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Evaluation of glued laminated timber beams reinforced with carbon fiber fabric for use in FEM modelling

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Abstract. Main focus of this article is on glued laminated timber beams reinforced with carbon fiber fabric. In the first part of this article, the tested materials are described, alongside with testing methods used. Several testing methods were used, as there was need for thorough determination of material characteristics. Obtained findings will be used as input data for future FEM models of reinforced GLT beams that should be comparable to real behavior.

Introduction

In nowadays civil engineering is the timber very popular material, as it is on rise again mainly because of the high demands on energy efficiency of buildings, it is appropriate to devote this material to try to find ways for its optimum utilization. When solid timber ceased to meet the demands of civil engineers, it was necessary to find a way to improve its performance. Accordingly, there was also first thought to remove these drawbacks by means of gluing timber elements to create a composite material with better properties than solid timber. That is glued laminated timber. The prime beginning of glued laminated timber (hereinafter referred to as GLT) dates back to England in 1866, where Josiah George Poole designed and built the still existing roof structure made of glued laminated timber at the University of King Edward in Southampton [1]. A significant shift in technology of GLT came in 1942 when has been introduced the first fully waterproof glue, which allowed the use of GLT in outdoor environment without the risk of degradation of glued joints. GLT is a high value construction material that has excellent properties and can replace solid timber where there no longer sufficient elements can be made of it. It consists of layers of lamellas that are glued together under pressure, using a waterproof adhesive [2]. At present, this material is mainly used in modern timber structures and roof structures of halls. Despite the frequent use of this material, the technology of production is still in development. There are new types adhesives being developed and also methods of reinforcing [5]. For this reason, the main material, which is an essential part of this research is glued laminated timber. The results published in this article are part of a larger project in which we have been focused on beams with rectangular cross section. The beams are made of spruce wood, originally from the Czech Republic and are reinforced with carbon fiber [4].

Tested material

Glued laminated timber beams. Primary tested material is glued laminated timber (GLT) in form of beams, made of spruce wood and classified as GL24h. Length of those beams is 4.6 m, width 0.1 m and height 0.32 m. Each row is made of from so called infinite lamella. Infinite lamella is made of timber parts without knots, those parts are then glued together by finger joints and cut to desired length. Lamellas are glued together with use of melamine-formaldehyde (MF) glue which is very similar to urea-formaldehyde (UF), but has better resistance to water and stability during change of environment. This glue is popular for its light color of hardened joints. Beams were stored under laboratory conditions and the humidity was under 12.0 %. In total, there were six beams (four reinforced with carbon fiber fabric and two beams without reinforcement). Reinforced beams were labelled with numbers 1,4,5 and 6 (Fig.1).

Figure 1 GLT beams

Carbon fiber fabric. Second used material is carbon fiber fabric. This material was used for additional reinforcement of GLT beams on the bottom surface. Type of used fabric is Carbon unidirectional UD CST 200 made of unidirectional carbon fiber with PES grid. It has thickness of 0.4 mm and grammage of 200 g/m^2. This fabric was attached to GLT beams with resin based glue epoxide LG 100 with hardener Flex 40. Glues was primary developed for high strength gluing of wooden based materials, mainly because the glue saturates the material and thus becomes part of the composite (Fig 2).

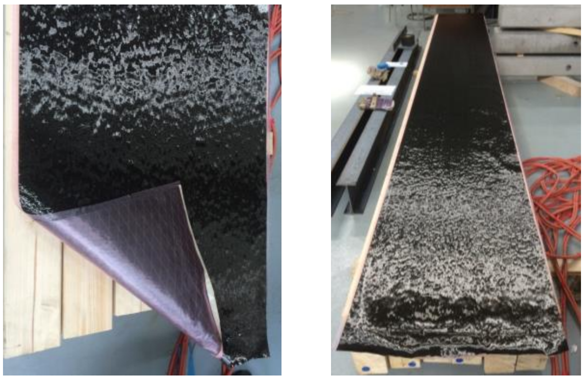

Figure 2 Carbon fiber fabric

Testing methods.

Destructive testing. Four-point bending test was chosen for GLT beams as it is most appropriate destructive method for timber, because the most stressed part is without shear force and bending moment is constant. During static loading test were measured vertical deflections and shifts depending on the loading force. Loading of beams was performed in steps, where size of force in each step risen by 4 kN every 240 seconds, until the destruction of specimen. The results of these tests are in form of graph of force and deflection, along with video recordings (Fig. 3).

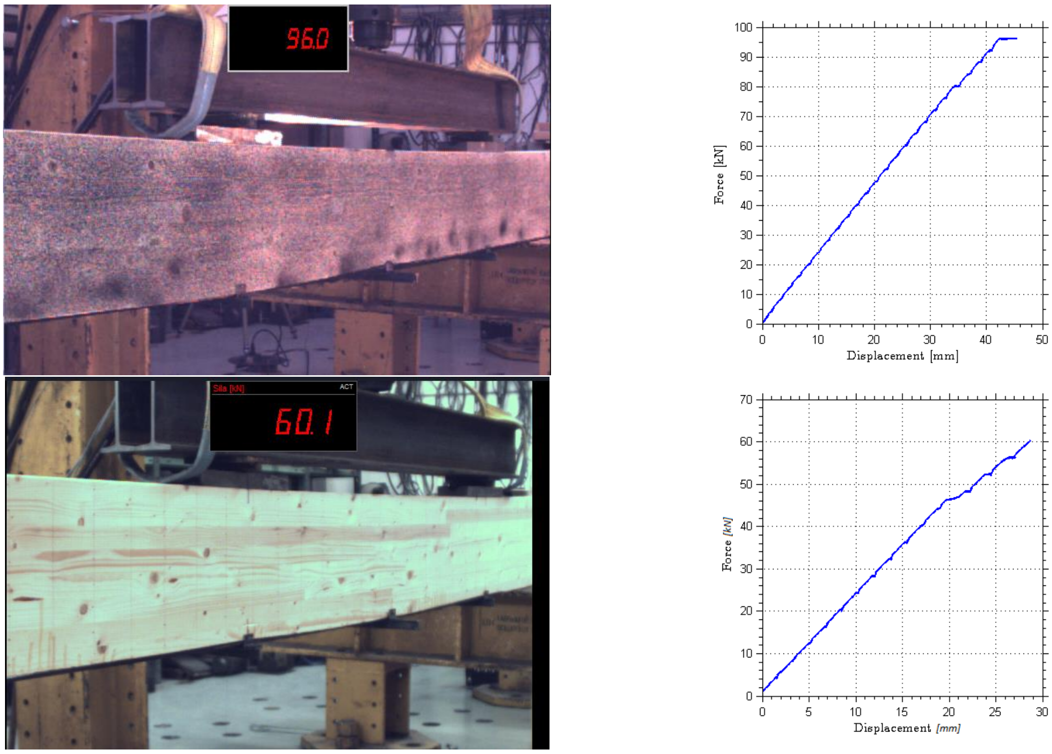

Figure 3 GLT beams 1 (**top one**) and 6 (**bottom one**) during load with corresponding graph of force and deflection

Real modulus of elasticity was calculated from cleaned values without noise of sensors for all tested beams (Table 1).

Name	Mean of E [GPa]	Standard error [GPa]
Beam 1	13.5	0.8
Beam 4	12.9	0.7
Beam 5	14.4	1
Beam 6	13.5	0.6

Table 1 Values of modulus of elasticity calculated for reinforced beams with standard error

Non-destructive testing. To obtain material characteristics in form of modulus of elasticity, two non-destructive methods were used. First one was method of spike. This method is among the available methods of assessing timber elements, without greater mechanical damage to the element, which would alter the mechanical properties of the whole. Method uses device called Pilodyn 6J, that shoots spike with normalized force and the depth of puncture is measured with precision to half of millimeter. Modulus of elasticity is than calculated from those values [5].

Second used method was the pulse method, that is suitable for determining the dynamic elastic properties of flexible materials which are preferably isotropic and homogeneous. The resonant frequency of the elements obtained from such materials, are dependent on the modulus of elasticity. From measured natural frequencies of beams, the modulus of elasticity is then calculated.

Conclusions

Reinforced glued laminated timber beams were thoroughly explored and tested through various testing methods (destructive four-point bending test and non-destructive method of spike and pulse method). From the four-point bending tests the graphs of progress of loading were obtained, alongside with video recording. Video recordings will be used to observe behavior of reinforced beams during static loading and destruction, mainly a moment before and after maximum load capacity is reached. Calculated values of modulus of elasticity will be used for comparison with FEM models of reinforced beams that will be made. Several variants of FEM models need to be prepared, until the load behavior of model will be compliant with real one. The aim is to create a FEM model, which will behave under load in the same way as the actual beams. Subsequently, it will be possible to change method of reinforcing of the beams (mainly type and thickness of carbon fiber fabric) so that it will be possible to find the ideal reinforcement effect on the beams.

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