WOOD RESEARCH
51 (4): 2006
11-22

INFLUENCE OF GLUING TECHNOLOGY ON VISCOELASTICITY PROPERTIES OF LVL

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SUMMARY

Influences of conventional hot (CH) and high frequency (HF) gluing on some relevant physical and mechanical characteristics, and creep at constant load and high humidity have been researched for LVL made from beach peeled veneer. The Standard linear and four-parameter viscoelasticity Burger model were considered. Unknown model parameters were determined according to the experimental creep results and the method of the least squares. Obtained results for different gluing procedures were showed and discussed.

KEY WORDS: LVL, conventional hot gluing, HF gluing, creep, viscoelastic model

INTRODUCTION

In wood industry gluing is the most spread technological procedure for wood bonding, as in wood parts industry, furniture production, civil construction and carpentry as well.

In order to speed the gluing process, the glue and wood warming is carried out at proposed temperatures, depending on gluing regime.

Different warming procedures and wood gluing have been developed recently. There are two procedures that are the most often applied in industry: Indirect (contacting) – conventional hot gluing (CH), direct (dielectric) – high frequency (HF) gluing. The essential differences between CH and HF gluing are in the manner of material warming, temperature and moisture content and gluing time. During use of glued parts the glued joint is exposed to relatively intense loading that cause different deformations as the result of the following factors: Loading extent, load forms (static, dynamic and cyclic), load duration time, temperature changes and humidity changes.

For stability analysis of product construction that is exposed to loading, it is important to know the relation between deformation (ε) and stress (σ). It was considered for a long time that linear dependence of stress and deformation was sufficient for product construction design (Hook's law). It was known that during long loading periods wood-bending strength becomes smaller. In practice, the difference between behavior of wood products and the result carried out according to Hook's law has been shown. The ratio between stress and deformation was not linear in the whole area and deformation was not entirely recovered. In 1947 "Madison curve" was published with the explanation that construction stability and life depended on loading history. By knowing viscoelasticity materials characteristics, good agreement of estimated results and real behavior of wood products has been reached. Wood and wood products have elastic and viscous characteristics and belong to viscoelasticity materials.

Viscoelasticity wood behavior is very complex and current theories describe it as unsteady relations between time, forces, deformations, temperature and moisture content. The two important characteristics of viscoelasticity behavior during the time are the creep at constant stress and stress relaxation at constant deformation. It is expected each product to optimally serve its purpose and to have as less production costs as possible.

Problems of influence of humidity changes and deformation during gluing on mechanical and rheological characteristics have recently realized many authors.

Klasnja and Kopitovic (1992) studied juncture strength of three-layer beech board glued with phenol - formaldehyde glue at temperature 155 °C and 170 °C and gluing time 11 and 15 minutes. They found out that increased temperature and longer time considerably influenced on glue joint strength.

Resnik and Sega (1994) studied thickness loss at conventional hot gluing of three-layer fir boards. The results showed that increased gluing temperature in all the samples caused unrecoverable thickness losses. The influence of temperature on thickness loss is bigger at higher gluing pressures and also the pressure influence is higher at higher temperatures. Moisture content in wood acts as a plasticizer and with higher moisture content creep increases (Schniewind 1968, Bodig and Jayne 1982). It is easier to measure larger deformations and it is the reason why most of creep studying is performed with bending loading. The least explained phenomenon is wood creep at cyclic humidity changes. Deformation – deflection is higher at one or more cyclic humidity changes than if the specimen is exposed to any of two extreme constant humidity contents. Armstrong and Kingston (1960, 1962), Hearmon and Paton (1964) described this phenomenon. Also, the creep extent depends on moisture contents and moisture gradient. Grossman (1976) explained this phenomenon and he called it out "Mechano-sorptive creep". Models of mechano-sorptive creep are often based on the assumption that the total strain, and its rate can be separated into four parts, Bengtsson (1999) and Srpcic et al. (2000):

$$\varepsilon = \varepsilon_e + \varepsilon_{vc} + \varepsilon_{ms} + \varepsilon_s$$

where ε_e is the elastic strain; ε_{vc} is the viscoelastic strain; ε_{ms} is the mechano-sorptive strain; ε_e is the shrinkage and swelling strain. The important explanations of mechano-sorptive creep mechanism were given by Hoffmeyer and Davidsson (1989), Hunt (1989, 1999), Hanhijari and Hunt (1998), Toratti (1992), Morlier (1994), Bengtsson (1999). From these and other researches, influential factors on mechano-sorptive creep can be summarized as anatomical structure wood, stress, stress history, time, moisture contents, moisture contents change, moisture contents history and temperature change.

Constant loading was realized by weights (Fig. 2 position 6). Mass of weights together with press device was 35.94 kg, which is 17.5 % of the maximal loading (sample fracture). The force was *F*=352.45N. Electrical provider LVDT (linear variable differential transformer) with accuracy ±0.0025 mm was used for deflection measuring. By means of electronic computer card A/D, the processor records data in the first 10 seconds with 5 data in a second, the next 600 s with one datum every two seconds, and then one datum every 600 s.

Cycle duration for different moisture contents is determined by experience according to preliminary experiments. Creep was investigated for four cycles of humidity change, two moistening (94 %) and two dryings (33 %). Formerly specimens were exposed to standard air condition (T=20 ^{o}C; φ=65%). First cycle was moistering with duration 21 days, and next three cycles alternately 15 days each.

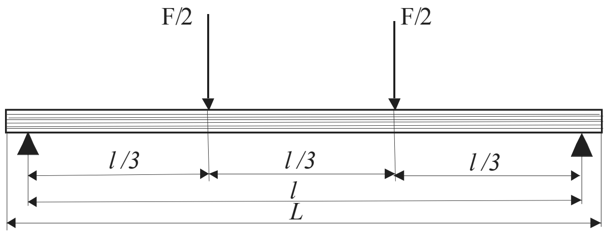

Fig. 3: Loading scheme with concentrated forces at creep test (L = 520 mm; l = 480 mm)

Experimental measurements for determining rheological characteristics were done on 8 samples cut from CH gluing boards and 8 samples from HF gluing boards.

Linear viscoelasticity may be represented pictorially by models comprising mass less Hookean springs and Newtonian dashpots. A simple possible formulation of linear viscoelastic behavior complies these springs and dashpots. Well-known simple models are the Maxwell, Kelvin, Standard linear and Burger model. Within the range of service stresses, wood at constant moisture content and constant temperature may be approximately considered as a linearly viscoelastic material. At variable humidity, the deformations of stressed wood are extremely complex and have so, eluded realistic mathematical description. Various significant advances to describe diverse aspects of the behavior have been made, e.g., by Pentoney and Davidson (1962), Nakai and Grossman (1983), Bažant (1985), Schniewind (1973), Dinwoodie (2000).

At relatively low stress levels of moisture content and temperature, wood may be considered as a linearly elastic material, and as a linearly viscoelastic material under others. Forms of the simplest viscoelastic models, which are used to represent the viscoelastic behavior of wood materials, are the Standard linear model and Burger model.

Equations of creep modulus for the simplest viscoelastic models can be presented as follows (Skrypek and Hetnarski 1993):

Equations (2) and (3) are produced according to standard linear model:

$$J(t)=\left[\frac{1}{E_1}+\frac{1}{E_2}-\frac{1}{E_2}\exp\left(-\frac{tE_2}{\mu}\right)\right] \tag{2}$$

and Burger models, respectively:

$$J(t) = \left[\frac{1}{E_1} + \frac{1}{E_2} \left(1 - \exp\left(-\frac{tE_2}{\mu_2} \right) \right) + \frac{t}{\mu_1} \right] \quad (3)$$

where *J(t)* is the creep compliance; *t* is the time; E_i is elastic constant for springs; and μ_1 is viscous constant for dashpots (*i* =1 and 2).

For the given loading situation, it is considered for viscoelastic materials that elastic modulus (E) is equivalent to relaxation modulus. For moderate loading values (comparing to bending strength) and for the linear viscoelastic material behavior, the creep compliance is equivalent to the reciprocal of the elastic modulus value:

$$J(t) = \frac{1}{E(t)}$$

Equation for deflection is defined as

$$\Delta U(t) = \frac{23Fl^3}{648EI} \cdot J(t) \quad (4)$$

where *F* is the force; *l* is the reference length; *I* is the moment of inertia of the beam's cross section and *E* is the elastic modulus.

If a viscoelastic beam is subjected to the same force, as in the elastic case, the deflection can be derived multiplying Equation (4) by *E*(*t*)/*E*, where *E*(*t*) is the relaxation modulus. If 1/*E*(*t*) is replaced with *J*(*t*), where *J*(*t*) is the creep compliance, Equation (4) becomes:

$$\Delta U(t) = K \cdot J(t) \quad (5)$$

where:

$$K = \frac{23}{648} \frac{F \cdot l^3}{I} \quad (6)$$

Unknown parameters for three and four parameters models that explain viscoelastic behavior of LVL elements can be determined by the least squares method (Bajramovic et al).

RESULTS AND DISCUSSION

Some relevant physical and mechanical characteristics for LVL were determined after standard conditioning according to the corresponding standard methods.

- ρ - density (kg/m^3) ISO 3805 (1977)
- w - moisture content (%) ISO 3806 (1977)
- σ_{bs} - bending strength (MPa) EN 310: (1993)
- E_m - modulus of elasticity (MPa) EN 310: (1993)
- σ_{ss} - shear strength (MPa) EN 314: (1993)
- TL - thickness loss (%)

Average values of these characteristic are given in Tab. 1.

Analysis of experimental results shows the influence of technological gluing procedure on thickness losses of LVL elements and on mechano – sorptive creep.

Depending on the applied gluing procedure there are various processes occurring in LVL boards. During the CH gluing, veneer layers warms up from outer layers towards the middle layers. Heat transfer to outer layers is from the hot pressing device. Depending on temperature, added heat and gluing pressure, the moisture in wood can evaporate. One part of moisture evaporates to the surrounding and the rest of it diffuses gradually into wood. Vapor moves toward the middle where the temperature is lower. As the heat is removed, vapor condenses and that produces higher moisture content and greater deformation in the outer layers comparing to the corresponding middle values.

During HF gluing the warming of veneer layers is fast and almost equally over the whole cross section. Because of different dielectric characteristics, glue is warmed faster than wood and a part of heat is transferred to the pressing device. A balanced temperature gradient enables fast and equal moisture distribution. According to the above conditions and results obtained from experimental research, the following conclusions are given:

CONCLUSION

From the described experiment following conclusions can be summarized:

- The thickness loss for LVL boards made by conventional CH gluing was 1.7 % (absolute difference) greater than in the case of HF gluing.
- The specimens made by conventional hot gluing had 4 % lower moisture content and 2 % higher density.
- Lower moisture content and higher density gave 6 % higher bending strength and small difference for elastic modulus 0.3 % for specimens made by CH gluing comparing to HF gluing.
- Shear strength for HF gluing was 5 % greater comparing to conventional CH gluing.
- Analysis of creep curves and models unknown parameters pointed out that the creep values depend on the duration time of gluing procedure.
- LVL made by HF gluing procedure had better rheological characteristics (smaller creep values), i.e. higher rheological parameters for both considered models.
- 4-parameter model was in better correlation with experimental data.

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