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EVALUATION OF THE IMPACT OF STRUCTURAL REINFORCING FIBRES ON THE FATIGUE OF SCOTS PINE WOOD UNDER CYCLIC LOADING

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Abstract

The article describes the experiment which, under laboratory conditions, confirmed the hypothesis concerning the positive impact of structural reinforcing fibres on wooden elements. Given the importance of identifying bending characteristics, especially the strength of individual components, in regard to the current practice by which they are constantly exposed to dynamic loading, the samples tested were subjected to high-cycle loading. Samples that had been fatigued in such a manner were reinforced with FRP lamellas and compared with the same reinforced lamellas, but without using cyclic oscillation loading. The resultant values confirming the initial hypothesis were/are presented in the tabular form to illustrate the influence of the reinforcing fibres on the individual scantlings measured/evaluated.

Key words: *beam, loading, strength, fatigue, bend*

INTRODUCTION

With the growing awareness of the population in regard to use of wood and wood materials, not only is the utilisation of primary products increasing, but also that of secondary products, i.e. those with a greater added value. Architects worldwide are increasingly designing more complex and unusual wood-based constructions, in addition to those with plain and simple elements, to fulfil individual requirements. It is the diversity of wood-based structures and of their elements that calls for the increasing necessity to learn as much as possible about the properties of this renewable material.

MATERIALS AND METHODS

In addition to static stress, wooden structures are also exposed to dynamic loading. This type of loading can happen particularly to bridges or to wooden roofs that are affected by wind loads.

The easiest means for dynamic loading, is using cyclic harmonic loading with a constant amplitude. Therefore for fatigue testing of materials, most commonly this type of loading is used. The effect of cyclic loading therefore leads to material failure by fatigue. Laboratory

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tests with a number of cycles greater than 10^4 that simulate dynamic loading are identified as high-cycle fatigue tests. In contrast, tests with a lower number of cycles are considered as low-cycle.

Fatigue of wood is a concept that can be explained as a long-term change in the properties of the wood content due to external loading forces. Methods of loading of wooden structures can be divided into random and long-term loading. During these types of loading stress transformation of the wood takes place and its ultimate strength is dependent on the rate of loading. If during the loading to the point of breaking the stress does not change this is an indication of the enduring strength of wood. Enduring strength of wood is defined as the resistance of the wood to long-term loading. This loading may be constant over time or may, to a certain extent, be regularly adapted. It is therefore necessary to make a distinction between static and dynamic enduring strength.

The enduring strength of the wood

Enduring strength of wood is defined as the resistance of the wood against long-term loading. This loading may be constant over time or may, to a certain extent, be changing regularly. It is therefore necessary to distinguish between static and dynamic enduring strength. With an increasing time of loading the limit values characterising the strength of the materials decrease and therefore in anticipating the impact of enduring loading it is not possible to utilise the results from a short-term static load, but necessary rather to use the values corresponding to the long-term nature of the loading.

Enduring strength under static loading

Enduring strength under static loading is defined by the level of mechanical stress at which the external forces affecting the wood over an undefined period do not cause a wood failure.

Enduring strength under dynamic loading

Enduring strength under dynamic loading is defined by the level of mechanical stress at which the external forces affecting the wood over an unidentified large number of cycles do not cause a wood failure, i.e. a break. In the case of oscillating loading there are two principal modes of activity of external forces: repeated loading and alternating loading. Wood failure, especially of beams, through the effects of dynamic loading, can be eliminated using structural reinforcing fibres. One of the possible methods is the use of fibre-reinforced plastics (FRP) as reinforcement for the drawn side of a section. It is important that the materials used for the reinforcement of the beams have a high modulus of elasticity, E, and a large proportional deformation at the edge of failure.

Methodology for determining the ultimate strength of the static bending in accordance with CSN 49 0115

If we place a simple beam on two supports and the force F acts at its centre, for our calculation we use the maximum stress in the surface layers defined by the Navier equation:

$$\sigma_{max} = \frac{3.F.l_0}{2.b.h^2}$$

F_{max} ...... fracture load in N
l … the distance between the centres of the supports [mm]
h ... the height of the specimen [mm]
b ... the width of the specimen [mm]

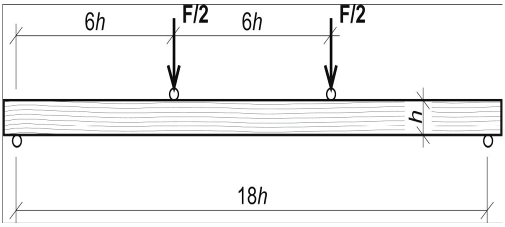

Figure 1 - Manner of positioning and loading of the scantlings for testing

Bending strength - the maximum bending stress that the specimen can withstand during testing

Bending stress σ_f **–** the nominal stress of the external surface of the specimen measured at the mid-span of the supports; this is calculated in accordance with an equation
Upon loading the specimen the tensile stress is effective in its upper part and the compressive stress in its lower part. The non-deformable part of the specimen without normal stress is called the neutral axis. There is also shear stress that functions between the tensile and compressive stress. Since the compressive strength of wood along its fibres is much lesser than its tensile strength, the failure of the specimen in the course of bending in the pressure zone starts with buckling of the fibres, which is rarely observable to the naked eye. The ultimate failure of the specimen occurs in the tensile zone, where, after exceeding the ultimate strength, first the outer fibres split and subsequently the specimen breaks apart completely.

The basic objective of the experiments carried out was to determine the influence of reinforcement using carbon lamella on the bearing capacity of the wooden beams exposed to high-cycle stress. The sections tested were fitted as simple beams and loaded with two forces positioned two of the thirds of the span (Fig. No. 1). Each wooden section was reinforced with one wooden lamella (size 10 mm x 0.5 mm) placed at the lower (drawn) edge of the scantling, in the middle of the section width, along the entire length of the beam. The load forces were gradually increased in increments of 4 kN. Between each two load step there was always a time delay, during which the deformation change was monitored while maintaining a constant level of the load. After the stabilisation of the deformation an additional load step was undertaken. This procedure was repeated until the failure of the beam occurred. Also additionally observed were the different failure modes of the individual beams. The scantling from each series was loaded evenly by single cycles until the ultimate limit state was reached and the value of maximum force $F_{max.}$ detected. A total of 3 series of tests were undertaken and in each series four beams were tested. One series consisted of the following group: a wooden beam 20 mm x 20 mm x 400 mm without reinforcement and with carbon lamella 10 x 0.5 mm, a wooden beam 20 mm x 20 mm x 400 mm both without reinforcement and with reinforcement, which were then subjected to high-cycle loading.

Each series of the experiment utilised 4 samples labelled A, B, C, D. Their characteristics are described in Table 1.

Sample A Wood scantling of Scots Pine with the dimensions of 20 mm x 20 mm x 400 mm. The test specimens were conditioned to a constant weight in a standard environment with temperature (20 ± 2)°C and relative humidity (65 ± 5)%. They were placed in the test press with a load fixture for four-point bending. Reading the loading force F at the time of the failure of the sample.
Sample B Wood scantling of Scots Pine with the dimensions of 20 mm x 20 mm x 400 mm. At the lower drawn side of the scantling a reinforcing lamella with a width of 10 mm and a thickness of 0.5 mm is glued, using epoxy resin. The sample was fitted into the load press and subjected to the same test as was sample A.
Sample C Wood scantling of Scots Pine with the dimensions of 20 mm x 20 mm x 400 mm. The sample was clamped in the SF test device that, under laboratory conditions, simulates real-life dynamic loading. The fatigue of the sample was simulated by using frequency oscillations with a value of 10^4. Subsequently, the sample was fitted into the load press, and again subjected to a load force until the failure of the scantling.
Sample D Wood scantling of Scots Pine with the dimensions of 20 mm x 20 mm x 400 mm. Sample D was stressed using high-cycle loading in the order of 10^4 oscillations. To the lower part of the sample fatigued in this manner identical lamella was glued as in the case of sample B and it was again fitted into the load equipment for four-point bending. The loading force F was read at the exact moment of the failure of the sample.

Table 1 Definitions of the experiment samples tested

RESULTS

In the course of the experiments carried out the values of loading forces were measured, from which the stress in the beams at which the failure of wood took place was calculated, i.e. the ultimate strength of the samples. From a comparison of the experimental results it is clear that the structural FRP-based fibres have a positive effect on the resistance of the wood samples.
The following table lists the calculated values.

series	Ultimate bending strength [MPa]			
	without cycle-loading		with cycle-loading	
	without reinforcement	with reinforcement	without reinforcement	with reinforcement
1.	94.5	117.9	93.78	116.8
2.	92.43	117.12	91.98	115.95
3.	93.8	115	93.21	117.06

Table 2 Ultimate bending strength of the individual beam samples

DISCUSSION

Several different manners of failure were observed in the course of experiments; these occurred in both the unreinforced and the reinforced beams. The most common type of failure was failure in the areas around the knots (in both drawn and compressed areas). Other types of failure were sudden collapse and the formation of longitudinal cracks. For beams reinforced with a lamella also progressive delamination occurred at the contact of the lamella with the underside of the scantling; therefore instead of a complete break only an augmented deflection of the sample was observed.

Given that wood is a heterogeneous material, its mechanical properties are affected by many factors. Apart from the basic geometric values and the macroscopic characteristics, the bending strength of wood is also affected by the following factors.

The effects on overall bending strength

- the influence of the chemical composition – the influence of the content of cellulose, lignin, hemicelluloses
- the influence of sub-microscopic structures – the negative impact of the diversion of the fibres in the cell wall
- the exponential effect of density on the strength and the flexibility of the wooden elements
- the effects of moisture
- the temperature characteristics

Through additional, more narrowly focused experiments it should be possible to demonstrate the effects of the individual factors on the overall strength of the individual samples.

Thanks to the knowledge obtained and the results of the fatigue tests on the wooden samples it is possible to predict the approximate life of the wood in the structures. In the event of complex irregular stress lifespan can be determined in accordance with the summative Palmgren-Miner rule.

CONCLUSION

The results of the measurements clearly indicate that this reinforcement method is suitable for wooden elements when there is a need to increase their effective load. However, due to the limited number of samples tested in the experiment, these results cannot be proved statistically. Another advantage is the partial elimination of the non-homogeneity of the wooden elements that cannot be predicted in advance and, within the section, it is difficult to determine. When designing new buildings it is possible to save on materials by using reinforcing fibres and to use smaller dimensions and lower strengths for the structural elements of the building. Their utilisation can also be found in the reconstruction of historical buildings, where the emphasis is on compliance with the shapes and dimensions of the existing features, in accordance with their original design.

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