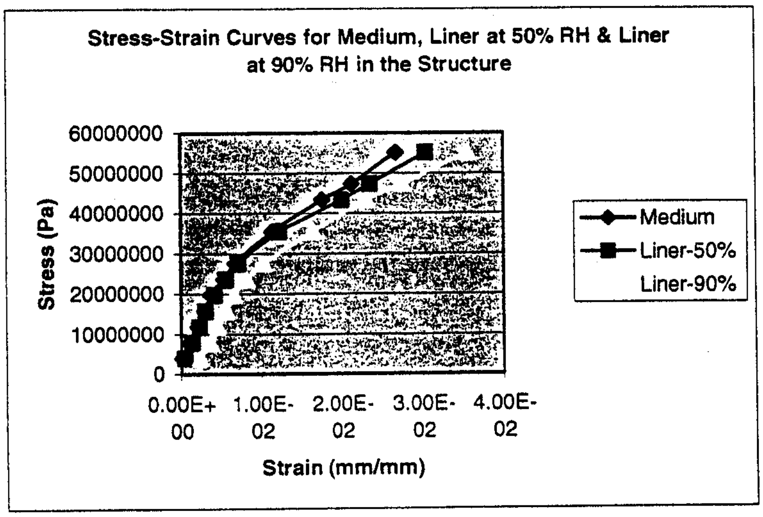

Figure 3: Loss of strength in linear due to RH chance from 50% to 90%

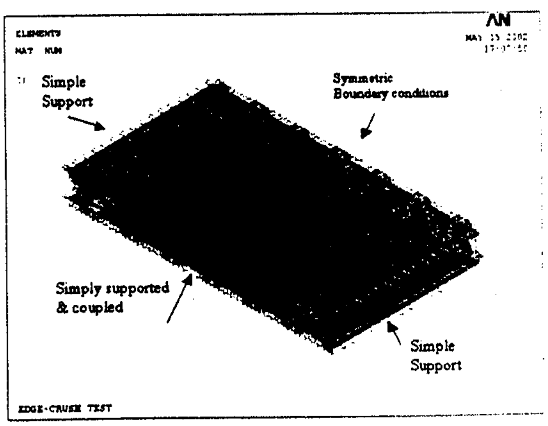

Figure 4: Fiberboard

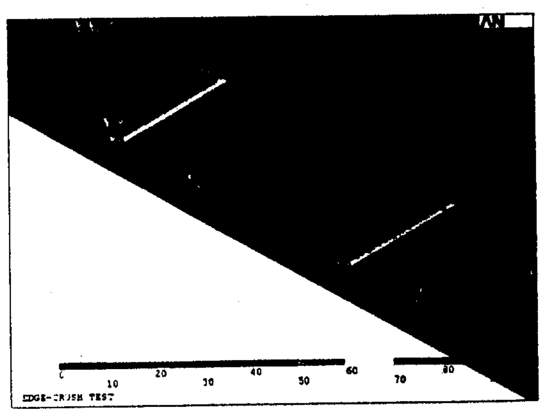

Figure 5: Moisture diffusion from 90%RH to 50%RH

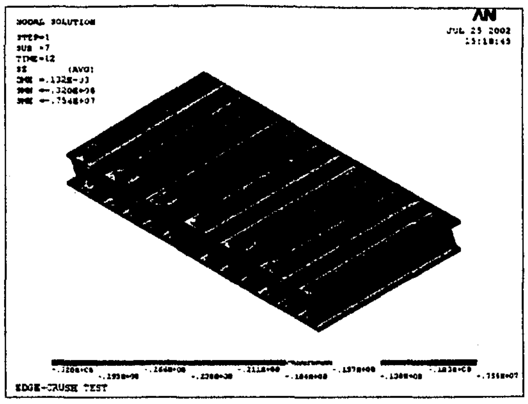

Figure 6: Axial Stress Distribution

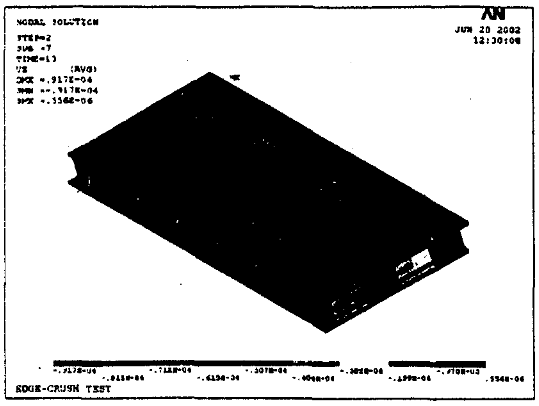

Figure 7: Axial Deflection

Discussion and Conclusions

High levels of stresses are visible at the connecting lines between liners and medium, this is in general agreement with experimental observations. Clear loss of strength (up to 22%) in the fiberboard structure as demonstrated by figure 2 due to 40% rise in relative humidity. Moisture flow in the fiberboard for the steady-state flow is a hear function as shown in figure 5 in accordance with the one-dimensional flow equation. The analysis is able to predict the coefficient of moisture conductivity per unit mass of water and the coefficient of moisture expansion a for the liner and the medium materials using analytical and numerical methods.

Acknowledgements

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