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SWELLING PRESSURE OF SPRUCE WOOD ALONG THE GRAINS MOISTENED IN HUMID AIR OR WATER*

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SYNOPSIS. The pressure kinetics of swelling and free swelling, maximum swelling pressure and the maximum swelling of spruce wood, moistened in humid air or in water, its compressive strength at the maximum swelling pressure, along the grains, and moisture content of this wood have been determined. The admissible value of temporary swelling was 0.5 µm.

KEY WORDS: uniaxial swelling pressure, pure swelling pressure, swelling, spruce wood (*Picea abies* Karst.)

INTRODUCTION

It is known that wood exerts significant pressure onto the obstacles restricting its swelling on moistening. This pressure, referred to as the wood swelling pressure, affects the stress state causing deformation of wood constructions. The wood swelling pressure is the only experimentally determined index describing the stress in wood on its moistening.

The hitherto published results concern almost exclusively the swelling pressure generated in the transversal directions. Only a few authors have been interested in determination of the swelling pressure along the grains (Ivanov 1962, Jorasz 1966, Krauss 1988, Perkitny 1951, 1961, Raczkowski and Krauss 1979, Stefaniak 1962, Suchsland 1979, Werdnis 1983). As follows from the study by Krauss (1988) the maximum swelling pressure along the grains for the wood

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*The experiments were performed at the Department of Wood Science The August Cieszkowski Agricultural University of Poznań.

samples moistened in water are on average 4-30 times higher than those hitherto reported. These results have also confirmed the thesis put forward in (Krauss 1988, Perkitny and Kokociński 1968) that the swelling pressure of wood in the directions of higher modulus of elasticity and strength should also be higher.

Among many still unsolved problems related to the swelling pressure along the grains an important question is the effect of the type of moisturising environment (different liquids and gases) on the maximum swelling pressure.

As follows from the study on wood swelling pressure across the grains, when the moistening is performed in humid air the swelling pressure is by 30 to 50% higher than when the moistening agent is water (Keylwerth 1962, Perkitny and Helińska 1963, Perkitny and Kingston 1972). To the best of the author's knowledge no study has been hitherto performed in the direction along the grains. The preliminary measurements performed at the Department of Wood Science, at The August Cieszkowski Agricultural University of Poznań, the maximum swelling pressure along the grains for the wood moistened in humid air and water do not differ significantly. From the energetic point of view, no significant differences between the swelling pressure on moistened in in humid air and water should be expected, because the main source of the swelling pressure energy is the sorption ability of cellulose whose heat of moistening and the energy of steam adsorption are practically the same. To verify these preliminary measurements, a study was undertaken on the swelling pressure in the direction along the grains. The aim of this study was determination of adsorption stress along the grains in the spruce wood samples moistened in humid air and in water.

METHODS

The measurements were performed on spruce wood (*Picea abies* Karst.) samples cut out in the form of double oars of the size 20(T) × 20(R) × 120(L) mm, narrowed in the middle to the size 4(T) × 20(R) mm along a section of 40 mm (Fig. 1). The choice of the samples in this shape followed from the fact that the values of wood swelling along the grains are small and the measurements along

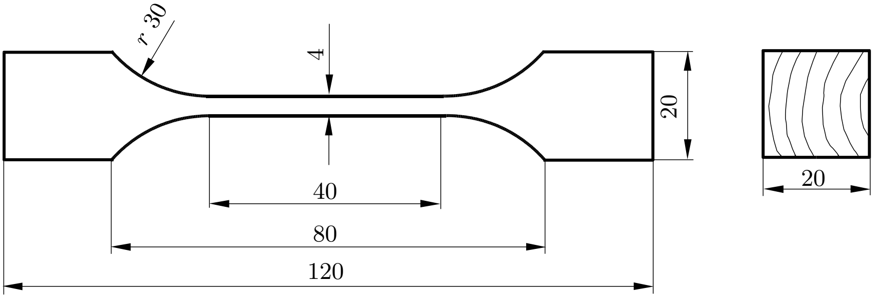

Fig. 1. The shape and size of the sample
Rys. 1. Kształt i wymiary próbki

this direction on the samples elongated in the same direction permitted a more accurate control of the wood suppression (Krauss 1988).

The samples were obtained from bolts from the central log of the thickness of 63 mm, seasoned in laboratory conditions for about 2 years. The average moisture content of the samples was close to 8%. From the circumferential zone of the bolts, some slabs of the cross-section of 20 × 20 mm were cut out and subjected to curving and milling in order to give them the desired shape of oars. The samples selected for the study were those of the grains parallel to their longer axis. The heads of the samples were carefully polished and dried in a laboratory drier at 103 ±2°C to the oven-dry state. From the same slabs of which the samples for swelling pressure measurements were cut out, also the samples for determination of wood density were prepared. The density of the samples in oven-dry state was in the range 430 ±15 kg/m^3. The swelling pressure along the grains was measured by the method worked out by Perkitny (1951), based on a direct measurement of the force needed to reverse the temporarily admitted linear swelling. Because of a significant effect of the temporarily admitted swelling on the swelling pressure measurements (Perkitny 1951, Stefaniak 1962, Suchsland 1976), the former was restricted to 0.5 µm. The swelling pressure measurements were repeated three times. The swelling pressure was calculated as a quotient of the swelling force to the cross-section area of the sample narrowing in the oven-dry state. In order to eliminate the contact deformations (Bodig and Jayne 1982) the samples were preliminary loaded to produce the stress equal to 5% of that at the limit of the proportionality under longitudinal compression in the wet state. The experiment was performed on the equipment described by Moliński and Raczkowski (1980).

In the first series of measurements the samples were moistened in distilled water of 20 ±1°C. In the second series of measurements the samples were placed in tightly closed vessels above the table of distilled water of the same temperature 20 ±1°C, while shielding their front surfaces with plane-parallel metal plates.

Free swelling along the grains, changes in the moisture content of the wood and instantaneous compressive strength of the wood along the grains were determined for twin samples in separate experiments in the same conditions as for the swelling pressure determination. The compressive strength was measured at the moisture content of the wood reached after the moistening time needed to achieve the maximum swelling pressure. The compressive strength was calculated as a ratio of the destructive force to the area of the cross-section of the sample at the central narrowing. The final results were averages of measurements for 5 samples.

RESULTS AND DISCUSSION

The mean values of the swelling pressure [σ^L] and free swelling [α^L] versus time are given in Figures 2 and 3, because of a small differences in the results.

The kinetics of the wood swelling pressure along the grains was approximated by the exponential function type $y = ae^{-bx}x^c$, which had been successfully used for this purpose earlier (Raczkowski 1962, Krauss 1988). The kinetics of free swelling of wood moistened in water or in humid air was described by the function

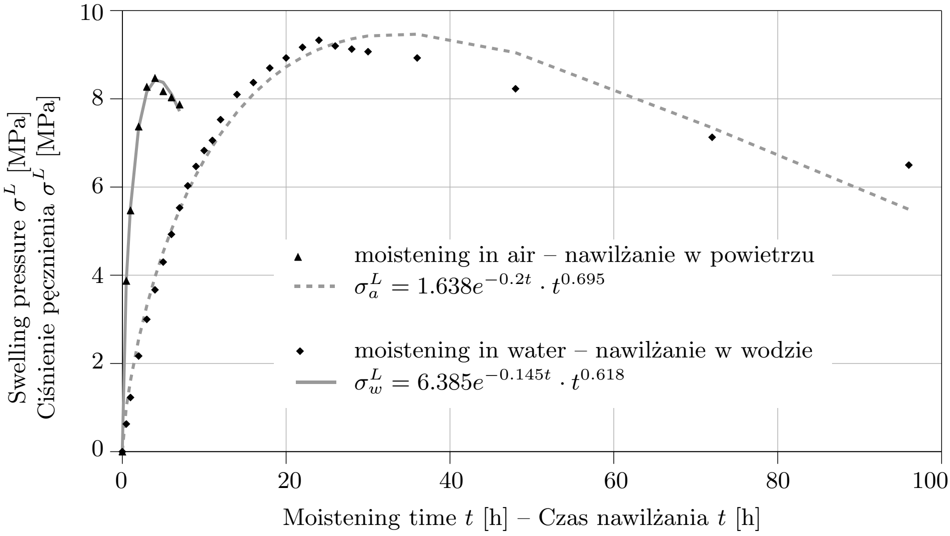

Fig. 2. Kinetics of the swelling pressure of spruce wood along the grains moistened in humid air and in water

Rys. 2. Kinetyka ciśnienia pęcznienia drewna świerku wzdłuż włókien nawilżanego w wilgotnym powietrzu i w wodzie

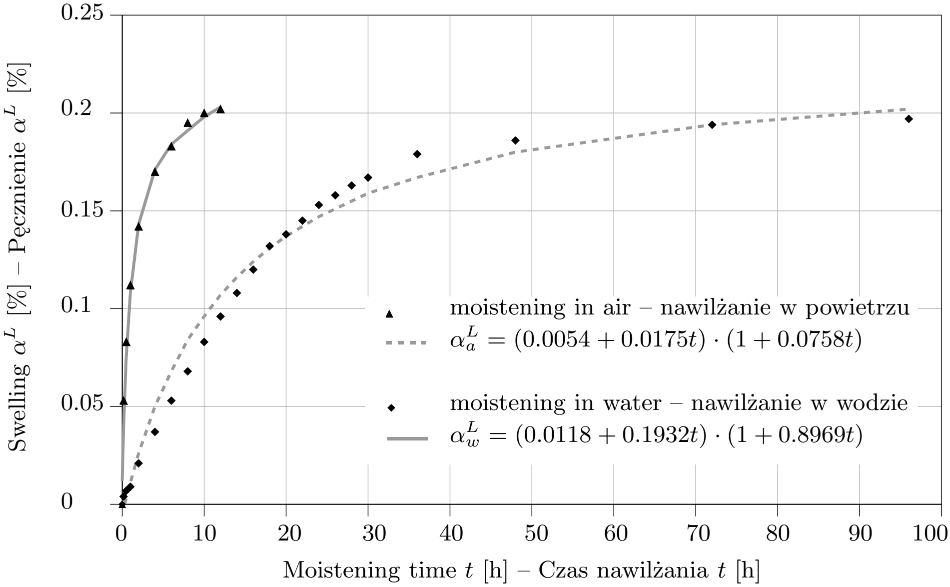

Fig. 3. Kinetics of the swelling of spruce wood along the grains moistened in humid air and in water

Rys. 3. Kinetyka pęcznienia drewna świerku wzdłuż włókien nawilżanego w wilgotnym powietrzu i w wodzie of the type $y = (a + cx)(1 + bx)$. As follows from Figures 2 and 3 the functions are good approximations of the relations analysed, which has been confirmed by high correlation coefficients varying from 0.982 to 0.999. The wood swelling pressure increases with the time of moistening in a decreasing rate, then having reached a maximum value starts to decrease. This increase is particularly well seen for the moistening in humid air. The character of the process is consistent with earlier reports (IVANOV 1962, KRAUSS 1988, WERDNIS 1983).

The results of measurements are presented in Table 1. The maximum swelling pressure along the grains is 9.33 MPa for the samples moistened in humid air $[\sigma_a^{*L}]$, and 8.47 MPa for the samples moistened in water $[\sigma_w^{*L}]$. The swelling along the grains at the maximum swelling pressure is 0.153% for the samples moistened in humid air and 0.165% for those moistened in water. As follows from the data of Table 1, the maximum wood swelling pressure and the free wood swelling along the grains do not depend on the type of the moistened environment (humid air, water).

At the maximum swelling pressure the mean moisture content of the wood samples moistened by different media was significantly different and equal to 13.5% for the samples moistened in humid air and 37% for the samples moistened in water. As the content of free water does not affect the swelling pressure and to reach the maximum swelling pressure the moisture content from 7 to 10% according to WERDNIS (1983) or from 10 to 15% according to KEYLWERTH (1962) is sufficient, it was assumed that in the experiments performed the conditions needed for the wood to reach the maximum swelling pressure were satisfied.

The compressive strength in the direction along the grains after the time needed to reach the maximum swelling pressure was on average 39.6 MPa for the sample moistened in humid air and 22.2 MPa for the sample moistened in water. These values are in agreement with literature data (KOLLMANN and CÔTÉ 1984), and the differences between the samples moistened by different media are a result of different moisture content of the samples.

The results illustrating the relation between the swelling pressure and the degree of swelling are shown in Figure 4. The degree of swelling measured for the samples whose swelling was unrestricted is equivalent to the swelling suppressed on determination of the swelling pressure. This swelling is referred to as the suppressed swelling. The relationships shown in Figure 4 were approximated by the exponential functions type $y = ae^{-bx}x^c$, with high correlation coefficients of 0.996 for the sample moistened in humid air and 0.990 for the sample moistened in water.

For the samples moistened in humid air, the relation between the wood swelling pressure and the size of suppressed swelling along the grains is nearly linear in the range from zero to 0.3 of the suppressed swelling at the maximum swelling pressure. For greater swelling, the same increments of the degree of swelling correspond to decreasing increments of the swelling pressure until its maximum is reached. For the samples moistened in water, the relation is nearly linear almost in the whole range of suppressed swelling, up till the maximum of the swelling pressure. The differences in the character of this relationship between the samples moistened in different media can be explained by a different dynamics of wood moistened in the two types of environments. An illustration of the differences in the dynamics of the

Table 1. The properties characterising spruce wood moistened in humid air or in water
Tabela 1. Wartości oznaczanych wielkości drewna świerku nawilżanego w wilgotnym powietrzu i w wodzie

Property Oznaczana wielkość	Wetting conditions Warunki nawilżania	
	humid air powietrze wilgotne	water woda
Maximum swelling pressure along the grains, σ^{*L} [MPa] Maksymalne ciśnienie pęcznienia wzdłuż włókien, σ^{*L} [MPa]	9.08…**9.33**…9.70	7.71…**8.47**…9.21
Time needed to reach maximum swelling pressure along the grains, t^* [h] Czas do wystąpienia maksimum ciśnienia pęcznienia wzdłuż włókien, t^* [h]	22…**24**…26	3.3…**3.5**…4.0
Degree of swelling along the grains at the maximum of swelling pressure, α^{*L} [%] Stopień pęcznienia wzdłuż włókien w chwili wystąpienia maksimum ciśnienia pęcznienia, α^{*L} [%]	0.141…**0.153**…0.165	0.151…**0.165**…0.179
Maximum degree of swelling along the grains, $\alpha^{L}_{\max}$ [%] Maksymalny stopień pęcznienia wzdłuż włókien, $\alpha^{L}_{\max}$ [%]	0.196…**0.200**…0.214	0.191…**0.202**…0.221
Mean moisture content at the maximum swelling pressure, w^* [%] Przeciętna wilgotność drewna w chwili wystąpienia maksimum ciśnienia pęcznienia, w^* [%]	12.8…**13.5**…14.7	35.2…**37.1**…39.4
Compressive strength along the grains at the maximum swelling pressure, R_c^{*L} [MPa] Wytrzymałość na ściskanie wzdłuż włókien w chwili wystąpienia maksimum ciśnienia pęcznienia, R_c^{*L} [MPa]	36.1…**39.6**…43.1	20.2…**22.2**…23.9

process is a much longer time needed to reach the maximum swelling pressure for the wood samples moistened in humid air than that for the samples moistened in water.

Analysis of the swelling pressure dependence on the suppressed swelling shows that on reaching the maximum swelling pressure, for the same degree of suppressing swelling the swelling pressure is lower for the samples moistened in water. This dynamics of swelling pressure increase can be explained by a rapid decrease in the

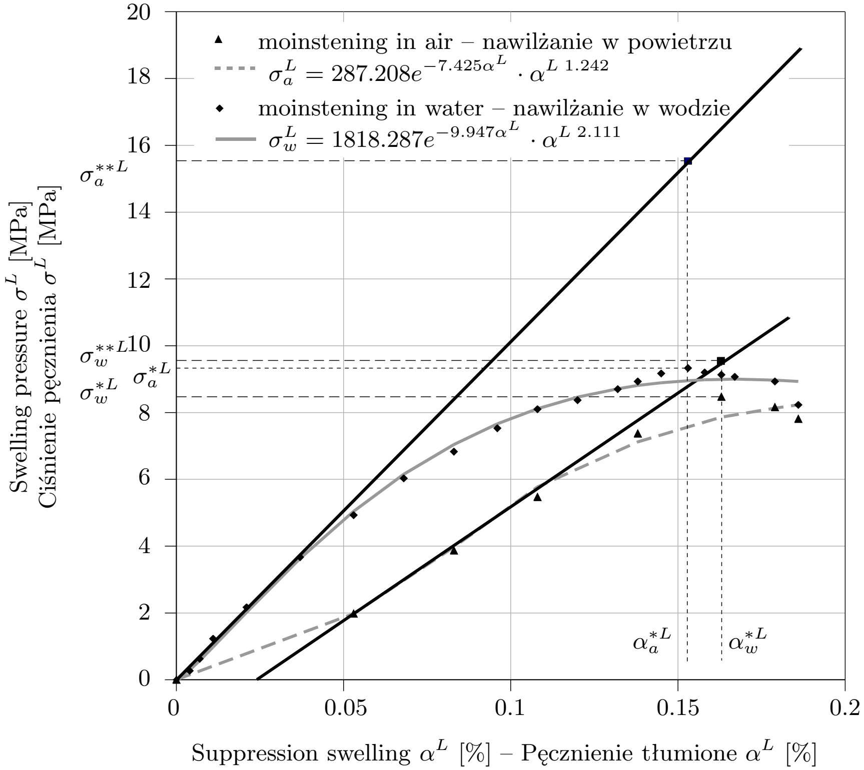

Fig. 4. The swelling pressure of spruce wood along the grains as a function of suppression swelling on moistening in humid air or in water
Rys. 4. Przebieg ciśnienia pęcznienia drewna świerku wzdłuż włókien w funkcji pęcznienia tłumionego podczas nawilżania w wilgotnym powietrzu i w wodzie

rigidity of the sample moistened in water. According to literature data (KOLLMANN and CÔTÉ 1984), the longitudinal modulus of linear elasticity of spruce wood decreases by over 20% on the moisture content growing from zero to the fibre saturation point, whereas by only ~5% on the moisture content growing from zero to 15%. The greater decrease in the rigidity of the sample moistened in water than that of the sample moistened in humid air is manifested by a significantly smaller slope of the linear section of the swelling pressure dependence on the suppression swelling (Fig. 4).

The swelling pressure is a rheological phenomenon (KEYLWERTH 1962, MISHIRO 1976). In order to determine the swelling pressure disregarding the effect of stress relaxation, the method of the so-called pure swelling pressure, described by MISHIRO (1976) was used. In this method the swelling pressure is obtained from the slope of the linear section of the swelling pressure dependence on the suppressed swelling. The linear section is extrapolated to intersect the line parallel to the axis of ordinates and passing through the point of abscissa corresponding to the maximum swelling pressure [α_a^{*L}, α_w^{*L}]. The ordinate of this point is the pure swelling pressure [σ^{**L}]. The value of this ordinate was 15.6 MPa for the sample moistened in humid air [σ_a^{**L}] and 9.4 MPa for the sample moistened in water [σ_w^{**L}]. The pure swelling pressure values can also be found on the basis of the regression equations describing the linear fragment of the swelling pressure dependence on the suppressed swelling.

Taking into regard the fact that the stress relaxed on wood moistening in humid air is significant, it has been assumed that analysis of relations between the swelling pressure and strength should be performed using the quotient of the pure swelling pressure along the grains and the compressive stress along the grains at the time of the maximum swelling pressure. The quotient values are 0.41 and 0.39 for the samples moistened in the water and humid air, respectively. They are consistent with literature data on the quotient of the maximum swelling pressure along the grains and compressive strength along the grains at the maximum swelling pressure (Krauss 1988).

CONCLUSIONS

The above-discussed results permit drawing the following conclusions.

1. The maximum swelling pressure along the grains does not depend on the moistening environment (humid air, water). In the experimental conditions applied the mean maximum swelling pressure along the grains was 8.9 MPa.

2. After the time needed to reach maximum swelling pressure in spruce wood along the grains the mean suppression swelling along the grains is 0.16%. This value makes 0.8 of the maximum swelling along the grains and does not depend on the moistening medium (humid air, water).

3. At the maximum swelling pressure in spruce wood along the grains, its mean moisture content is 13.5% and 37% for the samples moistened in humid air and in water, respectively.

4. The pure swelling pressure along the grains for the spruce wood moistened in humid air and in water are 15.6 MPa and 9.4 MPa, respectively. These values are higher than the mean values of the maximum swelling pressure by 75% and 6%, respectively.

5. The pure swelling pressure makes 0.4 of the compressive strength along the grains at the maximum swelling pressure and does not depend on the moistening medium (humid air, water).

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CIŚNIENIE PĘCZNIENIA DREWNA ŚWIERKU WZDŁUŻ WŁÓKIEN PODCZAS NAWILŻANIA W WILGOTNYM POWIETRZU I W WODZIE

Streszczenie

Badania dotyczyły niedostatecznie dotychczas poznanego zagadnienia rozwoju naprężeń sorpcyjnych drewna wzdłuż włókien podczas jego nawilżania w wilgotnym powietrzu i w wodzie. Badania przeprowadzono na drewnie świerku na próbkach w kształcie beleczek o wymiarach 20 × 20 × 120 mm przewężonych w ich środkowej części na długości 40 mm do wymiaru 4(T) mm. Nawilżanie przeprowadzano w powietrzu o wilgotności względnej wynoszącej ok. 98% i temperaturze 20 ±1°C oraz w wodzie destylowanej.

Gęstość drewna w stanie zupełnie suchym wynosiła średnio 430 kg/m^3. Oznaczano kinetykę ciśnienia pęcznienia i pęcznienia swobodnego wzdłuż włókien oraz wilgotność i wytrzymałość na ściskanie podłużne po czasie nawilżania potrzebnym do wystąpienia maksimum ciśnienia pęcznienia. Średnia wartość maksymalnego ciśnienia pęcznienia oznaczonego w wilgotnym powietrzu i w wodzie wyniosła około 9 MPa. Czas potrzebny do wystąpienia maksimum ciśnienia pęcznienia w wilgotnym powietrzu był siedmiokrotnie dłuższy od czasu potrzebnego do osiągnięcia maksimum ciśnienia pęcznienia w wodzie. Stopień pęcznienia tłumionego, przy którym występowało maksimum ciśnienia pęcznienia, nie zależał od środowiska nawilżającego i wynosił 0,16%. Wartość czystego ciśnienia pęcznienia drewna w wilgotnym powietrzu wyniosła 15,6 MPa, a w wodzie – 9,4 MPa i była wyższa od średniej wartości maksymalnego ciśnienia pęcznienia odpowiednio o 75 i 6%. Czyste ciśnienie pęcznienia stanowi 0,4 wytrzymałości na ściskanie podłużne w chwili wystąpienia maksimum ciśnienia pęcznienia.

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