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TEMPERATURE ENVIRONMENT

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ABSTRACT

The paper presents partial results of an ongoing project dealing with thermal diffusion and mechanical behavior of spruce wood in high temperature environment (up to 180°C). The objective of this part of study was to obtain rheological properties of spruce wood which will be used in future modeling of wood performance in high temperatures. Oven dry samples (30 x 30 x 700 mm^3) underwent constant mechanical loading in bending parallel to grain (σ_{max} = 7.3 MPa, load span 600 mm) at three temperature levels, namely 120°C, 150°C and 180°C, respectively. Deflection of the samples was measured using optical non-contact method. Four rheological parameters of Burger's model, describing immediate elastic, delayed visco-elastic as well as plastic (permanent material change) behavior, were determined which show the strong influence of the temperature on creep propagation. Experimental setup, results and further application in the modeling of high temperature treatment are discussed.

Keywords: creep, rheology, wood, high temperature treatment, spruce

INTRODUCTION

Properties of polymeric materials such as wood are strongly influenced by temperature and these properties include mechanical properties and rheological properties. In some cases, wood is exposed to high temperature environment (high temperature drying, pressing, bending, or wooden buildings under fire). Rheological properties are defined as a change of stiffness or strength due to elapsed time or moisture content change under loading. Several approaches have been used to describe creep behavior in wood. Haque et al. (2000) showed that Kelvin model and Burger's model fitted the wood rheology data satisfactorily. Burger's model (Maxwell and Kelvin rheological models in series) consists of four dash and spring type elements, which describe immediate elastic, delayed visco-elastic as well as permanent material change (plastic) behavior (Bodig and Jayne 1993). The model is more suitable for materials whose compliance under constant loading does not reach the plateau.

There are numerous studies dealing especially with low temperature conditions up to 130°C (Fridley et al. 2000, Babiak and Boruvka 2000, Haque et al. 2000). However, the objective of this study was to perform creep tests and obtain rheological characteristics of spruce wood, which will be used for future modeling of the wood performance in the high temperature environment.

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MATERIALS AND METHODS

Spruce wood from one tree stem was used for preparation of samples which have dimensions of 30x30x700 mm (RxTxL). After the preparation, the samples were stored in a dry room so that moisture content of the samples slowly dropped down to 6-8%. Prior to experiments, the samples were oven dried at 103 ± 2 °C. Four specimens at each temperature level were used for the measurement of the rheology properties.

The test equipment is shown in Figure 1 in which the specimen was loaded with four point bending. Before the loading, the specimen was heated to the desired temperature (120°C, 150°C or 180°C). During the test, hot air was circulated through a heating units and the test chamber to keep uniform temperature around the test specimen. One creep test at constant load lasted for 3 days. The load (F) was adjusted to 10% of failure load at MC 12% (F_{12}):

$$F = 0.1(F_{12}) \qquad (1)$$

The wood failure load was calculated from MOR of spruce at MC 12% (MOR = 73 MPa) given by Pozgaj et al. (1997). In order to keep exact stress at the outer fiber, the load varied from 399 to 429 N depending on the cross section of loaded specimens.

At the high temperature environment, deflection of the loaded specimen was measured using optical non-contact method (Lagana *et al*., 2007). The optical system was 8 m away from heated specimen therefore it was not affected by the high temperature in the test chamber. The system consisted of digital camera Canon EOS 350, 300mm Tamron lens, and a laptop used for data acquisition and image analysis. On each specimen, thin aluminum crosses were placed on the neutral axis at the loaded and supporting points as well as at the mid-length position of the specimen. Displacement of these crosses was measured using Digital Image Correlation technique in Shelrock™ software. The precision of measuring deflection for such setup was 0.1mm (Lagana *et. al.* 2007)

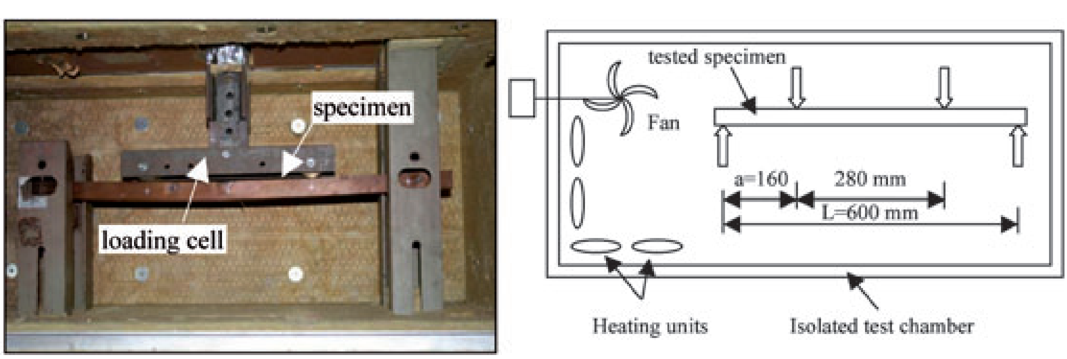

Figura 1: Details of the test setup and a loaded specimen in four point bending.

Apparent modulus of elasticity (E_{app}) of bended rectangular specimens loaded by two symmetrically forces was calculated according to ASTM D198:

$$E_{app} = \frac{Fa}{4bh^3\Delta}\left(3L^2 - 4a^2\right) \qquad (2)$$

where F is total load evenly distributed to two symmetrical loading points, L is the span of specimen beam, a is the distance between the supporting location and the nearest loading point, b and h are dimensions of the specimen beam and Δ is the deflection measured at neutral axis between the supporting location and the center of the specimen beam.

Assuming linear viscoelastic behavior is valid for low constant load, creep behavior of the wood in terms of compliance can be described by four parameters in Burger's model (Bodig and Jayne 1993):

$$\frac{1}{E_{app}} = J_{app} = \frac{1}{E_e} + \frac{1}{E_{ve}}\left(1 - e^{-\frac{E_{ve}}{\eta_{ve}}t}\right) + \frac{1}{\eta_{pl}}t \qquad (3)$$

where the four parameters are E_e, E_{ve}, η_{ve} and η_{pl} representing, respectively, the modulus of elasticity, the modulus of viscoelasticity, coefficients of viscoelasticity and plasticity at high temperature environment. t is the duration of the loading. These parameters were determined from a measured curve of apparent compliance J_{app} using the least square fitting method.

RESULTS AND DISCUSSION

As an example of the test result, the measured and fitted compliances at a temperature of 180°C are shown in Figure 2.

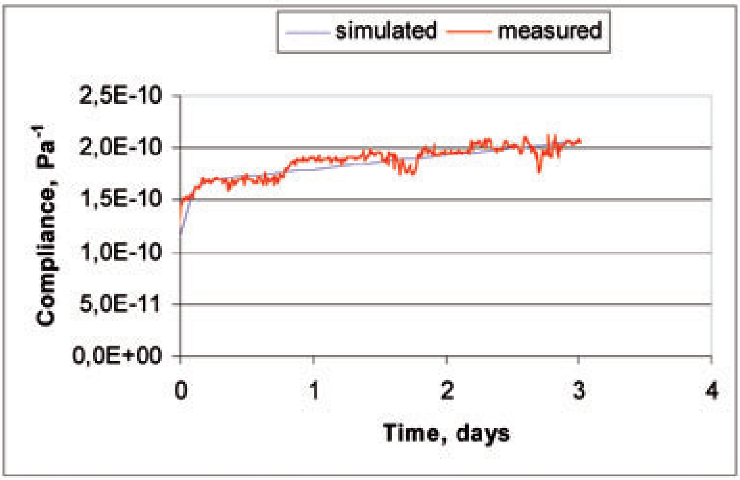

Figura 2: Measured and simulated compliances at 180°C.

From the results, it is seen that even after 3 days of loading, the creep of wood is not significant indicated by the relatively smooth change in the compliance. Significant creep would result in a reduction in E_e and an increase in J_{app}.

Creep parameters represented by E_{ve}, η_{ve} and η_{pl} do not show normal distribution. To obtain average value, we have to use natural logarithmic transformation. The final result of the creep parameters at different temperatures after back transformation is given in Table 1.

Table 1 Average creep parameters at different temperature levels

	unit	120°C	150°C	180°C
E_e	Pa	1,20E+10	1,28E+10	9,86E+09
E_{ve}	Pa	4,55E+10	4,05E+10	1,33E+10
η_{ve}	Pa s^{-1}	3,59E+14	2,21E+14	8,57E+13
η_{pl}	Pa s^{-1}	1,64E+16	1,60E+16	3,13E+15

The influence of temperature on the Burger's model parameters are shown in Figures 3 (a) – (c).

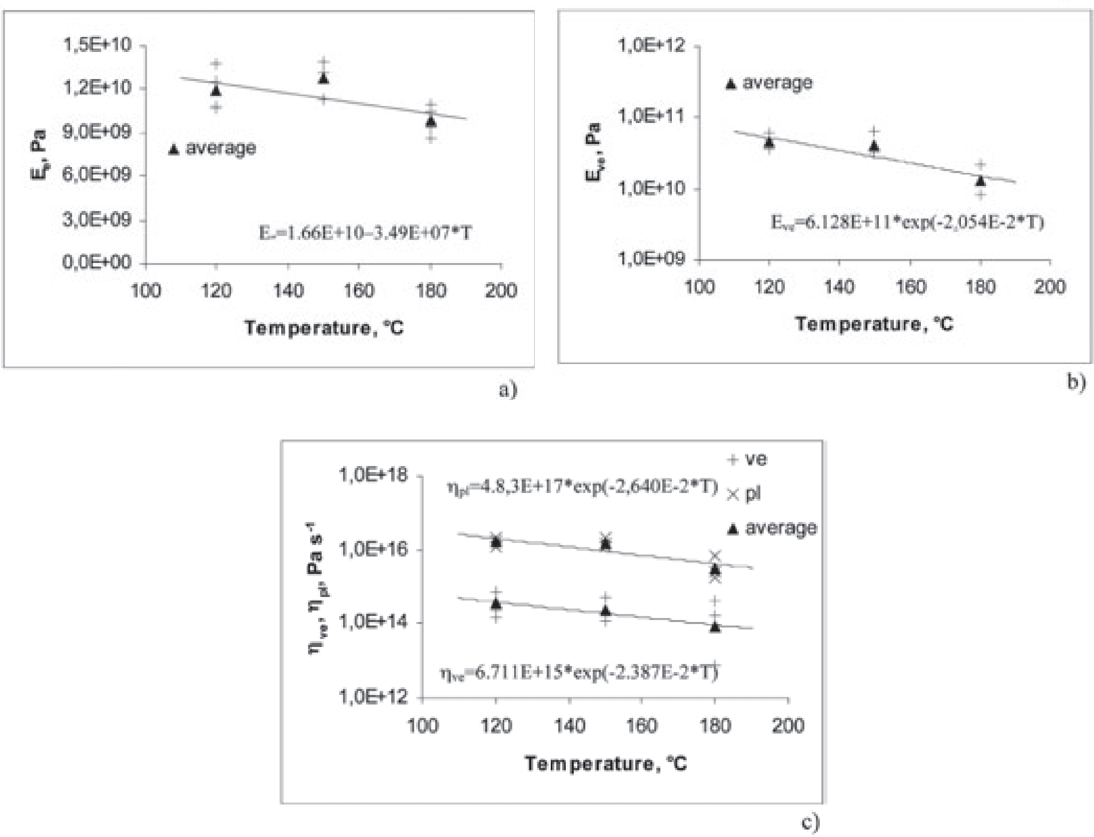

Figura 3: Influence of temperature on of the rheology parameters: a) E_e,b)E_{ve}, c) η_{ve} and η_{pl}.

All of the four parameters decrease with increasing temperature. Rising the temperature causes increase in the elastic deformation, the rate of deformation as well as creep. The root of this observation dwells in plasticization of native lignin in wood at high levels of temperature as well as de-polymerization that occurs in hemicelluloses.

Well characterized and well determined material properties are foundation for proper modeling of the wood creep feature. These parameters could be used in evaluation of wooden elements' performance under mechanical loading while being exposed to high temperatures. Such approach will take into account coupling effect of temperature and stress-strain relation of a constitutive model.
It should be mentioned that the observed creep also covers the permanent deformation that occurs due to high temperature.

CONCLUSIONS

The parameters of creep Burger's model have been determined from experiments. It has been shown that the material parameters of spruce wood are strongly affected by the environment temperature. All of the four rheological parameters of Burger's model decrease with increasing temperature. In order to get average values of parameters E_{ve}, η_{ve} and η_{pl}, natural logarithmic transformation method was used.

Further study will determine the level of linearity of the above parameters as a function of temperature at high temperature levels and, based on the experimental results, build a model for description of the wood performance in high temperature environment.

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