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Deformability of a glued wooden beam with pre-stressed composite reinforcement

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Abstract

The article proposes a method for pre-stressing a reinforced glued wooden beam that involves placing steel reinforcement in the form of metal rods in the compressed zone and pre-stressed composite reinforcement in the form of tape in the tension zone. The procedure for pre-stressing is outlined, and experimental studies of such bending elements have been carried out. Graphs of the distribution of deformations in both wood and reinforcement along the height of the calculated cross-section during pre-stressing and without pre-stressing are provided. It was found that the load-bearing capacity of the reinforced glued wooden beam increased by 45% during the pre-stressing process with composite reinforcement in the tension zone.

Keywords: wood, deformation, moment, pre-stressed reinforcement, bending element .

1. Introduction

Over the past few years, materials and products made of wood have become increasingly popular (Yasniy et al. (2022), Sobczak-Piastka et al. (2020), Pinchevska et al. (2021); Rudawska et al. (2018)). Designers are increasingly

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favoring wooden elements and structures due to their strength and reliability (Betts et al. (2010), Pysarenko et al. (1988), Da Silva and Kyriakides (2007); Bojok and Vintoniv (1992)). Wood is easy to process and lighter compared to metal (Iasnii et al. (2023)), concrete (Dvorkin et al. (2021)), and other composites (Imbirovych et al. (2023)). In many cases, the mechanical properties of wood depend on factors such as moisture (Homon et al. (2023); Janiak et al. (2023); Thygesen et al. (2010)), aggressive environment (Homon et al. (2023)), temperature (Sinha et al. (2012)), and various wood defects, influencing its performance under different working conditions (Sobczak-Piastka et al. (2023), Gomon et al. (2022), Bosak et al. (2021), Zakic (1974); Green and Kretschmann (1992)).

One of the most common load-bearing elements in construction is the wooden bending element (Zhao et al. (2020), Gomon et al. (2019), Nsouami et al. (2022), Zhou et al. (2022)). In the last few decades researchers have focused their attention on the reinforcement of wooden elements with various materials, such as metal (Soriano et al. (2016), and composite reinforcement (Anshari et al. (2017), Mascia et al. (2018), Rescalvo et al. (2020), Vahedian et al. (2019)). The introduction of a stiffer material into the cross-section increases the overall stiffness of beams, leading to reduced deflections. Previous experimental studies on wooden structures reinforced with composite materials based on synthetic fibers confirmed improvements in mechanical properties (Wdowiak-Postulak (2020), Subramanian (2010)). The development of thermoplastic and the availability of synthetic fibers have made composite reinforcement an effective alternative in the wood reinforcement industry.

Previously, experimental and theoretical studies (Gomon et al. (2022), Sobczak-Piastka et al. (2020), Gomon et al. (2023)) involving the simultaneous use of two types of reinforcement - steel and composite - in wooden beams were carried out. This has resulted in significant improvements in their stiffness and load-bearing capacity. However, the idea and possibility of further enhancing the performance of these beams have emerged by applying pre-stressing to the composite reinforcement in the tensile zone. This can be achieved without additional complex equipment and is performed in several simple stages.

2. Methodology of experimental research

For the experiment, two reinforced wooden beams were fabricated, containing steel reinforcement in the compressed zone in the form of two 12 mm diameter rods of grade A500C and composite tape made of carbon fiber SikaCarboDur S-512 in the tensile zone. The methodology of arranging combined reinforcement in wooden beams and their testing is described in scientific papers (Gomon et al. (2022), Sobczak-Piastka et al. (2020)). This study focuses on the peculiarities of pre-stressing the tape and the development of deformations in the calculated cross-section of the bending element that arise as a result.

For this research, a reinforced beam (GRB-12 (Prst)) from glued pine wood with pre-stressed composite reinforcement in the tensile zone and a beam (GRB-12) whose reinforcement did not undergo pre-stressing were fabricated. The test samples had a cross-section of 100x150 mm and a length of 3000 mm. The general scheme of their reinforcement is shown in Fig. 1.

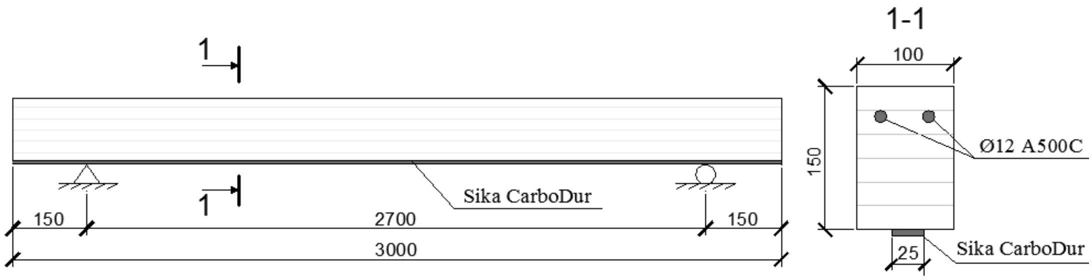

Fig. 1. Reinforcement diagram for the studied beams.

Special attention should be paid to the pre-stressing of the composite reinforcement in the beam GRB-12 (Prst) (Fig. 2). It was performed in the same setup as the main test and proceeded in several stages. The first step was to install the beam with pre-glued steel reinforcement into the grooves of the compression zone on the supports in an inverted working position of 180° (Fig. 2b). At this stage of the research, the decision was made to load the beam to the ultimate deflection w_{fin} established by design standards (DBNB.2.6-161:2017, EN 380:2008, Eurocode 5:2004, NDS:2018), which amounted to 18 mm. In this position, the tape was secured using an adhesive mixture (Fig. 2c; Fig. 3). The loading mechanism allowed the tape to be placed and fixed on top of the beam along its entire length. After the adhesive had fully cured (after two days), the structure was unloaded and flipped into the working position (Fig. 2d), where further testing took place until the loss of load-bearing capacity.

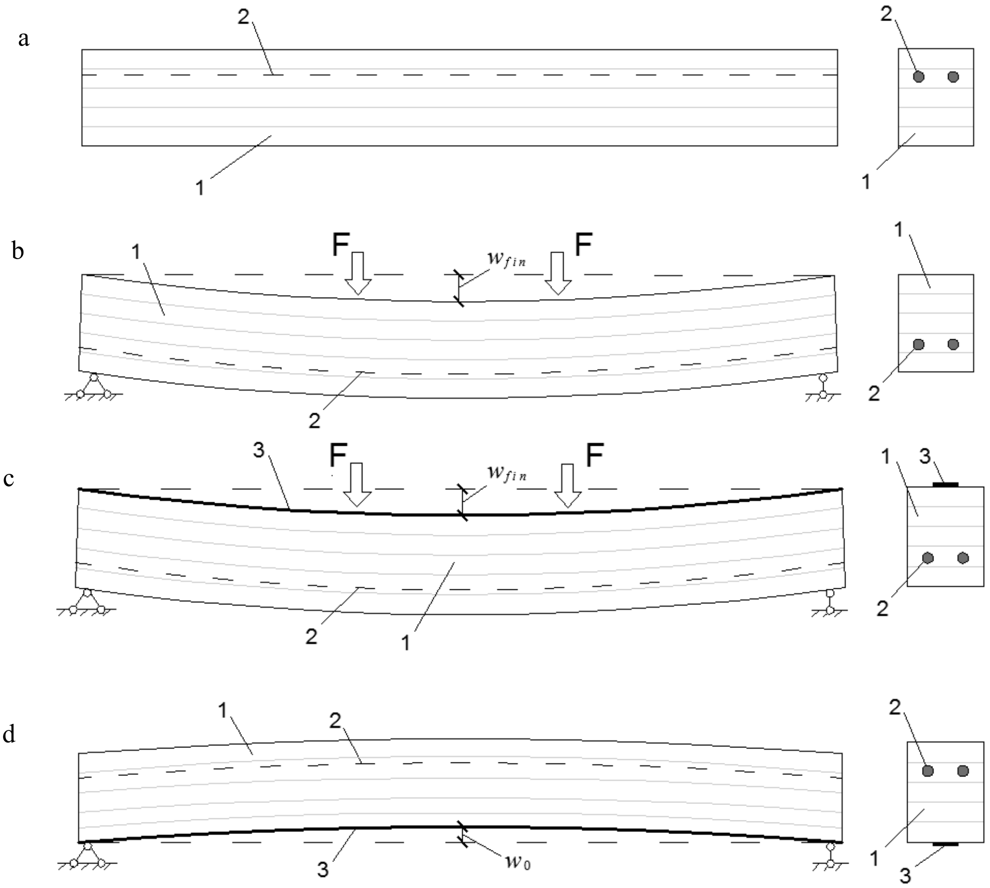

Fig. 2. Scheme of pre-stressing the external tape reinforcement: (a) beam before pre-stressing in the working position; (b) loaded beam at the moment before attaching the tape; (c) the process of attaching the tape; (d) beam after unloading in the working position (1 – wooden beam; 2 – steel reinforcement; 3 – composite tape reinforcement).

Upon unloading, the tape comes into action and prevents the beam from returning to its original position, thus obtaining pre-stressing and bending w_0 upon complete load removal. Thus, a wooden beam with pre-stressed reinforcement as a tape in the tensile zone is obtained.

To determine the relative deformations of wood in the middle of the span around the perimeter of the cross-section of the beam with a 12 mm step, strain gauges (G0, G1, G2…) were glued. Similar gauges were also placed on the reinforcement. Based on the readings of the gauges located on one of the lateral faces (in our case G2…G13), data were obtained, and graphs of fiber deformation at different layers of wood across the height of the calculated section were plotted (Fig. 4, Fig. 5, Fig. 6, Fig. 7).

Fig. 3. Wooden beam GRB-12 (Prst) under loading during the pre-stressing process of the composite reinforcement.

3. Results of the research and their discussion

The ultimate deflection w_{fin} = 18 mm, at which the tape was attached to the GRB-12 (Prst) beam, was achieved with a load of about 20 kN, corresponding to a bending moment *M'*=8.55 kNm. The graph of relative deformations up to this moment is presented in Fig. 4. Deformations are shown within the height of the calculated section in the middle of the beam span.

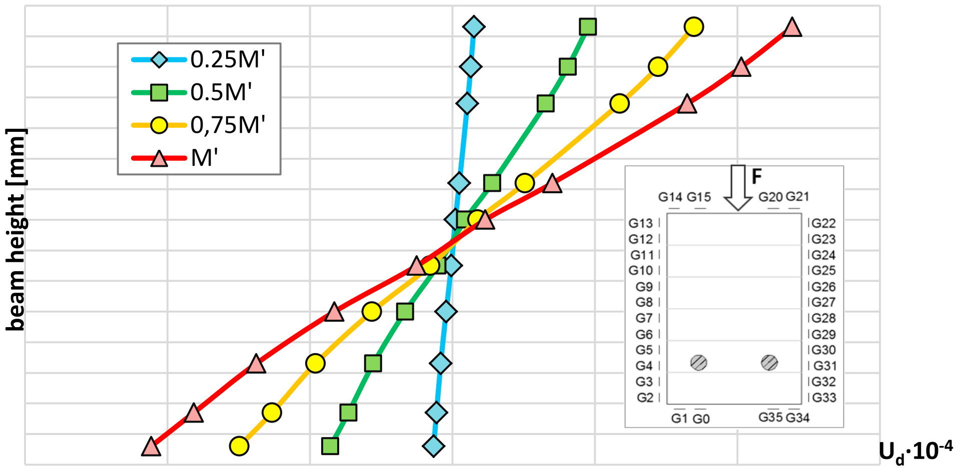

Fig. 4. Graph of deformation development along the height of the section of the GRB-12 (Prst) beam before attaching the tape.

Two days after attaching the tape, the beam was unloaded, and changes in relative deformations were also observed (Fig. 5). Notably, due to the involvement of the composite tape during unloading certain deformations in the wood remained at the moment of complete load removal.

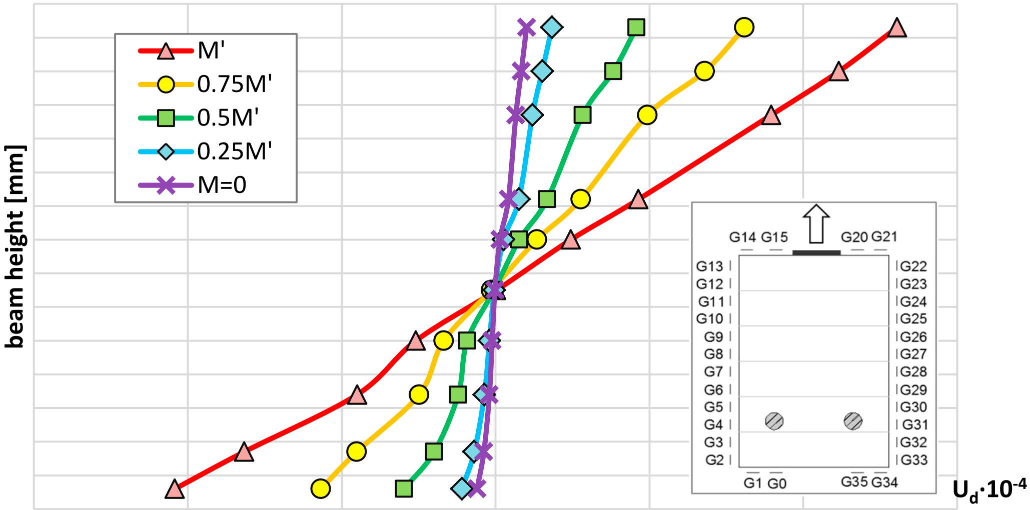

Fig. 5. Deformation development along the height of the section of the GRB-12 (Prst) beam during unloading after fixing the tape.

Subsequently, the beam was flipped into the working position, where the main test took place, bringing it to the loss of load-bearing capacity. Thus, the beam had an initial deflection w_0 = 4.7 mm. The graph of the development of relative deformations within the height of the calculated cross-section of sample B-1 with combined reinforcement and pre-stressing from the beginning of loading to failure is shown in Fig. 6.

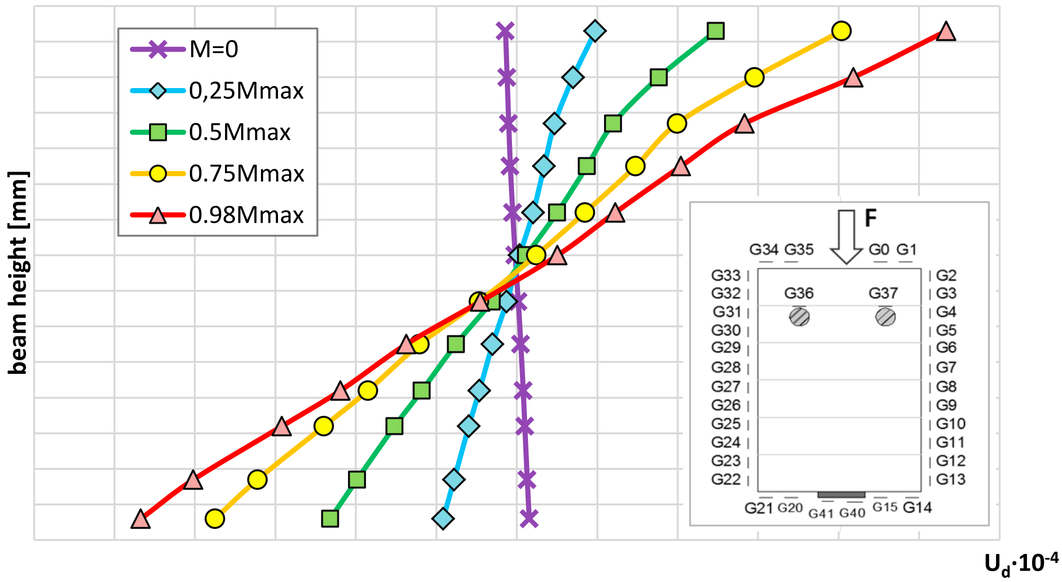

Fig. 6. Deformation development graph along the height of the section of the GRB-12 (Prst) beam with pre-stressed composite reinforcement during loading from 0 to M_{max}.

Sample B-1 failed under a load of 86 kN, corresponding to a bending moment M_{max} = 38.7 kNm. For comparison, Fig. 7 shows the development of deformations in the GRB-12 beam made with similar reinforcement but without pre-stressed composite reinforcement in the tensile zone. The GRB-12 sample failed under a load corresponding to a bending moment M_{max} = 26.55 kNm. The nature of the failure of both tested reinforced beams is shown in Fig. 8.

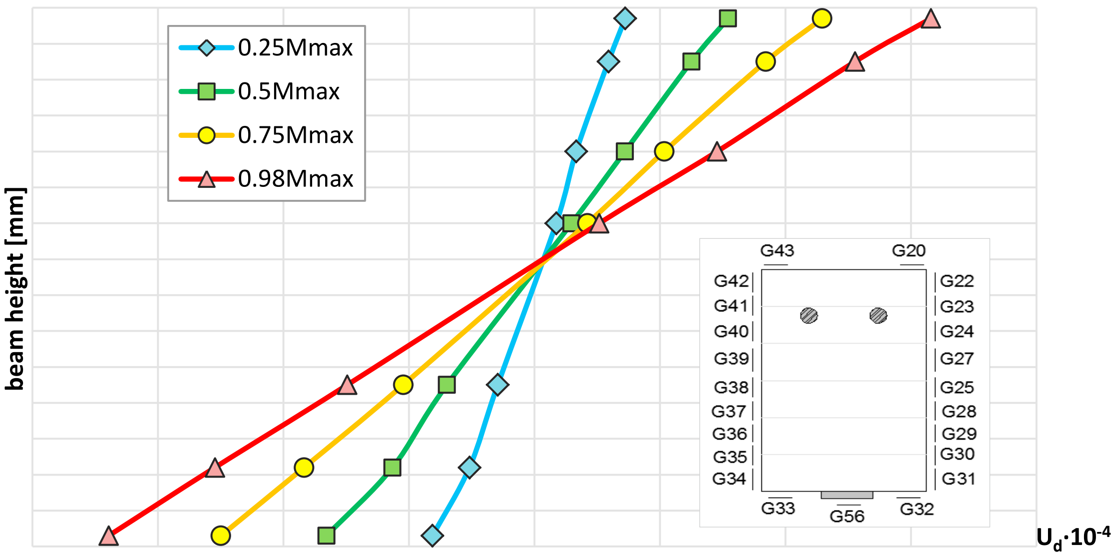

Fig. 7. Deformation development graph along the height of the section of the GRB-12 beam without pre-stressed reinforcement during loading from 0 to M_{max}.

a

b

Fig. 8. Nature of failure of reinforced beams: (a) GRB-12 (Prst) beam with pre-stressed composite reinforcement; (b) GRB-12 beam without pre-stressed reinforcement.

4. Conclusions

The pre-stressing composite reinforcement, performed in several simple stages without special additional equipment, has been presented. However, it allows for achieving significantly higher load-bearing capacity of wooden beams. The data on the deformation of a wooden beam with combined reinforcement within the calculated cross-section during the pre-stressing of the composite reinforcement in the tensile zone are obtained and compared with similar data for a beam without pre-stressed reinforcement. The experiments on two glued wooden beams revealed that pre-stressing increased the load-bearing capacity from 26.55 kNm to 38.7 kNm.

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