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Effect of self-tapping screws on moisture induced stresses in glulam

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ABSTRACT

Glulam structures in service may exhibit considerable moisture induced stresses perpendicular to grain that may affect the load-bearing capacity. An option to enhance the low tensile strength of glulam perpendicular to grain is the use of self-tapping screws, which has shown promising results in constant climates. In varying climates, however, the performance of such screw reinforcements is currently not well understood. The present paper reports results of both experiments and numerical simulations investigating the effect of self-tapping screws on moisture induced stresses arising in glulam exposed to single wetting and drying climate changes. It is shown that during wetting, the screw reinforcement significantly reduces the maximum tensile stresses arising in the cross section centre. With screw distances from 70 to 210 mm, stress reductions by 70–30% are achieved (compared to unreinforced glulam beams). The tensile stresses arising between the reinforcing screws depend not only on the screw distance, but also strongly on the cross section width and the annual ring pattern of the laminates. During drying, the additional restraint caused by the reinforcing screws resulted in a slight increase of the tensile stresses at the cross section border. These were, however, rather low compared to the tensile stresses arising during wetting.

1. Introduction

Timber structures, which are in service subjected to climate variations, may exhibit significant moisture induced stresses [1–4]. The arising tensile stresses may reach or even exceed the low tensile strength of timber perpendicular to grain. As this might decrease the remaining load-bearing capacity or even may lead to cracking in absence of external loads, countermeasures could be necessary. One method is to apply coatings on the timber surfaces exposed to weather conditions in order to keep the moisture exchange with the environment and thus moisture induced stresses low, e.g. [5]. Another measure is to enhance the tensile strength of timber perpendicular to grain by the use of a reinforcement. Thereby, different reinforcement methods are available. An efficient and aesthetically pleasing method is the use of self-tapping screws. Different studies have shown that screw reinforced beams in constant climates exhibit considerably increased load-bearing capacities compared to unreinforced beams [6,7]. In some cases enhanced ductility was observed in reinforced beams compared to unreinforced beams [6]. However, the performance of screw reinforced beams in varying climates is currently not well understood. The aim of the present paper is thus to study the effect of self-tapping screws on moisture induced stresses arising in glulam exposed to one-dimensional wetting and drying. The study is performed by means of both experiments and numerical simulations. The experiments concern the measurement of moisture induced stresses of reinforced glulam specimens upon wetting and drying. The numerical simulations address the effect of different parameters, such as varying screw distances, cross section widths and different geometrical configurations for the wetting case.

2. Materials and methods

2.1. Experiments

The specimens used in the experiments were sawn from standard glulam beams L40 (close to GL30c), which were manufactured by Moelven Limtre AS, Norway. The 40 test specimens with dimensions width (W) × height (H) × length in grain direction = 90 × 270 × 90 mm^3, consisting of six laminates of Norway spruce (*Picea abies*), were seasoned in a specific climate (until stable weight) prior to further handling. The experiments included a wetting and a drying analysis (20 specimens each). For wetting, the specimens were seasoned in a climate chamber with 50% relative humidity (RH), while, for drying, they were seasoned in 90% RH.

After seasoning, a self-tapping screw (SPAX, fully threaded with a diameter of 8 mm and an inner thread diameter of 5 mm) was inserted in the centre of each glulam specimen (without predrilling). Then, 9 black dots were painted along both the upper and lower edge of the cross section of the specimens for measuring purposes (Fig. 1). By means of a video extensometer (ME-46 Full Image

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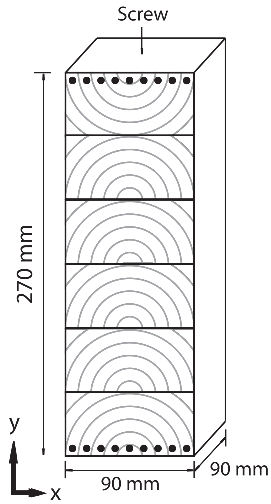

Fig. 1. Schematic illustration of a specimen cross section with black dots (measuring points).

Video extensometer, manufactured by Messphysik GmbH), the initial lengths (L_0) between two dots in direction of the specimen height (y-direction, see Fig. 1) were measured. The extensometer optically records x- and y-coordinates of all the dots marked on the specimen surface at once, based on which the distance between two dots can be calculated. After the initial measurement, the specimens were moisture sealed on four sides (front, back, top and bottom face) using duct tape to ensure one-dimensional moisture transport perpendicular to grain. The specimens were then exposed to a climate change, either wetting or drying, which induced a moisture gradient and caused deformation (expansion or shrinkage) of the specimens. For wetting, the specimens were exposed to 90% RH, while they were exposed to 50% RH for drying. The used relative humidities were selected to represent typical conditions for sheltered, unheated structures in Nordic countries [8].

After 5, 12, 21, and 38 days (d) of climate exposure, 5 wetting and 5 drying specimens were removed from the climate chamber and tested. First, the deformations of the cross sections were measured by recording the length between the dots (L_1) in the same manner as initially done. Then, the specimens were cut into slices with a band saw (in vertical direction). In total 7 slices were cut per specimen: three on each side (approx. 9 mm thick) and a thicker slice in the cross section centre containing the reinforcing screw. After sawing, the slices were immediately put together and the length between the black dots (L_2) was again measured.

The lengths L_0 and L_1 were used to calculate the mean restrained swelling or shrinkage strains in y-direction (see Fig. 1) over the measured length, according to:

$$\varepsilon_{restrained\ swelling/shrinkage} = (L_1 - L_0)/L_0 \quad (1)$$

With the lengths L_1 and L_2 the mean released strains over the measured length were calculated, according to:

$$\varepsilon_{released} = (L_2 - L_1)/L_1 \quad (2)$$

Table 1
Test program.

Test series	Seasoned in RH (%)	Exposed to RH (%)	Total no. of specimens	Parallel specimens	Days of wetting/drying until testing
Wetting	50	90	20	5	5, 12, 21, 38
Drying	90	50	20	5	5, 12, 21, 38

The moisture content of each slice was determined by means of the oven dry method: Each slice was weighed immediately after cutting and after drying at ca. 103 °C during 48 h. Table 1 summarises the test program.

2.2. Numerical simulations

2.2.1. Model and formulation

The performance of screw reinforcement was studied in more detail by means of numerical simulations for the wetting case, as this has shown to be more severe than drying [2,4]. The reinforced glulam specimen used in the experiments was modelled in 3D. In order to reduce calculation time, only one fourth was modelled with two symmetry planes, as shown in Fig. 2. The glulam part of the specimen was modelled with six cuboids lying on top of each other, representing the six laminates of Norway spruce. The annual ring pattern of each laminate was taken into account by defining local cylindrical coordinate systems in each laminate. The origins of these coordinate systems are defined by the piths in the corresponding laminates. This allows defining different material properties in the radial and tangential direction of the annual rings. In the present case, the piths were assumed to be located in the cross section centre on the bottom of each laminate (Fig. 2). The uppermost laminate faced outward, which is in accordance with cross sections in practice. In this laminate, the pith was correspondingly located on the upper border of the laminate (Fig. 2). The reinforcing screw in the specimen centre was modelled with a steel rod of diameter 5 mm, which corresponds to the inner thread diameter of the screw. Preliminary simulations have shown that the calculated results agreed best with experimental results when using this diameter (as compared to the full threaded section of 8 mm), although the differences were small.

Numerical simulations of moisture induced stresses developing in glulam cross sections are generally performed by using a one-dimensional moisture transport model coupled with a hygro-mechanical model. The equation of the three-dimensional orthotropic hygro-mechanical model is as follows, whereby the creep strain rate is neglected:

$$\dot{\boldsymbol{\varepsilon}} = \dot{\boldsymbol{\varepsilon}}_e + \dot{\boldsymbol{\varepsilon}}_s + \dot{\boldsymbol{\varepsilon}}_{ms} \quad (3)$$

where $\dot{\boldsymbol{\varepsilon}}$ is the total strain, $\dot{\boldsymbol{\varepsilon}}_e$ the elastic strain, $\dot{\boldsymbol{\varepsilon}}_s$ the linear shrinkage-swelling strain, and $\dot{\boldsymbol{\varepsilon}}_{ms}$ the mechano-sorptive creep strain rate. The dot denotes derivative with respect to time. The elastic strain rate is a function of the stress vector $\boldsymbol{\sigma}$ and the compliance matrix

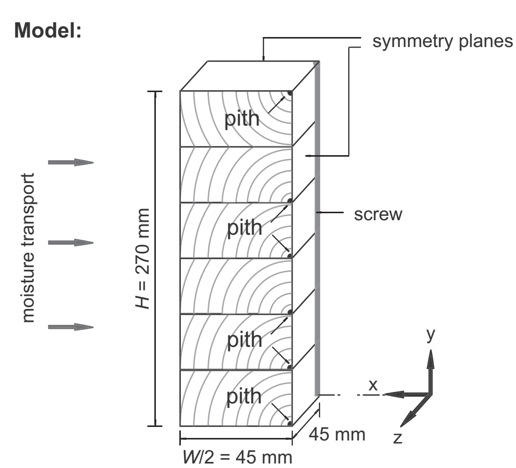

Fig. 2. Model with dimensions and two symmetry planes.