ACTA SCIENTIARUM POLONORUM
Acta Sci. Pol.
Silv. Colendar. Rat. Ind. Lignar. 9(1) 2010, 35-43

RESTRICTION OF SWELLING OF WOOD SUBJECTED TO BENDING STRESS AND MOISTENING IN THE COMPRESSED ZONE

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Abstract. The study was undertaken to show the possibility of wood swelling pressure determination on the basis of the time course of its mechano-sorptive creep induced by bending stress of different values and simultaneous moistening of the compressed zone. The creep was induced in the conditions of three-point bending of beech wood (*Fagus sylvatica* L.). The bending pressure applied in the radial direction was of the magnitude of 0.05, 0.1 and 0.15 of the mean destroying stress determined for the samples of moisture content of about 7%. Immediately after application of loading the samples were subjected to asymmetric moistening in the zone of compressive stress. For the sake of comparison also the free sorptive deformation of analogous samples was observed. On the basis of the linear relations between the deformation (recorded at specific time intervals during the process of mechano-sorptive creep) and the bending stress applied, it was possible to determine the values of the stress at which the samples would remain in the non-deformed state despite their asymmetric moistening. The maximum swelling pressure determined in this way is by about 50% greater than that found in the direct way.

Key words: mechano-sorptive creep, swelling pressure, beech wood, bending, asymmetric moistening

INTRODUCTION

The knowledge of stress appearing in wood upon its moistening or drying in the conditions restricting its sorptive deformation is of considerable practical importance. In particular it should be taken into account in setting wood drying programs and in predicting deformation of elements of wood structures exposed to changes in moisture content.

Unfortunately, the values of this stress determined in the traditional direct way [Perkitny 1951, Ilič 1970, Kingston and Perkitny 1972] do not reflect the actual magnitude of wood swelling forces as it has been established that wood is capable of passive with-

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standing of the load greater than the maximum swelling force determined in the direct way [Mishiro 1973 a, b, Moliński and Raczkowski 1982].

In this context it seems that the stress needed to restrict the wood swelling, determined on the basis of the time courses of mechano-sorptive creep, gives a more accurate approximation of the actual swelling forces [Moliński and Raczkowski 1988 b, 1997, Moliński 2000, Krauss 2004, Roszyk et al. 2007]. The values of the stress calculated from the linear relations between the mechano-sorptive deformation and the tensile, compressing or bending stress are much greater than those found in the direct way, which explains the wood capability of withstanding the load greater than the maximum swelling force.

In view of the fact that the complex mechano-sorptive creep is a resultant of overlapping of the mechanical and sorptive stress fields [Rybarczyk 1973], it is important to determine the kinetics of sorptive stress generated in wood subjected to loading in different modes and in different conditions of changes in its moisture content.

This study was undertaken to determine the swelling pressure on the basis of the time courses of the mechano-sorptive creep of wood subjected to bending across the grains and to moistening of the compressed zone of the bent samples.

MATERIAL AND METHODS

The process of mechano-sorptive creep of wood subjected to bending and moistening in the compressed zone was studied on samples of the size 20 mm (L) × 20 mm (T) × 150 mm (R), from beech tree (*Fagus sylvatica* L.). The samples were cut out of one plank conditioned in laboratory for 1.5 year. After this time of storage, the density of the samples selected for the study varied from 710 to 720 $kg \cdot m^{-3}$, while its moisture content was 7%.

To characterise the mechanical properties of wood to be studied its resistance to the three-point bending in radial direction at the support spacing of 120 mm was determined in the state of low moisture content (MC = 7%) and in the wet state (MC > FSP). The measurements were made on the testing machine ZWICK ZO50TH for the samples of the same size and shape as those for mechano-sorptive creep study.

The bending strength of beech wood in the radial direction determined on 10 samples was 22.8 ±1 MPa at the moisture content of 7% and 10.7 ±1 MPa in the wet state.

Measurements of mechano-sorptive creep[*] were made in the system of three-point bending under the bending stress applied in the radial direction. A sample of the initial moisture content of 7% was mounted on rotating supports placed on bearing, spaced at 120 mm. The bending load was applied at the middle of the sample length. The values of the hanging load were chosen so that the bending stress was 0.05, 0.1 and 0.15 of the mean destroying stress determined at the moisture content of 7%. Therefore, the absolute values of the stress were 1.14, 2.28 and 3.42 MPa. Directly after the sample loading, the front of the sample in the compressed zone was wetted with distilled water of 293K. The process of moistening was realised by the use of filtration tissue attached to the transversal plane of the sample with thin elastic rubber, whose opposite ends were placed in vessels with distilled water. The same method of asymmetric moistening of

[*] In experiments participated master Piotr Adamczak.

the bent samples was applied in other works on related subjects [Moliński and Raczkowski 1988 a, Roszyk et al. 2007].

The creep of the bent samples was evaluated by measurements of the sample deflection at the middle of the section delimited by the supports with the help of an electronic displacement meter coupled with a computer. The meter made by KEST ELECTRONICS K1603, permitted recording displacements to the accuracy of 0.001 mm, at 15 second time intervals. The stand for measurements of mechano-sorptive creep of bent wood is shown in Figure 1.

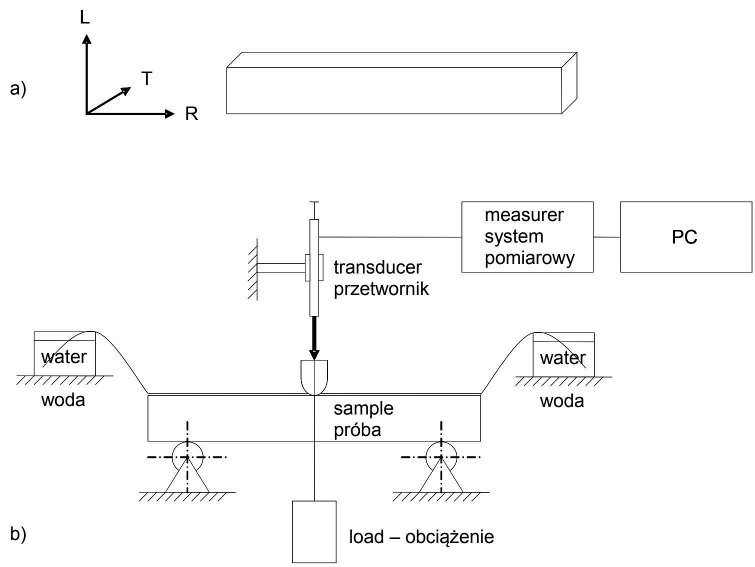

Fig. 1. A scheme of measurements of the creep of the wood samples subjected to bending stress across the grains and to asymmetric moistening in the zone of compressive stress

Rys. 1. Schemat sposobu pomiaru pełzania drewna zginanego w poprzek włókien i jednocześnie nawilżanego w strefie działania naprężeń ściskających

The process was continued until the restoration of deformation was clearly notable. For each value of bending stress measurements were made on 5 samples. Also 5 samples were used for measurements of free sorptive deformation ($\sigma_g = 0$).

Distribution of the wood moisture content on the cross section of the samples upon their asymmetrical moistening was established on twin samples subjected to moistening in the same manner as the samples used for creep measurements. At certain time intervals the central section of the samples of about 2 cm in length was cut out and sliced into 5 layers of the same thicknesses. The moisture content of the layers was determined by the gravimetric method.

RESULTS AND DISCUSSION

The time courses of mechano-sorptive creep of beech wood subjected to constant in time but different in value bending stress and to asymmetric moistening are shown in Fig. 2. The relative displacements of the extreme layers of the wood samples (ε) were calculated from the formula:

$$\varepsilon = \frac{6hf}{l^2} \cdot 100\,[\%],$$

where:

h – the sample height, along the grains, mm,
f – deflection arrow, mm,
l – support spacing, mm.

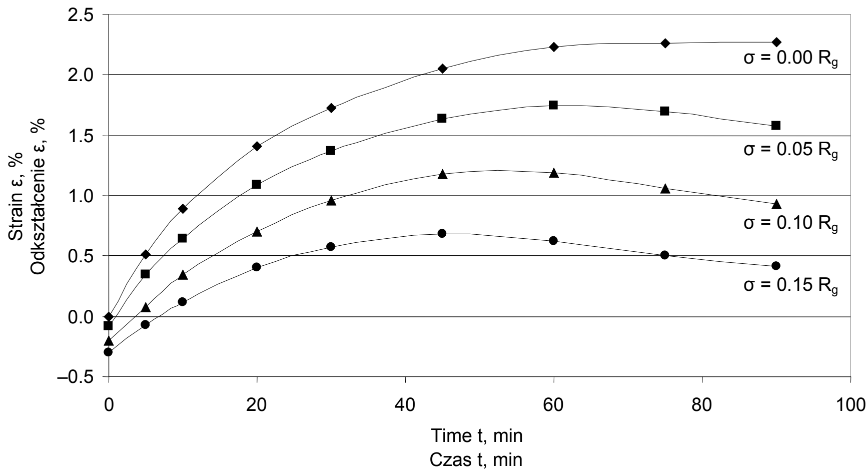

Fig. 2. Relation between the values of the bending stress (σ_g/R_g) and the deformations of the wood samples subjected to this stress and to asymmetric moistening in the zone of compressive stress

Rys. 2. Wpływ poziomu naprężeń zginających (σ_g/R_g) na przebieg odkształceń zginanych próbek podczas ich jednostronnego nawilżania w ściskanych strefach

The data shown in Figure 2 are the mean values of five times repeated measurements for each value of the bending stress. To illustrate the differences between the process of wood creep under loading and that of free warping of asymmetrically moistened samples, the same figure shows also the mean curve of the latter process.

As follows from analysis of the curves obtained, the external load, causing sample bending, restricts the free sorptive deformation of wood samples in the way practically proportional to the magnitude of the load. This observation is illustrated by Figure 3, showing the relative deformation as a function of the bending stress for different times of the creep.

Each of the lines describes the effect of wood moistening and the level of bending stress on the deformations of the samples recorded for specific times of the creep.

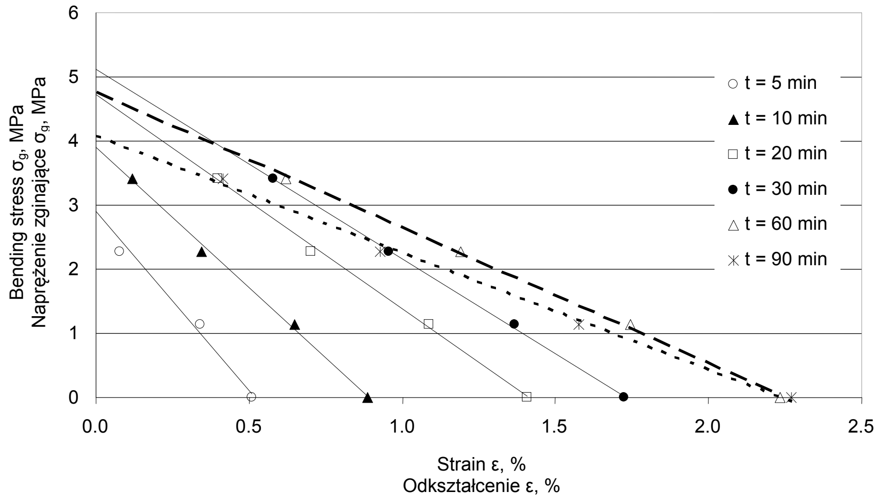

Fig. 3. Relation between the mechano-sorptive deformations and the bending stress applied to a wood sample for a few different times of stress application
Rys. 3. Zależność odkształceń mechaniczno-wilgotnościowych drewna od wartości naprężeń zginających i czasu ich trwania

On the basis of the linear relations between the deformations recorded for specific times of mechano-sorptive creep and the bending stress (Table 1), the values of the stress at which the samples would remain not deformed despite asymmetric moistening were calculated. The stress of these values would restrict the swelling of the wood sample zone subjected to moistening. The stress needed to restrict the sorptive swelling is also known as the pressure of swelling. Therefore, we are able to determine the magnitude

Table 1. Regression equations describing the deformations of the extreme layers of the wood sample subjected to bending stress as functions of the bending stress applied, for selected periods of the mechano-sorptive creep
Tabela 1. Równania regresji zależności odkształceń skrajnych warstw zginanych próbek od wartości działających naprężeń dla wybranych czasów pełzania mechaniczno-wilgotnościowego

Time t, min Czas t, min	Regression equation Równanie regresji	Coefficient of determinantion R^2 Współczynnik determinacji R^2
0	$\sigma = -10.987\varepsilon + 0.0729$	0.9966
5	$\sigma = -5.5965\varepsilon + 2.9069$	0.9889
10	$\sigma = -4.3583\varepsilon + 3.8861$	0.9969
20	$\sigma = -3.3435\varepsilon + 4.7177$	0.9981
30	$\sigma = -2.9550\varepsilon + 5.1268$	0.9994
60	$\sigma = -2.1115\varepsilon + 4.7669$	0.9989
90	$\sigma = -1.8247\varepsilon + 4.0766$	0.9956

of external stress needed to preserve the unchanged shape of the sample ($\varepsilon = 0$). According to the data from Figure 3, the stress needed to preserve the samples in the not deformed state has positive sign. It becomes obvious taking into account that the bending stress restricts the swelling of the upper zone of the samples. It is reasonable to assume that the stress needed to restrict the sorptive deformation of samples is of the same magnitude as that needed to restrict the swelling of the moistened zone of the sample. The time changes in the stress determined in this way (σ^R_{hm}) are presented in Figure 4 along with the time changes in the pressure of wood swelling (σ^R_{tr}) determined in the traditional method on the samples of the size 10 (L) × 30 (T) × 30 (R) mm. The size of the samples was chosen taking into account that the stress determined from the course of the mechano-sorptive creep was determined for the period of restriction of the adsorption deformation, so when the bottom parts of the asymmetrically moistened samples were still dry. The correct choice of the sample size is confirmed by the changes in wood moisture content at different heights of the sample upon its asymmetric moistening (Fig. 5).

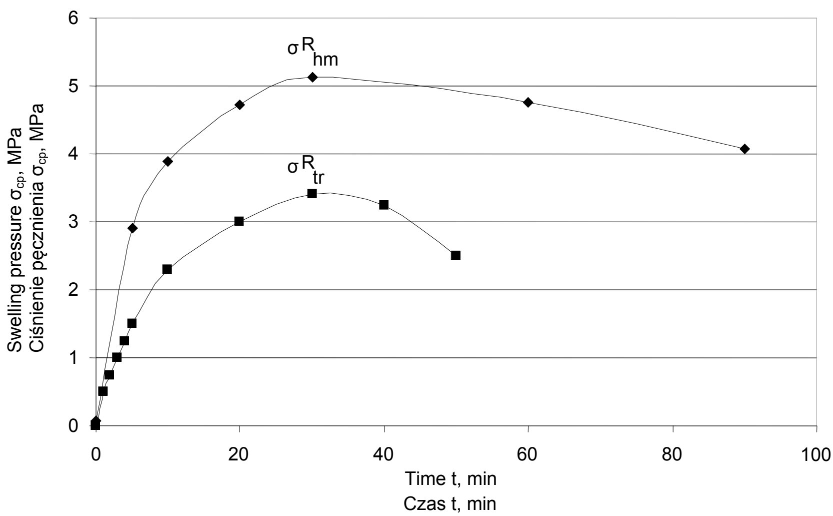

Fig. 4. Bending stress needed to restrict the sample deformation upon its asymmetric moistening and time changes in the swelling pressure determined by the direct method

Rys. 4. Naprężenia mechaniczne konieczne do powstrzymania odkształceń próbki podczas jej jednostronnego nawilżania oraz przebieg ciśnienia pęcznienia oznaczonego metodą bezpośrednią

Kinetic of changes in the wood moisture content at different heights of the samples (along the grains) was studied in the same conditions of moistening as those of the samples used for observations of the creep. The measurements of moisture content distribution along the height of the sample indicate that in the first period of the mechano-sorptive creep (that is till the moment when the deformations are restored) only the upper zone of the samples subjected to asymmetric moistening is wet.

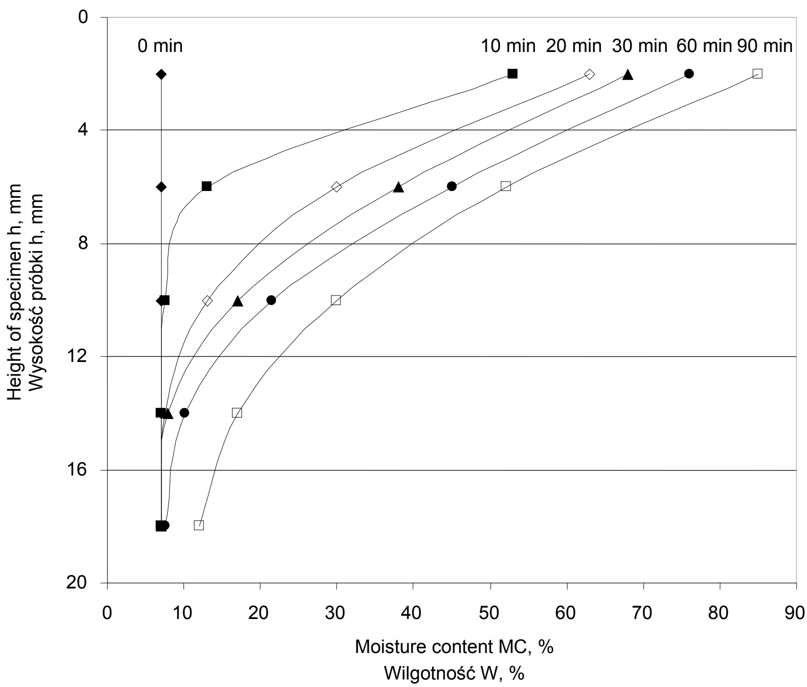

Fig. 5. Changes in the moisture content of wood at different heights of the sample upon its asymmetric moistening

Rys. 5. Zmiana wilgotności drewna na różnej wysokości próbki podczas jej jednostronnego nawilżania

As follows from the data given in Figure 4, the maximum pressure of swelling determined from the time courses of the mechano-sorptive creep is by about 50% greater than the value found in the traditional way. The pressure of swelling is a resultant of the wood swelling forces generated and the relaxation processes [Kanno 1994]. In the traditional method the swelling forces are obtained by summation of the cyclic increments in the external loading needed for restriction of temporary allowed sample swelling. However, it is known that in the conditions of cyclic increase in external loading the stress relaxation is much faster than in a typical rheological process [Raczkowski et al. 1992]. This seems to be an important reason for relatively low values of the swelling pressure determined by the traditional method. Another, probably decisive factor responsible for the enhanced relaxation of the swelling forces of wood upon their measurements by the traditional method is the relatively fast loss of stability of the already wet cell walls. This loss of stability is manifested in the data shown in Figure 4, as already in about 3 minutes of the experiment the increase in the swelling pressure of wood determined by the traditional method begins to divert from that determined from the course of the mechano-sorptive creep.

CONCLUSIONS

Results of the above-described experiment and analysis of the course of the mechano-sorptive creep of wood subjected to bending stress across the grains and to moistening in the compressed zone have shown that the wood deformation is proportional to the bending stress applied. The linear character of this relation permitted indirect determination of the stress needed to restrain the wood swelling. The maximum swelling pressure determined in this way was of over 5 MPa so by about 50% greater than the value found in the direct method. The probable reason for the differences is the fact that in the indirect method the free swelling of the moistened samples is not fully restricted so the possibility of the loss of the cell walls stability because of their buckling is reduced.

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HAMOWANIE PĘCZNIENIA DREWNA NAWILŻANEGO W ŚCISKANEJ STREFIE ZGINANYCH PRÓBEK

Streszczenie. Celem pracy było wskazanie możliwości oznaczenia ciśnienia pęcznienia drewna, na podstawie przebiegów jego pełzania, pod wpływem zróżnicowanych co do wartości naprężeń zginających i jednoczesnego nawilżania ściskanych stref zginanych próbek. Proces pełzania prowadzono w warunkach trójpunktowego zginania drewna buka (*Fagus sylvatica* L.). Naprężenia zginające, działające w kierunku promieniowym, stanowiły 0,05, 0,1 i 0,15 średniego naprężenia niszczącego, określonego przy wilgotności drewna wynoszącej ok. 7%. Bezpośrednio po obciążeniu próbek nawilżano je w strefie działających naprężeń ściskających. Zmierzono także „swobodną", wilgotnościową ich deformację. Korzystając z liniowych związków pomiędzy odkształceniami, zarejestrowanymi w określonych czasach trwania procesu mechaniczno-wilgotnościowego pełzania, i wartością działających naprężeń, oznaczono wartości naprężeń, przy których badane próbki, pomimo ich niesymetrycznego nawilżania, pozostawałyby w stanie niezdeformowanym. W ten sposób oznaczona maksymalna wartość ciśnienia pęcznienia jest o ok. 50% wyższa od wartości tej wielkości oznaczonej w sposób bezpośredni.

Słowa kluczowe: pełzanie mechaniczno-wilgotnościowe, ciśnienie pęcznienia, drewno buka, zginanie, nawilżanie niesymetryczne

Accepted for print – Zaakceptowano do druku: 21.01.2010

For citation – Do cytowania: Moliński W., Roszyk E., 2010. Restriction of swelling of wood subjected to bending stress and moistening in the compressed zone. Acta Sci. Pol., Silv. Colendar. Rat. Ind. Lignar. 9(1), 35-43.