Experimentální Analýza Napětí 2011
Experimental Stress Analysis

Beams from the Glued Laminated Timber with the High Performance Lamellas and their FEM Models

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Abstract: Article is focused on the optimization of thickness and materials of high performance lamellas in beams from the glued laminated timber. Destructive bending tests of thirty beams with the different types of reinforcements are used as base of this work. We have two types of materials and six different lamellas thicknesses in tests. FEM models are made precisely according to tested beams. Firstly, tests and FEM models are compared. Secondly, new FEM models with different thicknesses and material properties are made. Optimization of this type reinforcement is made from these FEM models.

Keywords: Glued laminated timber, High performance lamellas, FEM models

1. Introduction

This article is focused on the optimization of thickness and material of reinforcement lamellas used in the glued laminated timber beams. Twenty beams from the glued laminated timber without reinforce lamellas were elaborately described in our previous works [1, 2]. Precisely detections of modulus of elasticity in the fiber direction were made in each one of twenty beams and their distributions [3, 4].

We continue in our work with the next group of beams. In the new group of beams, high performance lamellas from composites are glued as the lower layers of the beams. Thirty reinforced beams are divided according used material of reinforcement lamellas on the two types. In the one half of reinforcement lamellas carbon fibers (C in the next text) are used. Second half is made from glass fibers (G in the next text). The carbon composites are used in three different thicknesses 2, 4 and 6 millimeters (C2, C4, C6 in the next text). Glass fibers are not as so solid as carbon fibers and are used in reinforcement lamellas in their thicknesses 5, 10 and 15 millimeters (G5, G10 and G15 in the next text).

This work is based on the destructive bending tests of twenty reinforced beams. Bending tests are the same as in case of beams without reinforcement. Loading capacity of each beam is represented of maximal bending moment. Loading capacity is evaluated in different groups. Result of this approach is the influence of material and thickness of high performance lamella on increase of loading capacity in timber members. The non-linear relationship between bending moments and reinforcement lamella thicknesses was demonstrated.

The same trend was verified for the displacements too. Displacements are very important quantity for reinforcement of beams from the glued laminated timber and for the use

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of other structural members. In this work, maximal displacements individually for each beam are compared at first and then they were compared in groups. This approach leads to selection of combination glued laminated timber and reinforcement lamella with high loading capacity in group of glass fiber composites and in group of carbon fiber composites. Secondly, we obtain the displacement comparison for the same level of loading for all beams.

If we evaluate all bending tests as precisely as possible we can make FEM models. At first we create new FEM models of thirty beams according to really tested beams. The correspondence between tested beams and FEM models is demonstrated. Secondly, it was selected really beam with small compression strength on the top surface. For this beam, different thicknesses and properties of reinforcement lamellas are simulated.

2. Compare of bending moments for the different types of reinforce lamellas for maximal loading level

In the first step we evaluate maximal bending moment during the beam destruction for six types of reinforcement. As it is mentioned in introduction part of this work, C2, C4 and C6 are groups of beams from the glued laminated timber with reinforcement lamella from carbon fiber thicknesses 2, 4 and 6 millimeters. G5, G10 and G15 are groups of beams with glass fibers in reinforcement lamellas with thicknesses 5, 10 and 15 millimeters. Statistical approach is more suitable for the bending moments comparing in groups. Normal distribution is used in Fig. 1 and 2. The basic statistical characteristics are in the Table 1. The comparing of bending moment for maximal loading on the 5% quantile from the statistic evaluation with the really measured bending moment for beam with minimal loading capacity from the same group is more important. In results from Table 1 are that 5% quantile moments are in all groups smaller than minimal moment from the same group (the fifth column in Table 1). We can use normal distribution for our next work for prediction of beam behavior with different thicknesses and types of reinforcement. For optimization of design we can use thickness of a lamella as a parameter for ideal distribution forces between a glued laminated timber and composites lamellas.

Table 1. Statistical parameters for bending moments (kNm) in case beams destructions from the glued laminated timber with different types of reinforce lamellas from the experiments

Reinforce lamella	μ	σ	*5% quantile*		*Min*
C2	86	2	76	<	80
C4	100	7	87	<	91
C6	111	13	90	<	96
G5	90	15	66	<	80
G10	104	11	85	<	86
G15	120	2	112	<	113

For the comparison of influence the reinforcement lamella on the loading capacity of beams from the glued laminated timber it is possible to use previously presented group of twenty beams with the same dimensions but without the reinforcement lamella. For this previously presented group, the average maximal bending moment is μ = 54 kNm and its minimum value is 42 kNm. The increase of loading capacity between beams without reinforcement and few reinforced beams is considerable. The increase of loading capacity is not linear with the increase of lamella thickness. This trend is shown in Fig. 3 and 4 including representing polynomial. Fig. 3 is for the beams with carbon composites and has different character of the curve from beams with glass composites as it is demonstrated in Fig. 4.

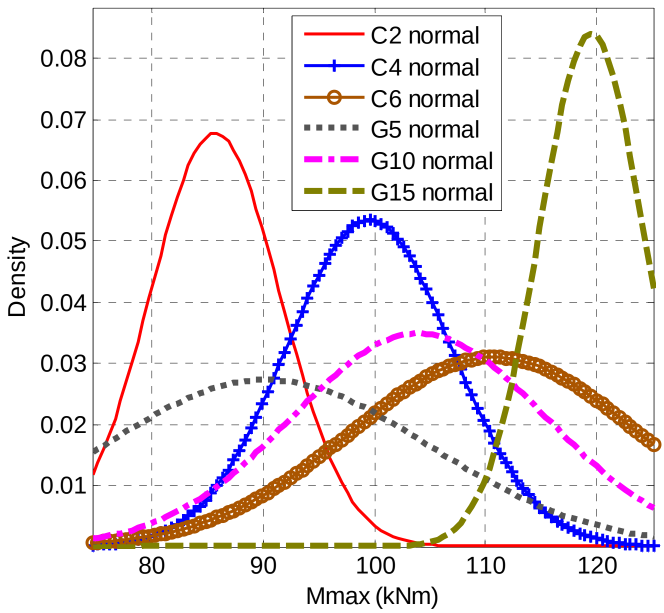

Fig. 1. Probabilistic density functions for bending moments and maximal loading level demonstrated in groups according to reinforcement lamellas (from measured values).

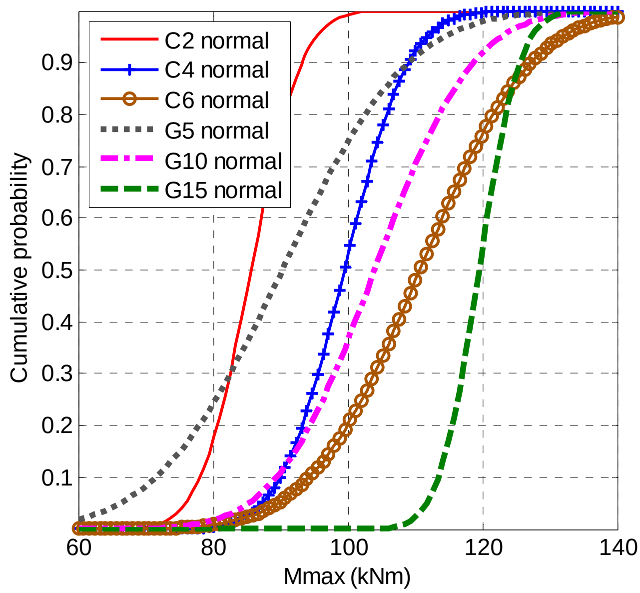

Fig. 2. Distribution functions for bending moments and maximal loading level demonstrated in groups according to reinforcement lamellas (from measured values).

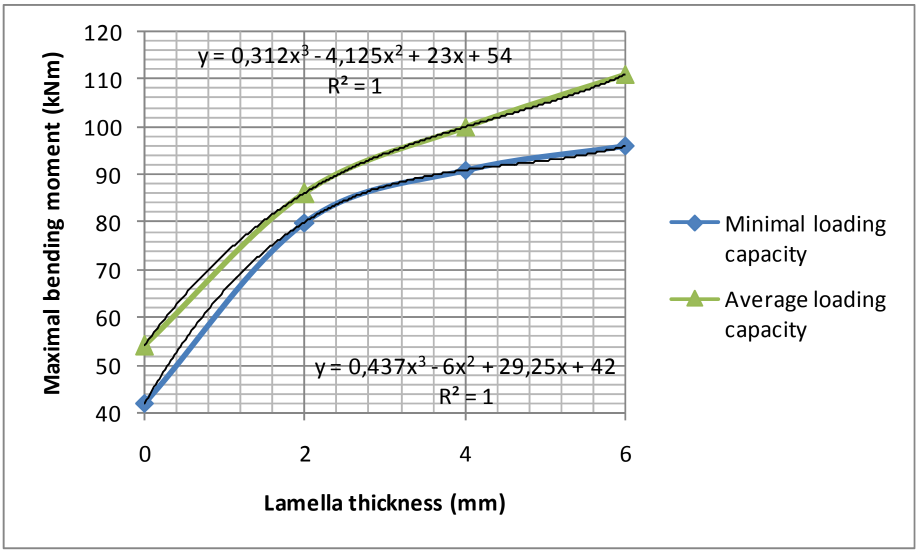

Fig. 3. Bending moments for maximal loading level and thicknesses of reinforcement lamellas relationship for the carbon composites (from measured values).

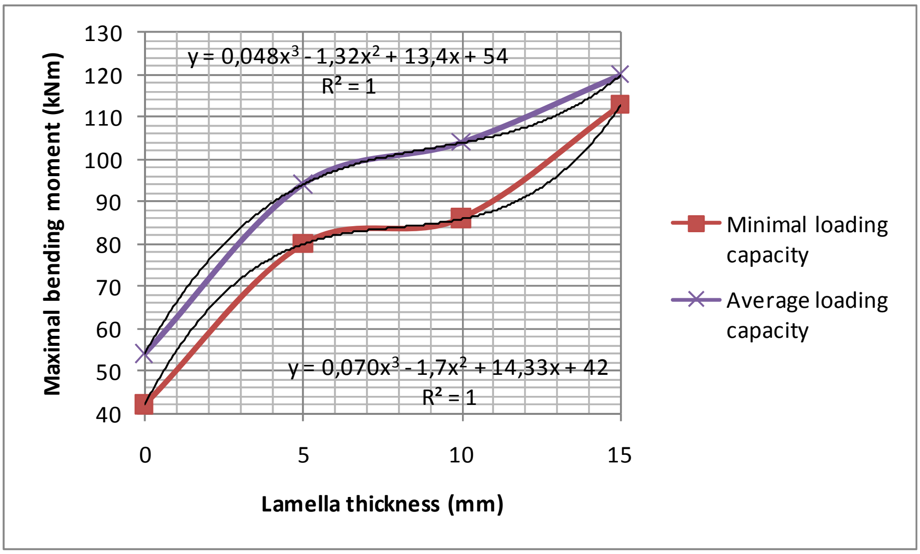

Fig. 4. Bending moments for maximal loading level and thicknesses of reinforcement lamellas relationship for the glass composites (from measured values).

3. FEM models of thirty reinforced really tested beams

In this part, thirty FEM models are made according to thirty really tested reinforced beams from the glued laminated timber. Beams were reinforced of high performance lamellas with terms C2, C4, C6, G5, G10 and G15. Six beams were in each group. One randomly chosen element from thirty beams is demonstrated in Fig. 5.

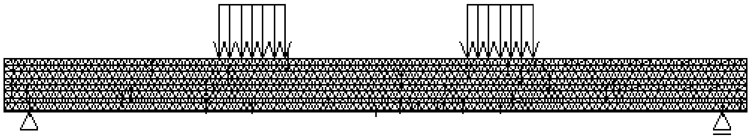

Fig. 5. FEM model of really tested beam

Displacements in the middle of beams are chosen as correspondence criterion between really tested beams and FEM models. Firstly, it was compared for the loading level (24 kN for each force) corresponding with the group of beams made from the glued laminated timber without reinforcement (Fig. 6). Secondly, it was compared for displacement caused by individual maximal loading level for each beam (Fig. 7).

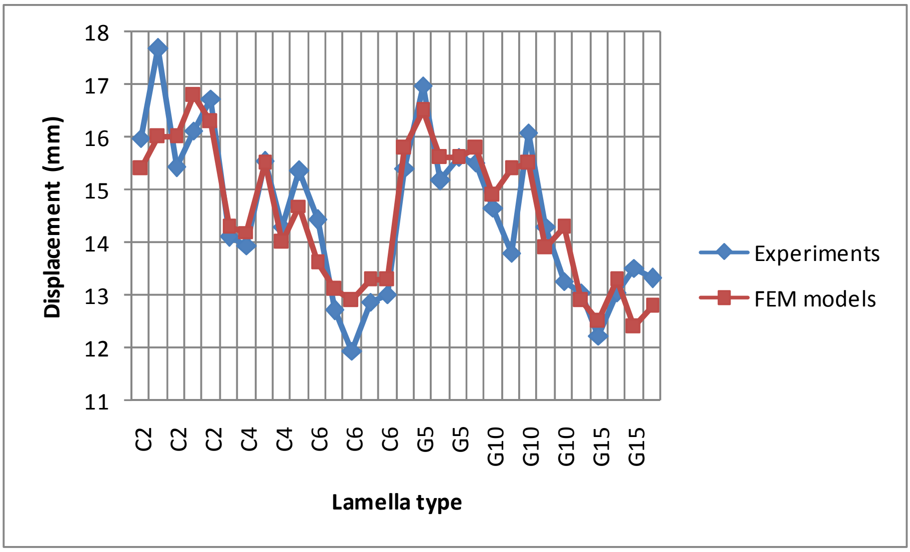

Fig. 6. Comparing of experimentally obtained displacements for thirty reinforced beams from the glued laminated timber and their FEM models. Comparative loading level is 24 kN each force, the same as for the glued laminated timber beams without reinforcement lamella.

The correspondence between FEM models and experiments is excellent for comparative loading 24 kN (Fig. 6). For extreme loading level, displacements on the really tested beams are higher than displacements in FEM models (Fig. 7). Maximal loading level is immediately before beam collapse, because tested beams are damaged and their measured displacements are higher. In FEM models, these effects are not, because for us displacements in high but not extreme loading level are more important. Beams without damage are in the real structures. Results of our work are that high performance lamellas decrease displacements and increase the load capacity of beams from the glued laminated timber. This effect is demonstrated in Fig. 8. Where excellent correspondence between experimentally measured and calculated values of displacements from FEM models are demonstrated. Loading level is 48 kN for each force. From the Table 1 it results that maximal loading level for the first destructed beam with the small loading capacity is 56 kN. If the value of each force is 56 kN, bending moment is 76 kNm.

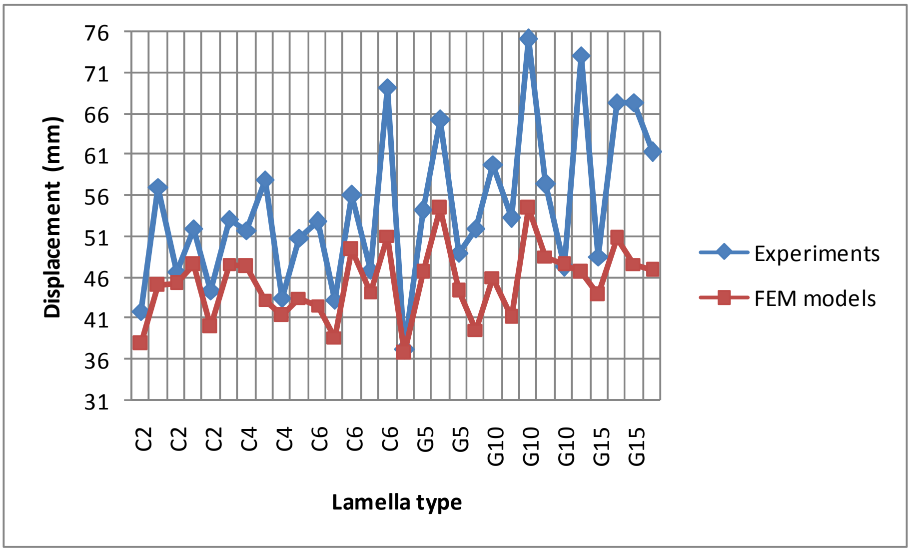

Fig. 7. Comparing of experimentally obtained displacements for thirty reinforced beams from the glued laminated timber and their FEM models. Loading is individual for each beam on the maximal loading capacity level.

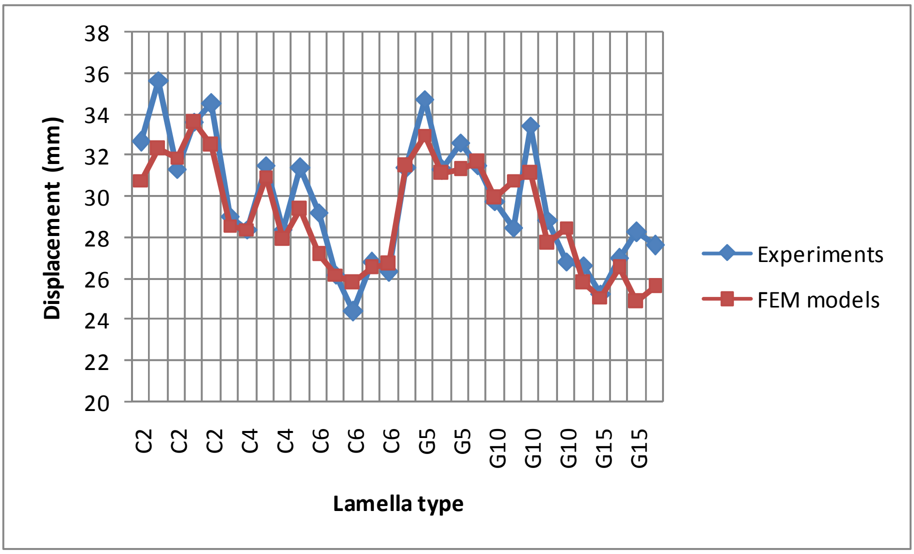

Fig. 8. Comparing of experimentally obtained displacements for thirty reinforced beams from the glued laminated timber and their FEM models. Comparative loading level is 48 kN for each force (85% loading capacity of reinforced beams).

4. FEM simulation of different thicknesses and materials of reinforced lamellas

Beam number 16 was chosen for the optimization. This beam had very low loading capacity in comparing with all of the thirty reinforced beams. Damage of this beam was on the compressed side for loading level 64 kN of each force. Randomly placed lamella with relatively small loading capacity was in the much compressed position in the real beam 16 during production. This beam is chosen for FEM simulation of different thicknesses and material properties of reinforcement lamellas. The loading level is 48 kN for each force. This loading capacity is three quarters of maximal loading capacity, because the beam is not damaged on this loading level. The used FEM model is in correspondence with reality. The stress on the compressed surface of the beam is controlled and observed. Critical value of the stress is 40 MPa.

Simulation of reinforcement lamellas is made for the both really used composites. Thicknesses of lamellas are in FEM models from 2 to 20 millimeters with the step 2 millimeters. The beam displacement is shown in the next graph for the both types of composites (Fig. 9).

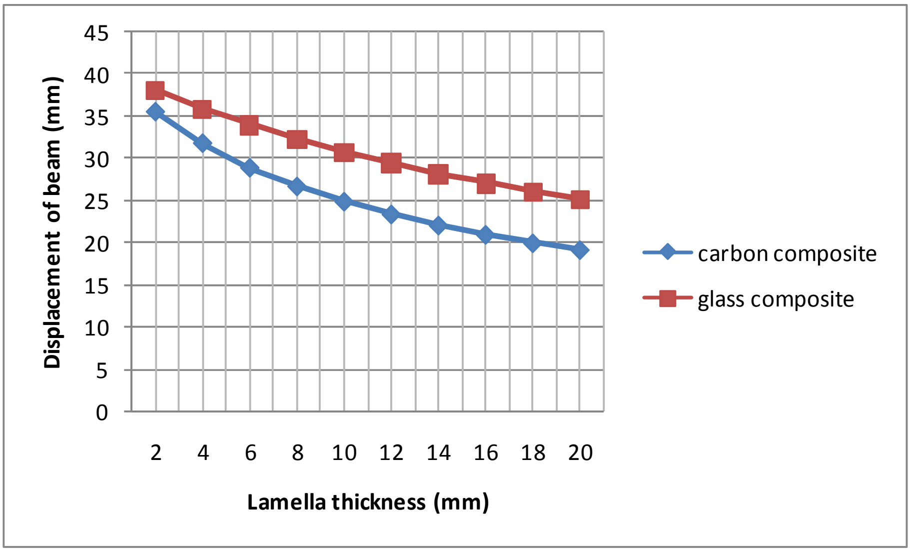

Fig. 9. Displacement of representative beam 16 and thicknesses of reinforcement lamellas relationship. Both types of really used composites are shown. These values are from FEM simulation and comparative loading level 48 kN of each force.

5. Conclusions

FEM models of thirty beams have excellent correspondence with the really tested beams. The displacement is smaller and maximal loading capacities are higher for beams reinforced by the glued laminated timber. From presented results is possible to obtain optimum for three parameters (lamella thickness, loading and maximal displacement). Optimization of thicknesses of the both reinforcement lamella types used in this work enable us define optimal new composite for beam reinforcement made from the glued laminated timber in our next work.

Acknowledgements

This outcome has been achieved with the financial support of the Ministry of Education, Youth and Sports of the Czech Republic, project No. 1M0579, within activities of the CIDEAS research centre.

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