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Investigation of the Deformations Due to Wood Swelling in the Process of Water Sorption by Speckle Photography

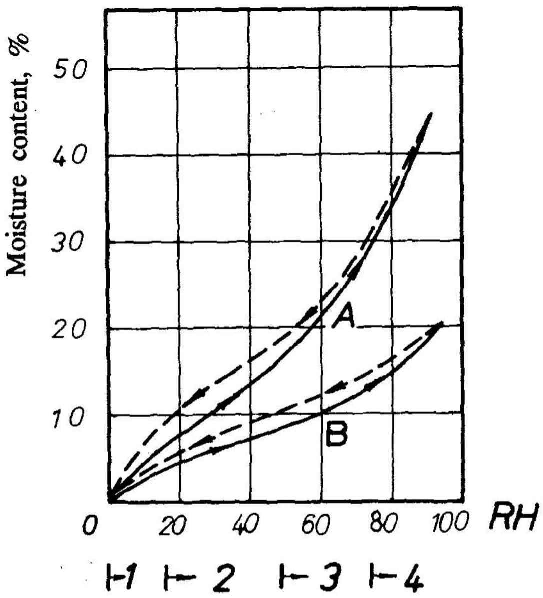
1. Introduction

The alteration of the wood form and dimensions in the process of absorption of water vapour from the air is a very important phenomenon connected with wood behaviour during exploitation. That is why the investigations of this process began as early as the end of the last century (v o n B e m m e l e n) [8]. The isotherms of sorption and desorption of cellulose and wood (Fig.1) as well as the interpretation of the different stages of this process [3, 4, 9] are well-known. The different stages have been defined on the basis of the assumption that the relative humidity of the air (RH) increases gradually, thus provoking the corresponding reaction of the wood.

The traditional methodics of the wood sorption investigation are realized by placing the samples in an environment of relative humidity exceeding 65%. This condition provokes practically the instantaneous beginning of swelling. Sorption kinetics is studied measuring the alteration of the moisture content in wood, which does not give a direct information about its swelling and the different stages in the development of the moisture sorption process cannot be distinguished. So, it is obviously necessary that there should be applied a new contemporary method allowing a non-contact study of the swelling process at a good enough sequence in time.

Speckle metrology is used [1, 5] in the investigations of solids displacements and deformation fields. This group of laser-optical methods, which mark a new tendency in Applied Physics, have been developed with an increasing success for two decades now.

In the present paper we have used a contemporary, non-contact and enough precise method – the double-exposure speckle photography [2], [7] to investigate the dynamics of wood swelling realization.



A - Cellulose fibres
B - Wood (beech)
1 - mono molecular film
2 - poly molecular film
3 - swelling
4 - condensation in the capillaries

Fig. 1 Hysteresis curves of water vapours sorption

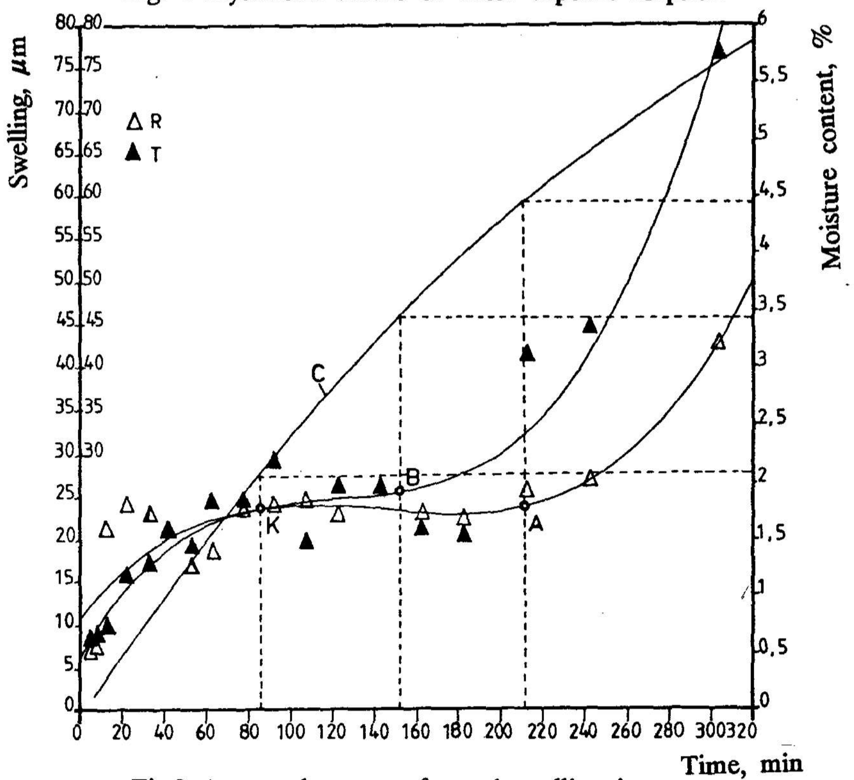


Fig.2 Averaged curves of wood swelling in black pine in radial R and Tangential T direction as well as sorption curve C

2. Material and method of investigation

There has been tested Pinus nigra Arnold sapwood. The test samples with dimensions 20 x 20 x 10 mm (the last dimension being along the fibres) are placed over a saturated solution of KCl, securing an 86% of air relative humidity. Several prior experiments have been made using samples which have been taken at random out of the ones, prepared for testing. The change in the water contents with time is defined by weighing. The averaging curved line of these dependencies up to the moment when the moisture content reaches an approximate value of about 6% is shown in Fig.2 (curve 1). We are most interested in the swelling deformation of the wood throughout the process of sorption when the moisture content of the wood reaches this value.

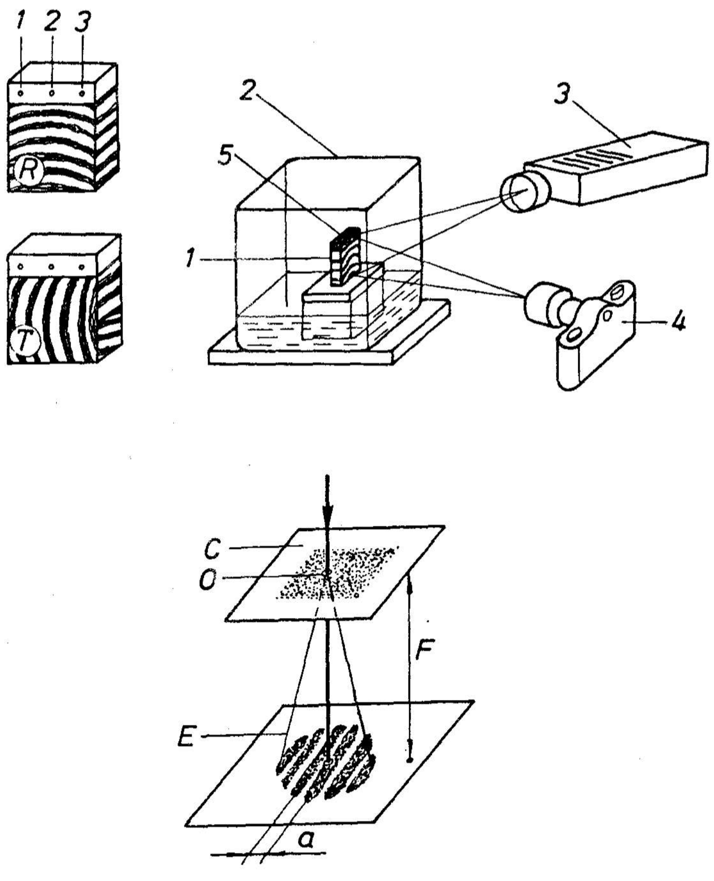


Fig. 3 Test setting for swelling process observation

The essence of the method used – the double-exposure speckle photography consists in the following: the surface of the tested sample is illuminated by laser light and then photographed; two exposures upon one and the same frame are made; the state of the surface registered during the first exposure is considered as an initial one, and the one, registered during the second exposure – as final. After the film treatment, a double exposure negative image of the investigated surface, called a specklegram, is obtained. The specklegram is point wise scanned by a narrow laser beam (Fig. 3.a). The laser light undergoes diffraction in the given small region O from the negative C. As a result of this, upon white screen E, placed at a distance F in front of the negative, there are observed parallel bright and dark interference fringes. The distance "a" between them is in an inverse dependence on the displacement "l" of the points "O" of the speckle gram, which are illuminated by the laser beam:

$$l = \frac{\lambda F}{m} \frac{1}{a} \tag{1}$$

where: λ is the length of the laser light wave;
m is optical magnification

The fringes direction is perpendicular to the displacement direction.

For the registration of the swelling deformations samples 1 (Fig. 3.b) are placed into a ,glass tray with flat sides. In the tray, the necessary RH value is ensured as well as a possibility for illuminating the object by an expanded beam of He - Ne laser 3 and photographing by the camera 4 (Fig. 3 b). Upon the sample there is placed freely a lamella of PVC called "rider" 5 (Fig. 3.b, c). This material does not change essentially its surface micro structure when placed into an environment with an increased humidity. By 18 consecutive double-exposure photographs in intervals of 5, 10, 15, 20, 30 and 60 min., there is obtained a possibility for measuring the integral deformation field during wood swelling within the section we are observing. To display the expected unsteady (irregular) deformation, the experiments for testing the swelling in radial (R) and tangential (T) direction according to the year rings are made using two different groups of samples (Fig. 3.c).

In practice no more than 3 minutes pass from the moment of placing the sample into the tray up to the moment of the first exposure. The last exposure is made nearly at the moment when the value of swelling starts increasing rapidly. Since the "rider" is a solid body, the vectors of displacement are measured only in 3 points (Fig. 3.c), which is absolutely sufficient for the observation of its displacement.

3. Experimental results and analysis

The swelling in radial (R) and tangential (T) direction, registered in the three points of the "rider" is shown graphically in Fig.4 and Fig.5 respectively. A quick reaction of the sample is registered in the beginning of the experiment, when the sample is placed in an environment with increased humidity. The sections where the curves 1, 2 and 3 coincide, show a uniform deformation of the sample. This is observed more often in radial swelling.

Figure 6a. shows the displacement vectors and the corresponding to them interference fringes, derived in the interval between the exposures at the 123-rd and 143-rd minute, when an evident coincidence of the three wood swelling curves is registered (Fig. 4.). Figure 6b. shows the vectors, defined in the interval between exposures at the 53-rd minute and the 63-rd minute during the swelling in tangential direction, when a tild of the "rider" is registered. The different reaction of the tested wood in both directions is evidently due to the anisotropy of its structure.

Curves 2 and 3 in Fig. 2 show the alteration of the radial and tangential swelling, with time. As it has been mentioned above Curve 1 in this figure is the sorption isotherm in the section under observation. After the 210-th minute at curve 2 and after the 150-th minute at curve 3 (points A and B), there is observed a considerable increasing of the curved lines slope, indicating a quick increasing of the swelling. The deformations at this point are respectively 0.11% and 0,12%. As related to the sorption curve and expressed in percentages, the moisture content of the wood is respectively 1.75% and 1,85%. Up to that moment the swelling changes within close limits.

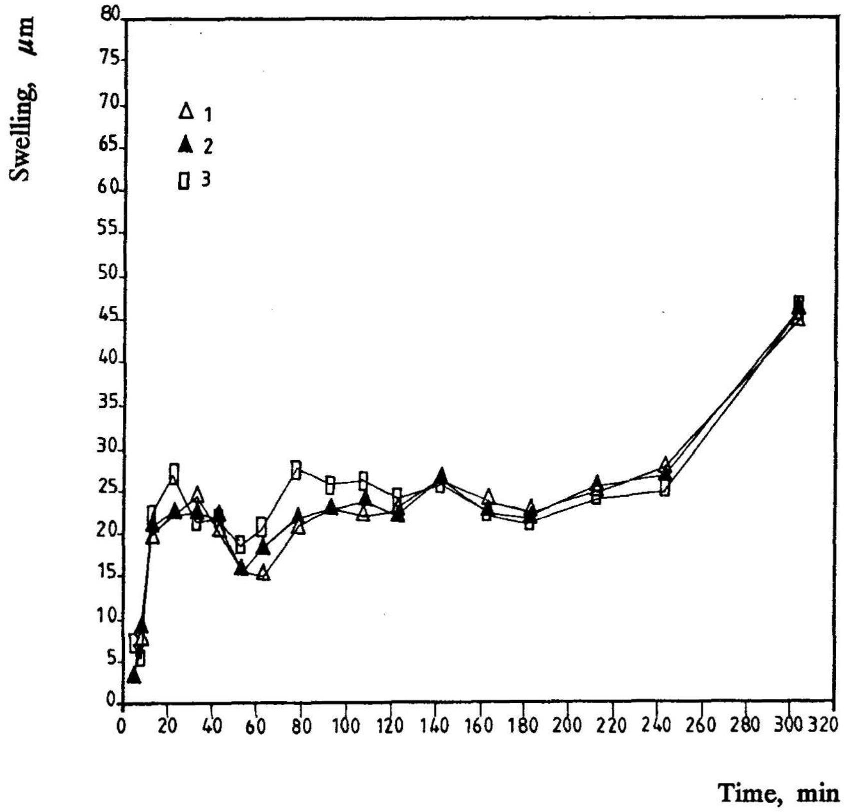


Fig. 4. Curved lines of the wood swelling of black pine in redial direction

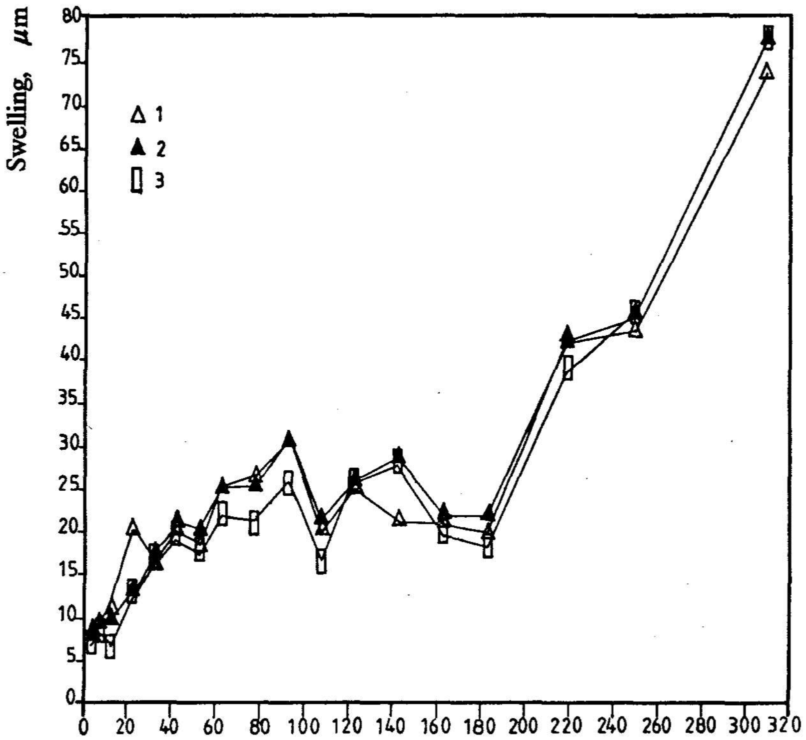


Fig. 5 Curved lines of wood swelling of black pine in tangential direction

The observed graphic dependencies show a good agreement with the theoretical ideas about the sorption behaviour of wood [3,10]. When the sample is placed at working conditions (RH= 86% and t=20 C), the water molecules (mono molecules and clusters) penetrate in it and get into the micro capillary space between the cellulose fibres. Because of the great adhesive ability of the dry fibre walls, the water mono molecules are attached practically immediately to them and cover them with a mono molecular film. This is the reason for the great initial water vapour sorption rate. A poly molecular film formation on the mono molecular firm begins simultaneously (the beginning of the phase 2 Fig.1) [10]. At these conditions the so called surface (or mycelium) swelling exhibits a sharply increment of the specimen integral swelling at the first 60 min from the experiment beginning. (Fig.2 - curves 2 and 3). The mono molecules and the

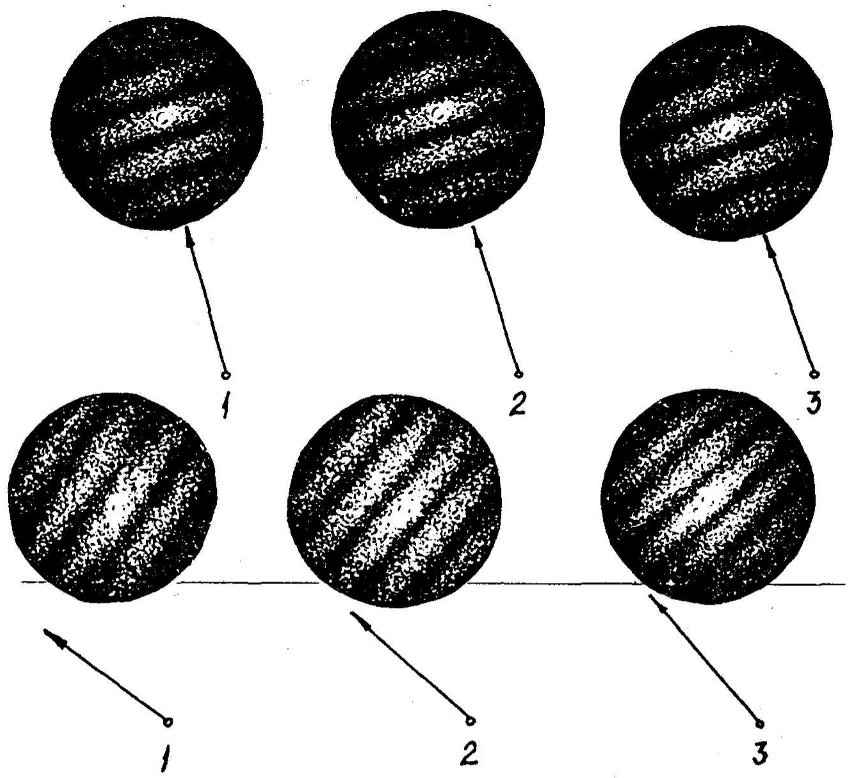


Fig. 6 Vectors of shifting in radial direction, determined by double-exposure speckle-photography with the corresponding interference fringes.
a — The time interval between the exposures at the 123 rd and 143 rd minute
b — The time interval between the exposures at the 53 rd and the 63 rd minute

clusters penetration into the inter fibre space (i.e. water sorption) continue without velocity change (Fig.2 -curve 1). Due to the still great enough fibre adhesive power, processes of the so called contraction (destruction) of the water molecules and their compression around fibres are running. These processes are accompanied by a significantly decelerating and even stopping of the integral specimen swelling (Fig. 2 - curve 2 and 3). The water pressure on the fibre walls increases too. When the pressure reaches some critical value, the water molecule overcomes the fibre walls potential barrier, penetrates into the space between the cellulose molecules and quickly begins to collect around them, forming a mono molecular film. The so called molecular (permutation) swelling begins. According to some authors, the critical pressure value is reached when the moisture content in the cellulose is about 3%. The experimental curves (Fig. 2 point K) show the moisture content in the wood specimen at that moment (beginning of phase 3-Fig. 1) 2.1% . As it is logical to be anticipated, the obtained value is lower than the one, obtained for the pure cellulose.

The above described mechanism consisting of a poly molecular film formation, pressure increase and water molecules penetration, develops now regarding the inter cellulose molecular space and molecules. The points A and B in Fig. 2 probably conform to the moment when the water molecules overcame the last potential barrier. At this moment the molecular swelling process begins. The integral specimen swelling quickly accelerates (Fig. 2 - curves 2 and 3) and the third swelling phase (according to Fig. 1) is established.

There is registered a swelling of 0.37% in tangential direction and 0.19% in the radial one, 300 minutes from the experiment beginning. At this moment there is determined the anisotropy coefficient $\varepsilon_{\alpha} = 2$. This value is comparable to the one, determined by other authors at the end of the swelling process by the conventional measure method.

Conclusions

1. The obtained results confirm the existing theoretical ideas about the process of wood swelling in water vapours. According to these ideas the swelling develops in three phases. These phases are differentiated experimentally. It is shown that in the second phase the swelling process significantly decelerates and even stops, regardless of the continuous water sorption.
2. At the first two sorption phases is observed a swelling anisotropy (Fig. 4 and Fig. 5). The tangential directed deformation is more uniform than the radial one.
3. The swelling in radial and tangential direction alters within close limits reaching a 2% moisture content in the tested wood (Fig. 2 - curves 2 and 3). There follows a significant acceleration of the swelling deformation process. The tangential deformation is bigger than the radial one. An anisotropy coefficient $\varepsilon_{\alpha} = 2$ is determined about 300 min after the experiments beginning. This value is comparable to the one obtained by other authors in the swelling process, when a conventional measure method has been used.
4. The obtained new information shows that speckle photography is a sensitive enough, applicable and useful method for wood swelling kinetics investigation.

Acknowledgements

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