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REINFORCEMENT OF TIMBER BEAMS WITH CARBON FIBERS REINFORCED PLASTICS

ABSTRACT

Wood is a polymeric material with many valuable features and which also lacks some negative features. In order to keep up with high construction rates and the minimization of negative effects, wood has become one of the most valuable materials in modern engineering. But the use of timber material economically is also an actual problem in order to protect the environment and improve natural surroundings. A panel of scientists is interested in solving these problems and in creating rational structures, where timber can be used efficiently. These constructions are as follows: glue-laminated (gluelam), composed and reinforced wooden constructions. Composed and reinforced wooden constructions are examined less, but according to researches already carried out, it is clear that significant work can be accomplished in creating rational, highly effective and economic timber constructions.
The paper deals with research on the formation of composed fiber-reinforced beams (CFRP) made of timber and provide evidence of their effectiveness. The aim of the paper is to investigate cross-bending of CFRP-reinforced gluelaminated timber beams. According to the results we were able to determine the additional effectiveness of reinforcement with CFRP (which depends on the CFRP material's quality, quantity and module of elasticity) on the mechanical features of timber and a whole beam.

KEY WORDS

- *Timber beam,*
- *Carbon fiber-reinforced plastics (CFRP),*
- *Load-carrying capacity*

INTRODUCTION

In order to increase the quality of a construction, it is very important to decrease its material-consuming and labor-consuming features. One of the main ways to solve these problems is to use light composed constructions, which are first of all wooden and plastic building constructions. Often it is advisable to use these materials and combine them, which is especially effective in glued constructions.
In the case of a traditional building material, the high relative firmness of wood gives us the opportunity to create 100 m and more wooden and plastic building constructions. The production of rot-resistant, bio-resistant and fire-resistant protective facilities has brought about fresh perspectives in using wooden material in a construction. Furthermore, wood is accounted as a remarkable and permanent material in a chemically aggressive environment. That is why it is used it in the chemical industry; in constructing warehouses for mineral fertilizers it is very effective compared to concrete and steel materials.
The production of man-made rigid polymeric materials and synthetic adhesives gives us the opportunity to create combined and composed gluelaminated and wooden-plastic building constructions. They are characterized by having a high degree of relative firmness, more stability in a chemically aggressive environment, a low linear expansion coefficient, low degree of heat conduction, lightness, the possibility of creating random cross-section forms, high resistance against rot and combustion, and less residues. Each component made from these constructions (wood,

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synthetic adhesives, plastic) consists of polymeric materials, which is the main reason scientists are interested in order to create progressive constructions using these materials, the physical-mechanical features of which are similar.
Research on rational form constructions using these materials has been going on for more than half a century. A few successes have been achieved. There are many scientific achievements expected in the near future.
As research on the materials shows, searching for progressive building methods, improving calculating methods, and the continuing development of the chemical and other fields has given us the opportunity to implement many new scientific-technical innovations in order to achieve more progress with more economic efficiency and to use newer building materials and local natural resources as well.
The rational merge of materials with different strengths and elasticity modules into a single construction composition, with the most positive properties of each of these materials being used in its operation, enables the creation of roofs with heightened strength, rigidity and reliability with a sufficiently effective degree of economy.
Reliable work with wood materials under compression, and of fiber-reinforced plastic materials (FRP) in one composition in the form of wood - FRP beams shows they can work together. As high-strength materials use carbon fiber-reinforced plastics (CFRP), all theoretical calculations and experimental measurements in this paper can be realized with this material.

MATERIALS AND METHODS

The object of this research is to investigate CFRP-reinforced gluelam timber beams on cross-bending and to determine the load capacity and stiffness of timber-CFRP beams in an experiment and to compare them with a mathematical-physical model.
The mathematic-physical model can be realized both by an ordinary known mechanical building method and FEM, which is more universal and, what is more, it is possible to use the ANSYS computer program. The use of ANSYS gives us the opportunity to input the orthotropic properties of a wood material as well.
The general idea is to:

1) Investigate an ordinary timber beam's load capacity (a beam, which is only made using a timber material and is not reinforced with a highly rigid material).
2) Investigate the same timber beam with the same cross-section and span, but which is reinforced with a high-strength material.
3) Compare the results achieved, analyze them and see what effect is gained by reinforcing the timber beams.

According to the results achieved, we can determine an additional-degree of efficiency of the reinforcement with CFRP (which will depend on the CFRP material's quality, quantity and module of elasticity) on the mechanical features of the timber and the whole beam.

Beams researched:

We tested five beams with the following configurations and amounts:

a) Not reinforced gluelam beam (2 pieces). They were used for comparing the results with the reinforced beams.
b) One-sided reinforcement of a gluelam beam (2 pieces). The reinforcement consists of one sheet of CarboDur S512.
c) Two-sided weak reinforcement of a gluelam beam (1 piece). The reinforcement consists of one sheet of CarboDur S512 placed on both the stretched and compressed edges. In the case of a large amount of buckling the beam will become reinforced on one-side and will be measured as a one-sided reinforced gluelam beam.

The cross-section of these composed timber beams is 440 x 160 mm, and the length is 9,5 m, therefore the span from one support to the other is 9 m. The beams are composed of 11 pieces of 40 x 160 mm cross-section lamellas, which are glued to one another, which is why the cross-section of the tested beams is 440 x 160 mm. The lamellas are longitudinally connected to one another by finger joints. For a more reliable connection, the finger joints used are also glued to each other. The module of elasticity (E) is variable according to each beam because of the variability of the wood material's properties. In the case of reinforced beam carbon fibers (CFRP), Sika S512 is used as a reinforcement. These are sheets made of carbon fibers with

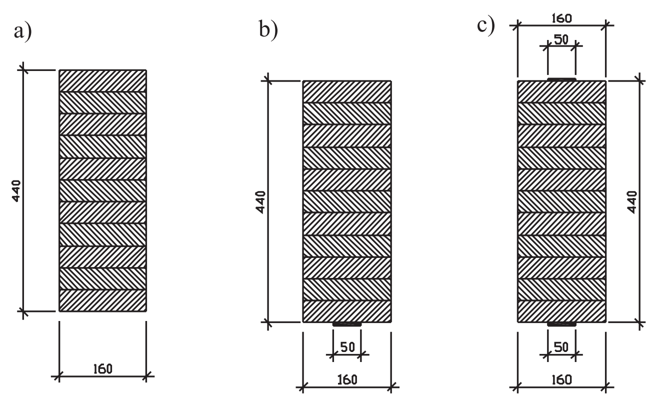

Fig. 1: *Configurations of reinforced timber beams for testing: a) Not reinforced gluelam beam; b) One-sided reinforcement of a gluelam beam; c) Both-sided reinforcement of a gluelam beam*

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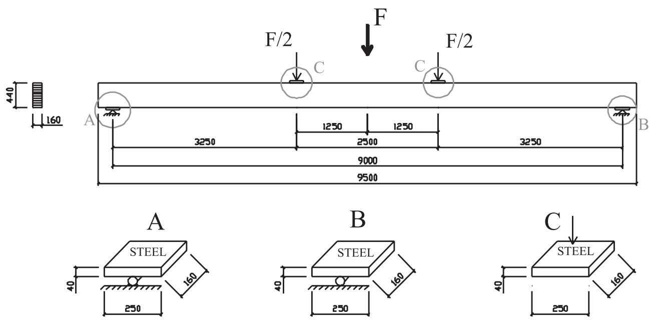

Fig. 2: *Scheme of the beam tested*

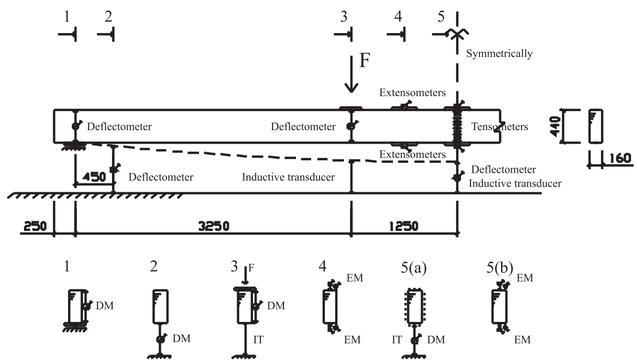

Fig. 3: *Scheme of places measured*

a 1,2 x 50 mm cross-section and a 60 mm^2 cross-section area, which are glued on the whole length of a beam in special gap cuttings. The module of elasticity is E = 165000 N/mm^2 and the resistance to tension f_t = 2400 N/mm^2.

Our goal was to get exact results in this experiment, which is why we have decided to test composed timber beams in natural sizes and did not use beam models. Loading was carried out in two equal loads, which were placed symmetrically to each other and from the end of the beam. The distance from the support to the loading is 3250 mm and 2500 mm between the loadings. The loads were transferred to a beam by pressure equipment through special metal plates which were placed on the beam. We only took short-term loadings into account in this experiment. In Figure 2 the scheme of the beam tested with the loading locations and supports is shown:

Testing equipment:

The experiment on each beam was realized separately. We used five beams, so we had to do five tests. We used the following equipment for the measurements in this experiment: extensometers, deflectometers, inductive transducers and tensometers. As we know, tensometers and inductive transducers are connected to a computer and give us electrical data which are automatically saved in the computer's memory. The deflectometers and extensometers in our experiment were the same measuring instruments – the indicator times and data from them had to be written by hand on special tables that we had prepared before the experiment. In testing each beam the same number of measuring instruments was not used because some beams were reinforced and some were not. Twenty tensometers were attached to each beam, but only 16 of them were connected to the computer (Spider), the others served as a reserve. Three inductive transducers placed under the beam were used for each experiment – Two of them under the loading areas and one of them in the middle of the span. An inductive transducer measures deflection. Seven deflectometers were fastened to each beam. Six extensometers were used for the wood material in each experiment and three extensometers for each reinforcing sheet. Figure 3 shows the scheme of the places measured and how the measuring equipment was placed on the beam:

RESULTS

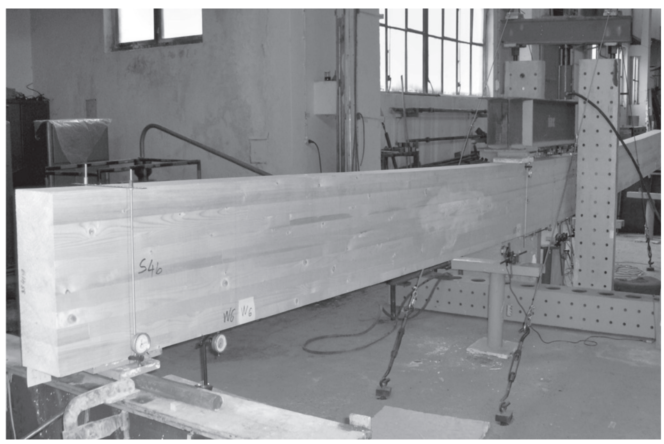

Fig. 4: *Load transferring to the experimental beam is going on (Beam №3)*

Fig. 5: *First cracks of the beam (Beam №3)*

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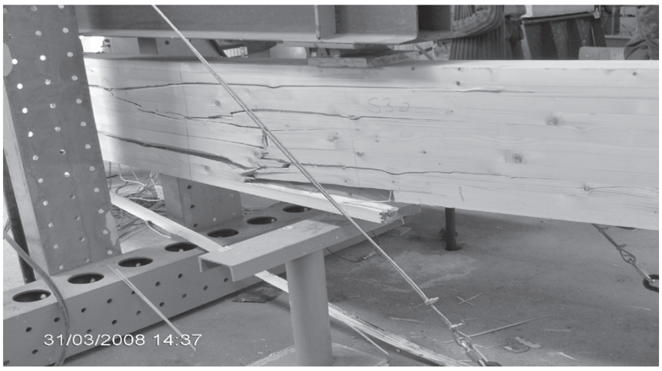

Fig. 6: *Failed beam with loosened load-carrying capacity (Beam №3)*

Beam №1

The first beam was not reinforced. When the loading reached 114 kN, the beam lost its load-carrying capacity.

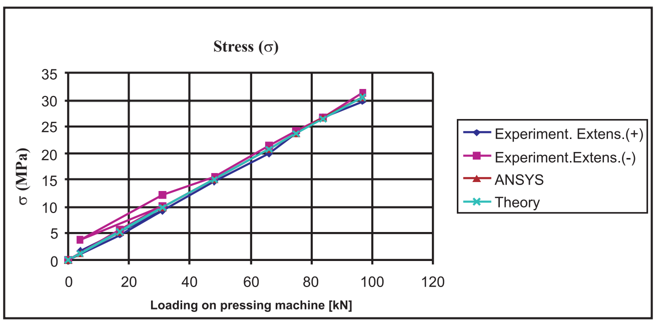

Fig. 7: *Comparison of beam №1 stresses*

Beam №2

The second beam was reinforced on one side. When the loading reached 73 kN, the beam lost its load-carrying capacity.

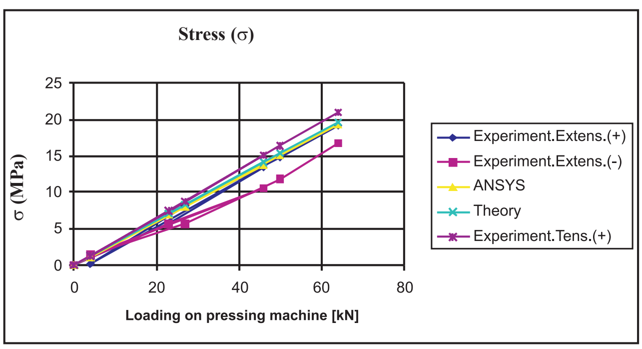

Fig. 8: *Comparison of beam №2 stresses*

Beam №3

The third beam was reinforced on one side. When loading reached 89 kN, the beam lost its load-carrying capacity.

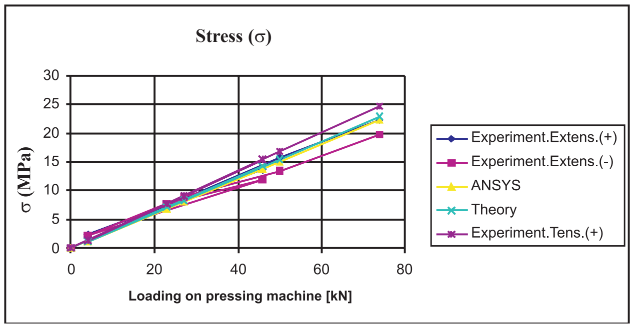

Fig. 9: *Comparison of beam №3 stresses*

Beam №4

The fourth beam was reinforced on two sides. When the loading reached 113 kN, the beam lost its load-carrying capacity..

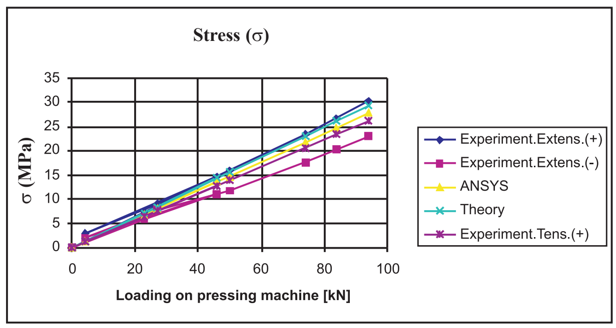

Fig. 10: *Comparison of beam №4 stresses*

Beam №5

The fifth beam was not reinforced. When the loading reached 81 kN, the beam lost its load-carrying capacity.

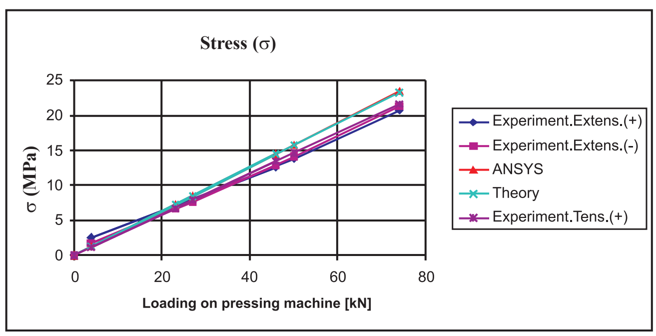

Fig. 11: *Comparison of beam №5 stresses*

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Comparison graphs: (the strength class of the wood material in the beams is GL 28h).

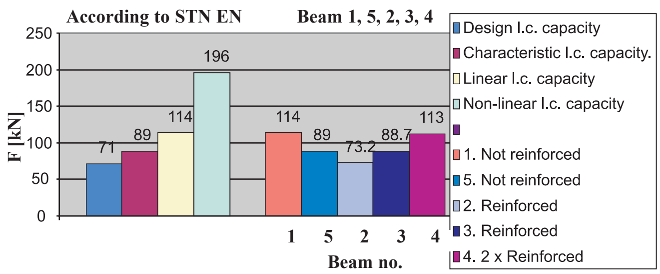

Fig. 12: *Comparison of theoretically and experimentally researched load-carrying capacities*

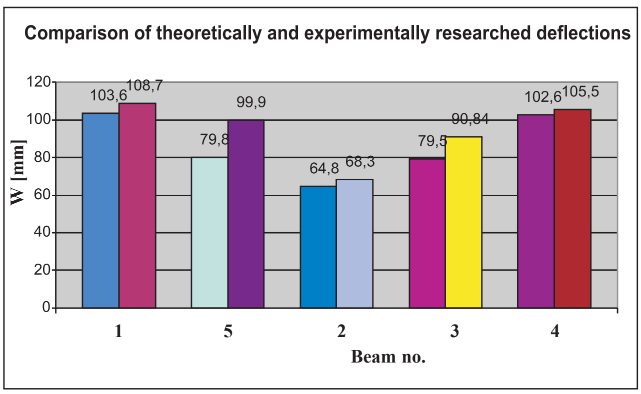

Fig. 13: *Comparison of theoretically and experimentally researched deflections before collapses*

SUMMARY AND CONCLUSION

The theoretical calculations performed by the Transformed Sections Method (TSM) and the Finite Element Method (FEM) show that in our case, one-sided reinforcement can cause an increase in the load-carrying capacity of the beams researched by 1.5 ~ 4% and their stiffness by 2~3% (but the cast can increase much more), which makes the reinforcement effect disputable in our case and can only be used in justified cases.

For a theoretical analysis and design of beams, we can apply a technical theory of elasticity as an easier way and the finite element method (FEM) as more difficult. The difference between these methods is negligible – approx. 0 – 3 %.

- The Technical Theory of Elasticity is more suitable for the practical design of beams.
- FEM is necessary for a numerical analysis of beams, essentially using the ANSYS program.

All five of the experimentally measured beams as well as equivalent types show us a large degree of variance in the load carrying capacity results – up to 30 %. Such a large variance was initiated by manufacturing defects, which overlapped the expected effect from reinforcing the beams by 3 – 6 %.

Generally, the experiment showed that the reinforcement of timber beams with CFRP materials can increase their load-carrying capacity and stiffness.

ACKNOWLEDGEMENT

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