INFLUENCE OF TECHNOLOGICAL AND STRUCTURE PROPERTIES ON SHAPE OF ASYMMETRIC PLYWOOD SHEET

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ABSTRACT

The paper presents a numerical study of the technological process and plywood structure (veneer arrangement and thickness) influence on the shape of the sheet. The technological process after the gluing process, including the conditioning of the sheet in various moisture-temperature conditions is numerically modeled. Technological treatment- conditioning produces the stress-deformation field in the sheet. The behavior of wood material produce the stress-deformation field change in time. The standard linear solid model constitutive model of material is used in the analysis. The coupled moisture- temperature- stress analysis is done by using the Finite element method. The moisture- temperature conditions on the boundary of the sheet is defined by polynomial equations. The rational moisture-temperature conditioning parameters and plywood structure are proposed that provide the necessary shape of the sheet and its stability in time.

Key words: Technological process, plywood structure, standard linear solid model, stress-deformation field

INTRODUCTION

Rational structures with minimal material consumption and weight is one of the main research fields in today's structural engineering science. Wood resources could be rationally used (with small amount of sawdust and other less useful materials) by making plywood sheets. It is very popular to use flat plywood sheets in building as load bearing elements or covering elements. From the structural engineering point of view more effective it is to use curved plywood shells than flat sheets because of better cross section characteristic- second moment of area. The main obstacle for using curved shells is its difficult and expensive manufacturing. It could be significantly simplified by making the sheet with special asymmetrical structure and curved using veneer orthotropic moisture expansion properties. The curvature is obtained after gluing flat sheets with standard techniques and than conditioning in special moisture- temperature conditions (Šliseris, Rocēns 2010). The sheet with asymmetrical structure is more sensitive to moisture-temperature change and structure imperfections (Sliseris, Rocēns 2010). The special moisture-temperature conditioning has to be projected for the sheet to obtain the necessary shape. In many works the moisture diffusion problem is analyzed, for example (Olek, Weres 2007). The coupled moisture-temperature diffusion problem is considered in many works (Avramidis, Englezos, Papathanasiou 1992, Wook, Woo, Chang, etc. 2008).

There are many works where the moisture-stress problem is solved in small, idealized wood samples (Fortino, Mirianon, Toratti 2009, Jönsson 2005).

In many works composite structures are optimized including wood structures that are affected by mechanical loading or moisture-temperature loadings (Sliseris, Rocens 2011, Goremikins, Rocēns 2010, Goremikins, Serdjuks 2010, Brauns, Rocens 2008). In very few works the temperature-moisture diffusion problem in modified wood (plywood) is solved. In the literature there is not any work dealing with the moisture-temperature-stress problem in plywood sheets with asymmetrical structure. This problem is numerically studied in this work.

NUMMERICAL METHOD OF MOISTURE-TEMPERATURE-STRESS ANALYSIS

Moisture analysis

The moisture analysis is done by using one dimensional moisture transfer model. It is assumed that moisture distribution through the thickness of the sheet is the same in any place of the sheet. Mathematically the moisture diffusion is modeled by the Fiks law (Liping 2005, Olek, Weres 2007):

$$\frac{\partial m}{\partial t} = \frac{\partial}{\partial z}\left(D\frac{\partial m}{\partial z}\right), \quad -a < z < a, \quad t > 0 \qquad (1)$$

where m- moisture content (dimensionless), z- coordinate, on axis perpendicularly to the sheet surface, t- time, D- moisture diffusion coefficient ($\frac{m^2}{h}$), that is calculated by the following equation (Wook, Woo, Chang etc 2008):

$$D = 5.76\exp\left(1.45m - \frac{5280}{T}\right) \qquad (2)$$

where T- temperature (K).

The moisture diffusion coefficient depends on temperature T, therefore, the moisture diffusion process depends on temperature diffusion.
The following initial and boundary conditions are used in the analysis:

$$m(z,t=0)=m_0$$
$$D\frac{\partial m}{\partial t}=k_m(m-m_0),z=\pm a,t>0 \quad (3)$$

where k_m – surface moisture emission coefficient.

Temperature analysis

Temperature analysis is done by using the classical Fourier law :

$$\rho(m)c(m,T)\frac{\partial T}{\partial t}=\nabla(\lambda(m,T)\nabla T) \quad (4)$$

where ρ – density of plywood (kg/m3), $c(m,T)$ – specific heat of plywood, $\lambda(m,T)$ – heat diffusivity coefficient, ∇ – Nabla operator (partial derivative with respect to coordinate).

The following initial and boundary conditions are used in simulation:

$$T(z,t=0)=T_0$$
$$-\lambda(m,T)\frac{\partial T}{\partial t}=h(T-T_{sur}),z=\pm a,t>0 \quad (5)$$

where h- surface temperature emission coefficient for plywood assumed it to be $h=25\frac{W}{m^2K}$ (Fortino, Mirianon, Toratti 2009), T_{sur} – surrounding temperature (K).

Stress analysis

Typical plane stress shell element is used (Zienkiewicz, Taylor 2000). In the stress analysis the results from moisture and temperature analysis are used to calculate moisture caused stress (Ranta-Maunus 2003, Brauns, Rocens 2004). The total time is divided in small time steps and in each step the calculated stress value is corrected according to the standard linear solid model that consists of elastic spring in series of dashpot that is parallel to other spring elements. The constitutive equation is defined by the standard linear solid model, that could be used for solving technological problems of wood (Ugolev 1971, Rocens 1979):

$$n\frac{\partial\sigma}{\partial t}+\sigma=nH\frac{\partial\varepsilon}{\partial t}+E\varepsilon \quad (6)$$

where n- relaxation time (min), σ – stress component (MPa), ε – deformation component, H- instantaneous Joungs modulus (MPa), E- long term Joungs modulus (Mpa).

Using the mentioned constitutive equation in each time step the stress distribution curves that are obtained by the Finite element analysis are corrected. The stress values are corrected in particular points (in this case there are used 19 points) through the thickness of the sheet. Assumed that there is no shear deformation through the thickness of the sheet and deformation values through the thickness of the sheet could be approximated by linear equation. The stress-strain values are corrected in the direction of the main deformations without interactions to other directions. In addition two equations are used- the total internal force and moment should be zero, because there is no external moment of force. The final system of equation is the following:

$$\begin{cases} n_1\frac{\partial\sigma_1}{\partial t}+\sigma_1=n_1H_1\frac{\partial\varepsilon_1}{\partial t}+E_1\varepsilon_1 \\ \cdots\cdots\cdots \\ n_{19}\frac{\partial\sigma_{19}}{\partial t}+\sigma_{19}=n_{19}H_{19}\frac{\partial\varepsilon_{19}}{\partial t}+E_{19}\varepsilon_{19} \\ \int_{-a}^{a}\sigma dz=0 \\ \int_{-a}^{a}\sigma\cdot zdz=0 \end{cases} \quad (7)$$

The system of equation (7) is used to correct the values of stress and deformations. The displacements, curvatures are obtained using the small deformation theory (Zienkiewicz, Taylor 2000). The rheological coefficients are dependent on temperature and moisture. It is assumed that only rheological coefficients in tangential direction of wood depend on temperature and moisture. The relationships are the following (Ugolev 1971) (when stress is under 85% of strength of wood):

$$H(m,T)=2235.15-7007m-\ldots$$
$$22.7T+28.58mT+5700m^2+0.079T^2 \quad (8)$$
$$E(m,T)=574-926m-\ldots$$
$$3.76T-9mT-5460m^2+0.0026T^2 \quad (9)$$
$$n(m,T)=294.7-1236m-\ldots$$
$$1.36T+3.17mT+1380m^2-0.00063T^2 \quad (10)$$

RESULTS OF MOISTURE-TEMPERATURE-STRESS ANALYSIS

In the numerical analysis a sheet with total thickness 20 mm was simulated. The total thickness of the layers that are orientated in longitudinal and shear direction are h_2, h_1, respectively. The initial moisture content of the wood is 6% and final moisture content 12%.

Three different temperature conditioning regimes (TCR) are simulated. In each TCR there are different air temperature change relationships with respect to time. These relationships are shown in Fig. 4.

Before stress analysis moisture-temperature diffusion in the sheet transversal direction was simulated. The surface of temperature and moisture distribution in time through the thickness of the sheet is shown in Figure 1 and Figure 2.

The obtained moisture and temperature distribution curves were used in stress analysis. In all three TCR the stress- deformation state of the plywood sheet was analysed. In Figure 3 the main curvature of the sheet depending on time for three temperature conditions is shown. The linear model indicates that there was used the linear relationship between stress and strain instead of rheological equations (6). It can be figured out that in this range of parameters used in the numerical experiment the difference in linear and nonlinear analysis is approximately 25%. The results for various TCR changes are in range of 5%.

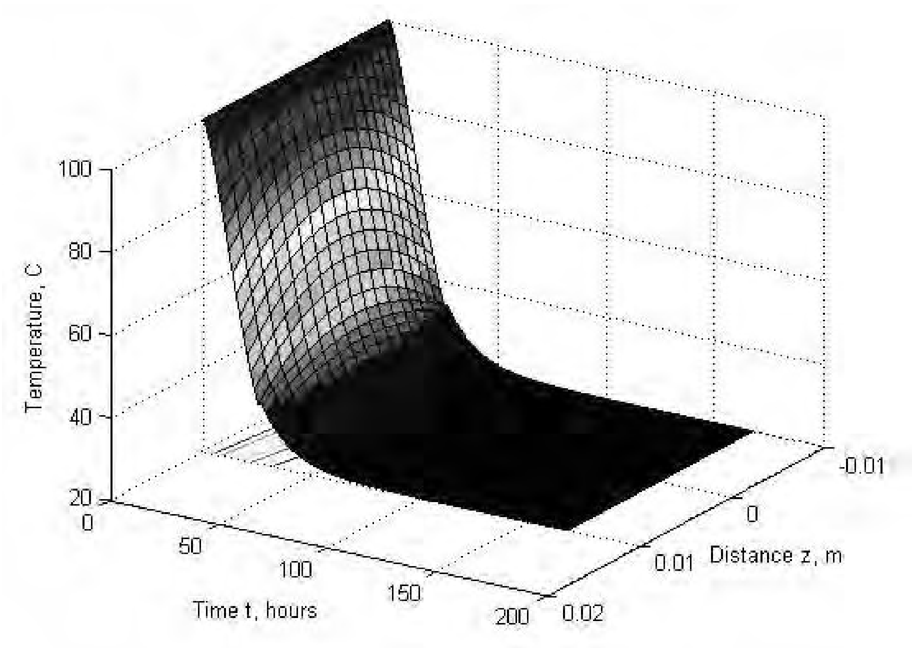

Figure 1. Temperature distribution through the thickness of the sheet in time in 1. TCR.

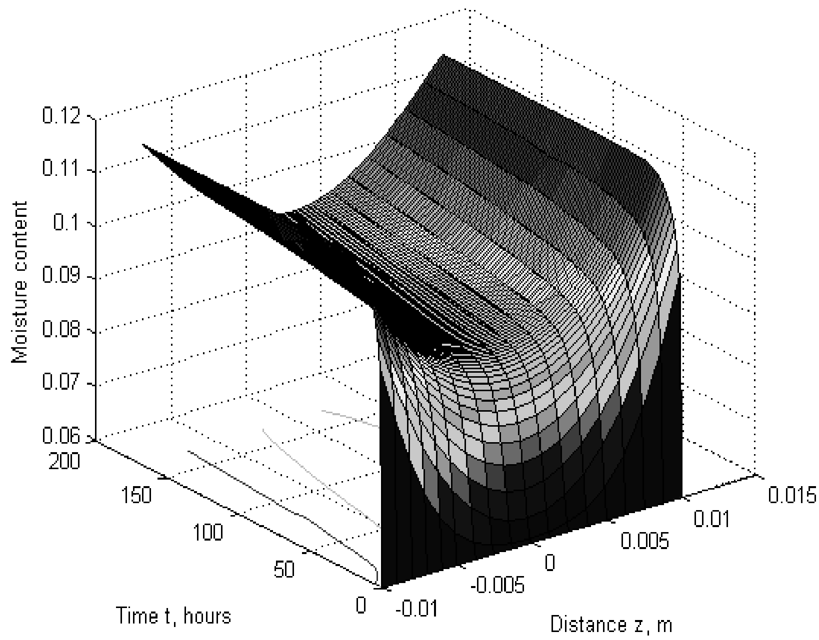

Figure 2. Moisture content distribution through the thickness of the sheet in time in 1. TCR.

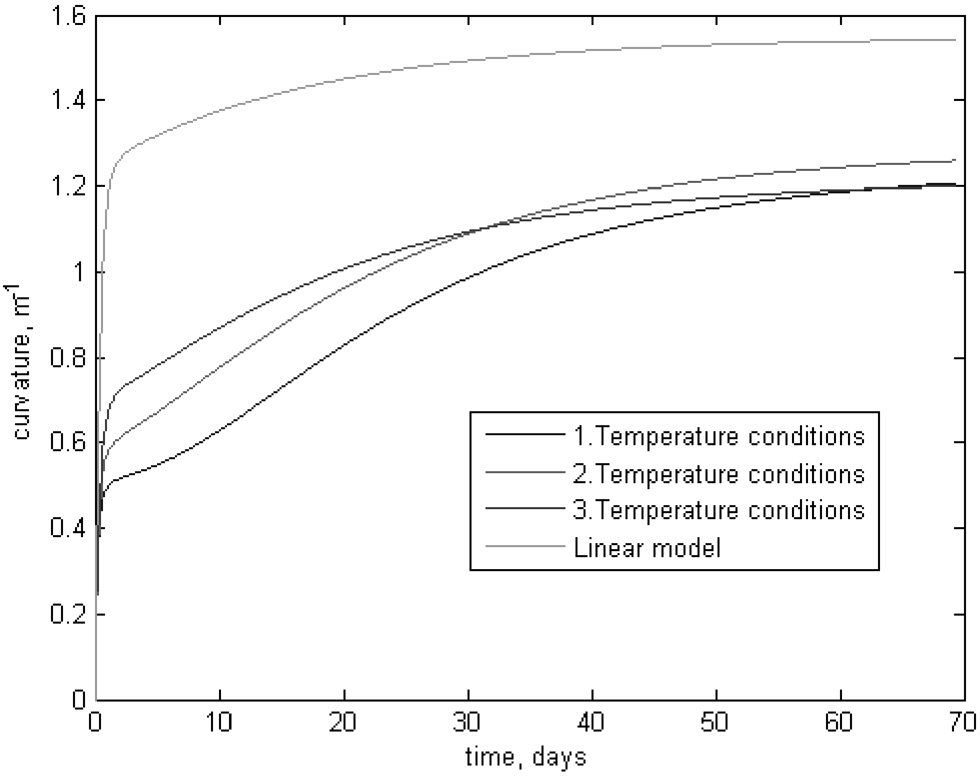

Figure 3. Curvature of the sheet depending on time for various TCR (see Fig. 4.).

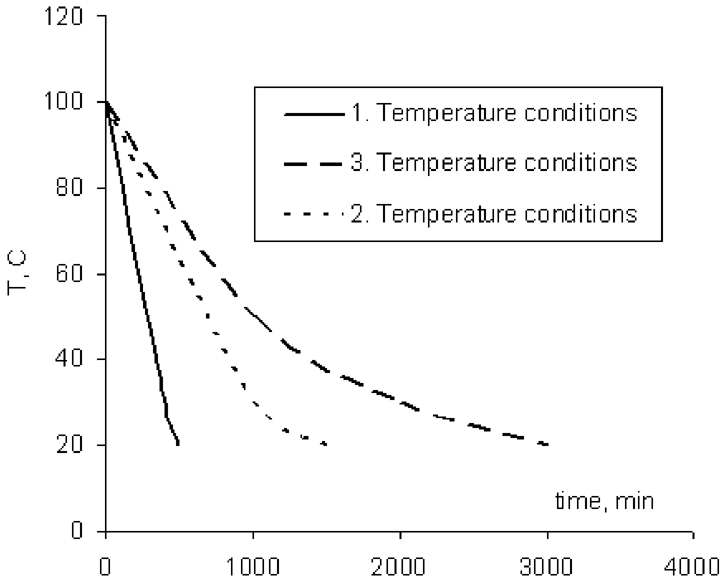

Figure 4. Temperature conditioning regimes (TCR).

In other numerical experiments the curvature of the sheet change in time for various ratios of shear and longitudinal layer thickness were analyzed. The obtained results are shown in Figure 5. It could be seen that in this range of ratios the curvature is increasing when the ratio is increasing. Although there the ratio when the maximal curvature is obtained is between 5..7, depending on veneer properties and TCR and moisture regimes. In case if there are very large ratios then the shape stability is significantly decreased.

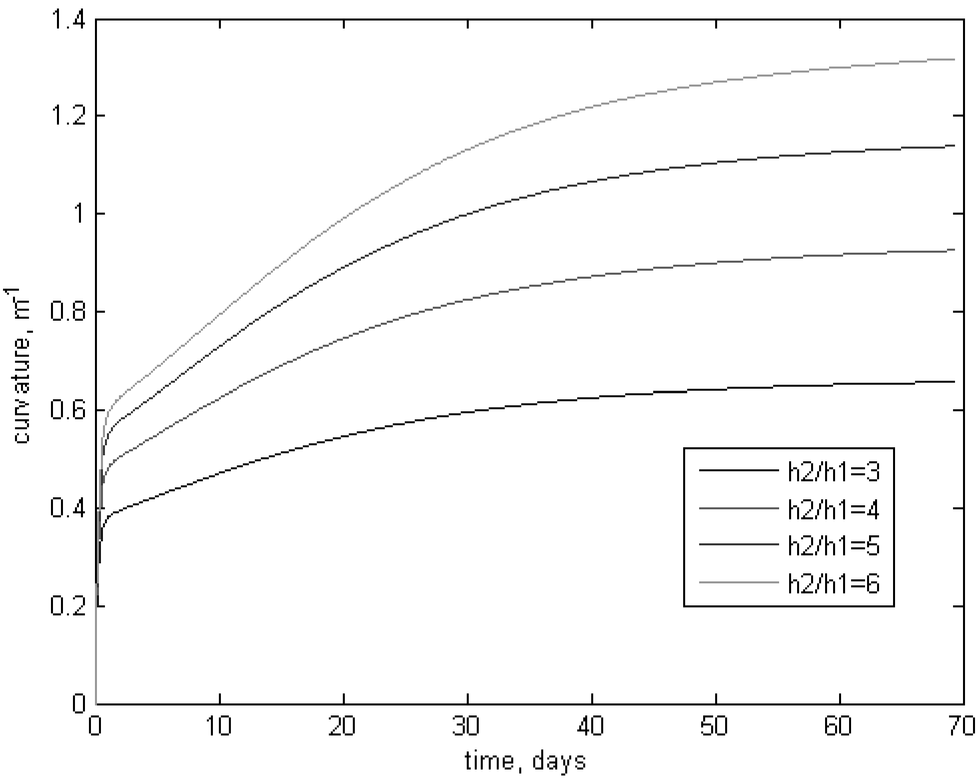

Figure 5. Curvature dependence of the structure of the sheet (ratio of shear and longitudinal layers thickness).

CONCLUSIONS

The influence of temperature conditioning regime and structure of asymmetrical with respect to mid surface plywood sheet are obtained by solving the coupled moisture-temperature-stress problem.

The temperature conditioning regime affects the final shape of the sheet in the range of 5 %. The maximal curvature of the sheet in the shortest time could be obtained by using the linear temperature conditioning regime with total time approximately 20..30 hours.

The results show that rational ratio of thickness of longitudinal and shear layers vary from 5..7 that gives maximal curvature of the sheet and provides shape stability in a long period of time.

The wood rheological properties inclusion in the analysis change the results in the rage of 20..25% compared to the linear analysis.

In future the proposed model that takes into account rheological properties of plywood with experiments and other models should be verified.

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