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Timber beams strengthened by carbon – fiber reinforced lamellas

P. Neubauerová[a]*

[a]*Institute of metal and timber structures, Veveří 95, Brno 602 00, Czech Republic*

Abstract

This paper deals with strengthening timber beams with polymer lamella reinforced by carbon fibers dispersed in the matrix. The influence of the reinforcing on strength and stiffness of the beam was investigated. For the experiments the beams of a common cross section for the structure of ceilings were used – 160x100 mm, 140x100 mm and 120x100 mm with the distance between supports of 3,0 m (the beams acted as simple beam). The cross section of the lamella was chosen according to the possibilities of the manufacturer – 50x1, 2 mm. The lamellas were bonded to the beam externally (using special glue based on epoxy resin) in the tension part in the middle of the width. This problem was solved particularly in light of numerical simulation (using some computer program based on the finite element method) and particularly in light of practical analysis. During the experiments the composite material based on connection timber – carbon was tested and the maximal limit force and maximal vertical deformation was measured and each beam was loaded to rupture. Several modes of failure were observed within the experiments – depending on the quality of the timber material, number of knots in the tension part of the cross section, moisture etc. This research is realized in the co-operation with the company of "PREFA KOMPOZITY" at Brno, which deals with the development and research of fiber composites, among others. In light of experimental analysis, results of the pilot tests are presented.

Keywords: Timber; carbon; lamella; beam; reinforcing

1. Introduction

Within experiments the cross sections mentioned in abstract were used and the influence of the reinforcing over stiffness and strength of a timber beam was investigated. Tests were worked out both on reinforced and non-reinforced beams to obtain the possibility of comparison. Three samples of each beam were tested. Each beam was loaded to failure and during the experiments the value of the loading force and maximal vertical deformation were observed and took down. In a few cases also the strain between the layers was measured, see

* Tel.: +420-549-245-212; fax: +420-549-245-212
E-mail address: neubauerova.p@fce.vutbr.cz

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Fig 1. The focal point of the research is the comparison of the test results and determining the influence of reinforcing.

2. Component parts, loading system

The carbon fiber reinforced polymer was applied to the beams in form of lamellas to the tension edge of each beam and was connected on it by special glue based on an epoxy resin, see Fig 1.

The carbon fibers are dispersed in the polymer matrix based on epoxy resin as well. In the end the adhesive joint has shown to be a critical point of the composite material because of a bad adhesion between the glue and the lamella.

The beams were tested with the theoretical span of 3, 0 m and 4, 0 m as mentioned above. All the beams acted as simple girders (supports were realized by special supporting steel pads) and were loaded by a hydraulic press. The force was transmitted to the beam through a steel cross beam. The experiments were going on as a four – point bending, see Fig 2.

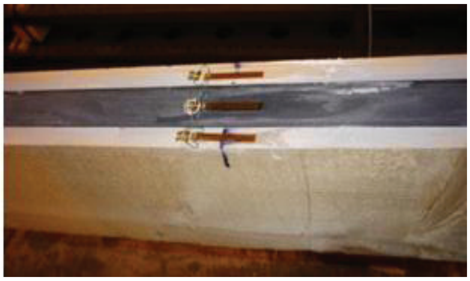

Fig. 1. Lamella and strain gauges bonded to the timber beam (upside down)

Fig. 2. Test arrangement

The lamellas with the dimension of 50 x 1, 2 mm were used and they were applied to the middle of the width of the timber beam as also visible in the Fig 1. The bonding of the lamella is necessary to be made very thoroughly (this is provided by the supplier of the lamellas) and the glue needs a week of hardening to obtain the correct properties.

The connection turned out as of very high strength but, as mentioned above, the joint between the layers lamella – glue was broken very often. The separation of the lamella occurred in a case of many experiments but usually not in all range of the span. If the lamella was separated in some parts a piece of timber material was pulled out of the cross section, see Fig 3.

A few words about the loading system were mentioned yet. The force was transferred to the timber beam via the steel cross beam and this one was located on special steel pads (the supports of the beam were realized by like pads) which acted against high value of contact stress in the timber.

Fig. 3. Separation of the lamella

3. Test results

The results of the experiments do vary a lot depending on the mode of failure, strength of the connections, moisture of the timber etc. Although the timber material was a high quality we mentioned a small number of knots which became the most frequent mode of failure, especially if one of them was located within the tension fibers near the mid-span. Generally we observed four most frequent modes of failure:

- failure caused by a knot,
- sudden fracture of the beam with a low value of the loading force without any previous signs of failure,
- longitudinal cracks (in this case the deformation of the beam was almost like a deformation of two connected boards),
- increasing of the vertical deformation and no rising of the loading force (which occurred in case of the best quality material and then the test had to be interrupted).

3.1. Results of the pilot tests

Table 1. Average values of maximal force and maximal vertical deformation measured in the mid-span within pilot tests

220x100	Non-reinforced	Reinforced	
F [kN]	48,0	50,6	Increase by 5%
w [mm]	87,0	91,5	
200x100	Non-reinforced	Reinforced	
F [kN]	34,6	43,0	Increase by 23%
w [mm]	74,7	88,0	
180x100	Non-reinforced	Reinforced	

F [kN]	25,7	128,331,7	Increase by 23%
w [mm]	85,7	91,5	

The experiments were initiated with the beams with the span of 4, 0 m and the cross sections of 180x100, 200x100 and 220x100 mm. Values of the maximal force vary a lot for each sample (as possible to see in Table 1, the results in the tables are presented in their average values). A problem occurs if one of the results has very different values compared to the rest. In this case, this result changes significantly the average values of all the set.

According to the tables and charts it is possible to mention the influence of the reinforcing to the strength and stiffness of the timber beam. This trend is more significant in the case of cross sections of a small height. In a case of the beam with the height of 220 mm almost no increase occurred.

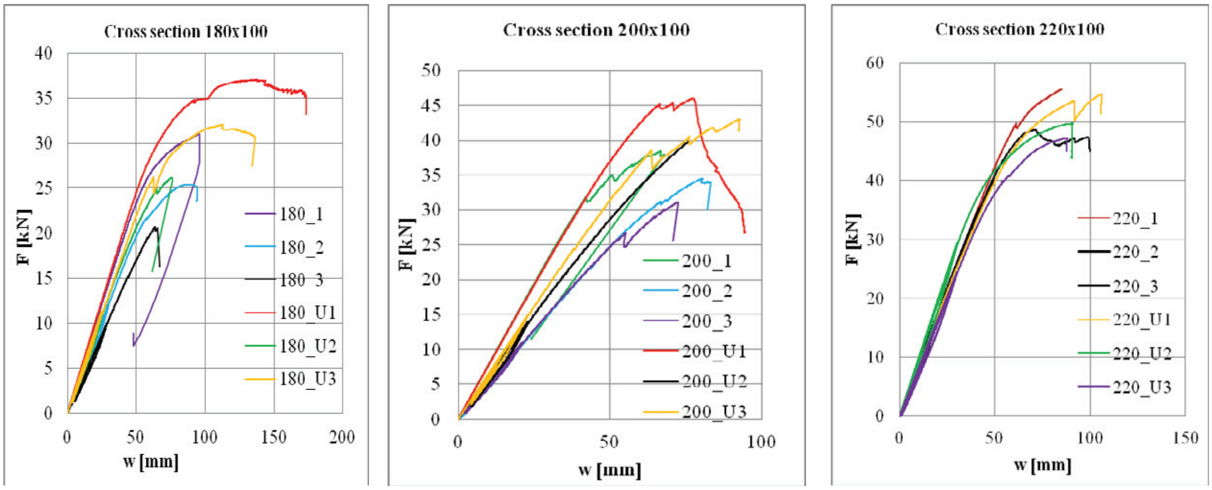

Fig. 4. Results of experiments for the cross sections used within pilot tests

3.2. Results of the following tests

The experiments worked out on the cross sections with the height of 160, 140 and 120 mm followed fluently after the pilot tests. The basic information stays the same in this case. But the experiments give different results. We did not observed the trend which occurred within the pilot tests – increasing the influence of reinforcing hand in hand with reducing the height of cross section, see Table 2 and Fig. 5

Table 2. Average values of maximal force and maximal vertical deformation measured in the mid-span within following tests

160x100	Non-reinforced	Reinforced	
F [kN]	39,7	42,0	Increase by 6%
w [mm]	125,1	159,7	
140x100	Non-reinforced	Reinforced	
F [kN]	33,9	33,8	No increase

w [mm]	208,0	194,7	

120x100	Non-reinforced	Reinforced	
F [kN]	17,2	24,5	Increase by 42%
w [mm]	73,5	93,3	

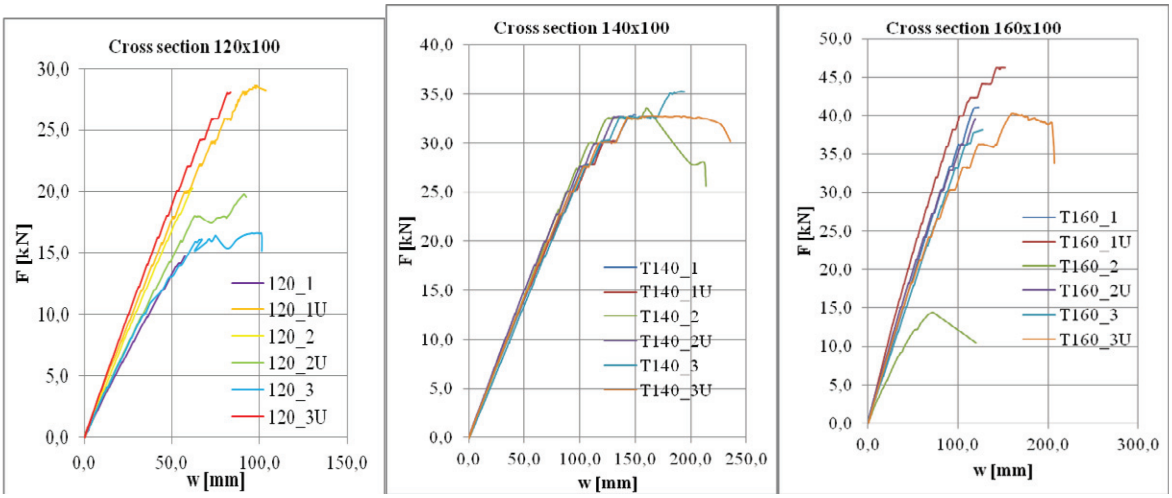

Fig. 5. Results of experiments for the cross sections used within following tests

3.3. Shear stress between layers

As was mentioned above the stress on the borders of materials between the layers timber – lamella (realized by the layer of epoxy glue) was measured. The gauges were bonded to the beam as is visible in the Fig. 1. As results of the gauges we observed the values of the strain ε. Calculations based on these values were worked out. First we calculated the theoretical value of ratio of modulus of elasticity of timber to modulus of elasticity of carbon *n*. In the case of timber the modulus of $10 \cdot 10^9$ [Pa] was considered and in the case of carbon the modulus of $155 \cdot 10^9$ [Pa] was considered. The calculation of *n* follows.

$$n = \frac{E_{timber}}{E_{carbon}} = \frac{10 \cdot 10^9}{155 \cdot 10^9} = 0{,}065$$

The value of theoretical value of *n* was compared with the measured values for each cross section. The results are presented in the average values in the Table 3. Also the reciprocal value $1/n$ is presented to show clearly the difference between the stresses on the borders of materials. This difference causes the shear stress between layers and that is why these values are important. The shear stress acts straight to the layer of the glue which needs to stand this loading. During the experiments we observed breaking the glue layer very often, see Fig. 3. This fact probably occurred because of wrong preparing and manufacturing of the reinforcement. It is necessary to say that perhaps the problem was caused by smooth surface of the lamellas. It could be recommended to the manufacturer to try to change it.

There is probably no relationship observed between the value of ratio of modulus of elasticity of each material and the dimensions of the cross section. The measured values approximate to the theoretical value of 0,065. Experiments proved theoretical preconditions used within calculations.

Table 3. Average values of ratio of modulus of elasticity of timber to modulus of elasticity of carbon *n* measured during experiments

Cross section	Ratio of E - *n*	1/*n*
220x100	0,058	17,27
200x100	0,072	13,86
180x100	0,069	14,57
160x100	0,100	10,74
140x100	0,062	16,19
120x100	0,062	16,08

4. Conclusion

According to the charts and the tables it is clear that increase of the strength influenced by the reinforcing is significant in the case of cross sections of 120x100, 180x100 and 200x100 whereas in the case of cross sections of 140x100, 160x100 and 220x100 slight increase or even no increase occurred. This means that there is no unequivocal trend of increase of the strength depending on the dimensions of a cross section which is caused by conditions of experimental verification (e. g. small number of tests in connection with a variability of material characteristics of timber) and also by random phenomena (e. g. defects within material). For more general results it is necessary to work out sufficiently representative set of tests and for concrete evaluation of the results it is suitable to use a kind of probabilistic methods instead of statistic methods, for example design assisted by testing combined with sensitivity analysis.

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