



A numerical analysis of different methods for strengthening beams made of glulam with CFRP fiber composites

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ABSTRACT:

Due to the favorable properties, composite materials are increasingly used in construction. Especially, they are often used to reinforce structural elements made of traditional building materials. The article presents numerical calculations of glued laminated timber beams reinforced with CFRP fiber composites in the form of tapes and bars, used in a different geometrical arrangement. The analysis was performed in the linear-elastic range in the ANSYS program. Based on numerical calculations, it was determined that the most effective method is strengthening using a horizontal tape pasted between the last and the second last sipe.

KEYWORDS:

glulam; FRP; strengthening; fiber composites

1. Introduction

Currently, composites are commonly used in construction. Especially, they are often used as reinforcement for strengthening various types of construction (concrete, steel, wooden, masonry) [1-4]. Composites are characterized by favorable properties: low self-weight, high tensile strength, high resistance to biological and chemical corrosion.

However, the building material that has recently been experiencing a renaissance is wood, which, in combination with composite materials, allows the final structural element to obtain particularly favorable physical and mechanical properties.

Many studies present various methods of strengthening wooden elements using composites [5-8]. Due to the method of production, it is easier to use composites to reinforce elements of glued laminated wood, and so these will also be analyzed in this article.

The problem that arises is the lack of relevant Polish standards relating to the necessity for practical construction solutions applying to the use of composite materials. Due to the lack of official design guidelines, numerical analyzes carried out with the help of computer programs are often used [9, 10].

The article will present the results of numerical calculations, followed by a comparison of the reinforcement efficiency of various reinforcement methods in beams made from laminated wood with various materials from FRP fiber composites.

2. Reinforcing beams made of glulam with FRP materials

In the literature, many different design solutions use FRP fiber composites to strengthen laminated timber beams. One of the first, and still more popular, methods was to use composite tapes. The straps are attached in various ways. In most cases, they are glued to the bottom sur-

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face of the beam [11, 12]. Alternatively, the straps can be glued between the last and the second last lamella during the production process, both in the tension and compression zone area of the beams [13]. A more labor-intensive method, but using a larger amount of reinforcement in the form of a composite, is to glue several rows of tapes into the last lamella also in various stress zones [13, 14]. Composite bars can also be used as reinforcement in a variety of configurations. The most widely discussed application of this solution is the cutting of square holes into the external surface of the beams and using epoxy glue to attach the round bars that can also be hidden between the slats [13, 15].

3. Materials and methods

Numerical calculations were carried out on three 3D models of wooden beams reinforced with FRP composite materials and on a wooden reference beam without any reinforcement. Calculations were made in the ANSYS program, which is used for the analysis of structures designed using FEM (Finite Element Method).

3.1. Geometry

In all of the analyzed models, a free-supported beam loaded with two concentrated forces was adopted in order that the area of pure bending would occur in the middle of the beam span. Based on the publications mentioned in the first two sections, a 3.4 m beam length and 80 x 160 mm cross-section were assumed. The static diagram of the analyzed beams is shown in Figure 1.

Three different reinforcement methods that use FRP composite materials and an unreinforced beam were analyzed. The cross-sections of the analyzed beams are presented in Figure 2. The B0 beam is the control beam, and the B1 beam is a beam reinforced with three composite bars glued between the last and the second last slat, the B2 and B3 series beams are reinforced with carbon composite CFRP (Carbon Fiber Reinforced Polymer), positioned respectively between the lamellas and pasted into the lower lamella. The cross-sectional areas of the composite material and hence the percentage of reinforcement in all the reinforced beams was the same.

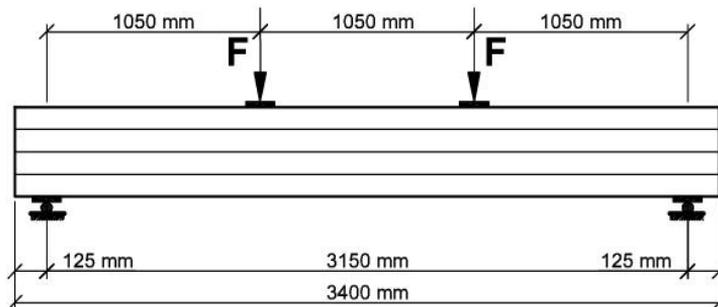


Fig. 1. Static scheme of all tested beams

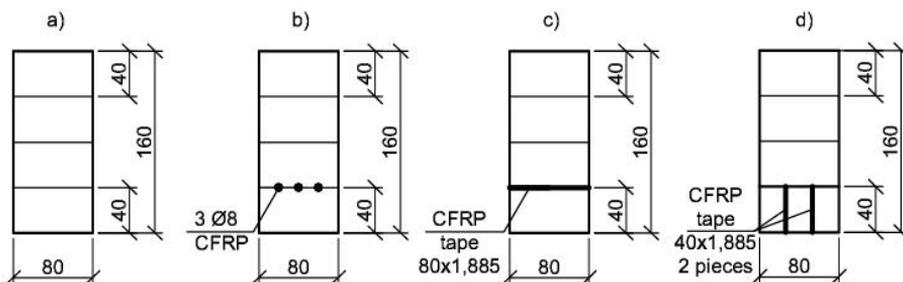


Fig. 2. Cross-sections of beams: a) B0, b) B1, c) B2, d) B3

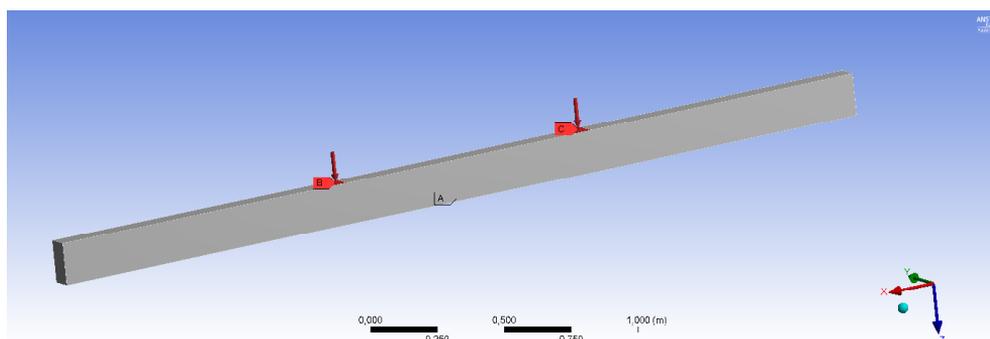


Fig. 3. Numerical model created in ANSYS

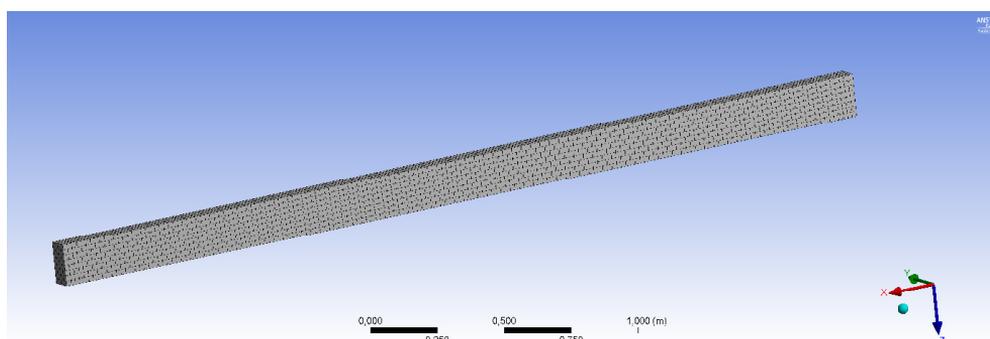


Fig. 4. Finite element mesh

All beams were modeled in the same way as 3D spatial models (Fig. 3). Beam models and calculations were made in ANSYS. In the areas, where the concentrated forces were applied and in places of support, steel washers were simulated, with an area of 100 x 80 mm. These prevented the point application of forces that could possibly falsify results during the numerical analyzes. The B0 beam model's reticulation is shown in Figure 4. The connections between the lamellae were not modeled because, due to the high quality of the adhesives, the connection rigidity is comparable with solid wood. The contact between the wood and composite elements were in each case modeled as "glued". This assumption can be found in other publications and it shows high compliance with the results of experimental studies [16].

3.2. Materials

Wood is an anisotropic material. However, because with more detailed analysis, three characteristic directions (longitudinal - L , tangent - T , and radial - R) can be distinguished, wood can be treated as an orthotropic material. In the case of orthotropic materials, to perform a numerical analysis, it is necessary to know nine material constants. For the purposes of the analysis, the class of all beams was assumed to be GL24h, whose general material data was read from the PN-EN 14080: 2013 standard. Wooden constructions - laminated timber and solid laminated timber - Requirements [17]. To determine the necessary data to be implemented in the computer program, the relationships between Young's modules for L , T and R directions given in [18] were used. These are presented below:

$$E_T/E_L = 0.043 \quad (1)$$

$$E_T/E_L = 0.078 \quad (2)$$

$$E_T/E_L = 0.064 \tag{3}$$

$$E_T/E_L = 0.061 \tag{4}$$

$$E_T/E_L = 0.003 \tag{5}$$

The longitudinal axis of the beam is assumed to be the x axis (L), the vertical axis is the z axis (T), while the horizontal axis is the y axis (R). At the same time, it was assumed that the tangent axis (T) is the z axis, while the y axis is the radial axis (R) in relation to the fiber arrangement in the lamellas. Data on CFRP composite materials were taken from an extensive study on the numerical modeling of carbon strips [19]. Material data of wood and composite materials adopted for the analysis is presented in Table 1.

Table 1
Material data adopted for numerical calculations [17-19]

	Parameter	Unit	Timber	CFRP (tapes, bars)
Modulus of longitudinal elasticity	E_x	[MPa]	11 500	165 000
	E_y		897	10 000
	E_z		494.5	10 000
Modulus of transverse elasticity	G_{xy}	[MPa]	736	5000
	G_{xz}		701.5	5000
	G_{yz}		34.5	500
Poisson's ratio	ν_{xy}	[-]	0.372	0.3
	ν_{xz}		0.467	0.3
	ν_{yz}		0.435	0.03

4. Results and discussion

Figure 5 presents the deflection graph of the analyzed beams for all types of reinforcement (series B1-B3) and for the control beam B0. B1-B3 beams (reinforced beams) have lower deflection values than the B0 beam. The beam showing the least deflection is the B2 beam, in which the reinforcement is a horizontally glued composite tape between the last and the second last lamella. Deflections, regardless of the reinforcement used, showed the same character. Deflection at a load of $F = 15$ kN for individual series was adequate: B0 - 55.251 mm, B1 - 50.276 mm, B2 - 16.33 mm, B3 - 44.764 mm.

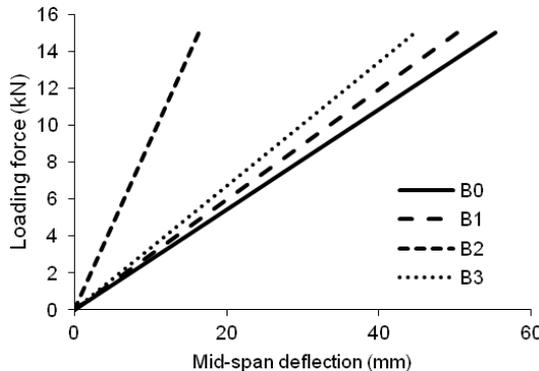


Fig. 5. Graph of deflections of analyzed beams

5. Conclusions

The article presents the numerical analysis of various laminated wood beam reinforcement solutions using CFRP carbon fiber strips and composite rods. All reinforced beams showed lower deflection values compared to an unreinforced beam, which suggests a beneficial effect of using composite materials. Based on the results of numerical calculations, the most effective method of reinforcement is to use a composite tape and glue it horizontally between the last and the second last lamella. For the above solution, the deflection value is smaller than the unreinforced beam by 70.4%. In the case of the other two constructional solutions, the deflection reduction is 19% for tapes transversely glued in the last lamella and 9% for CFRP bars. Due to the nature of the numerical calculations, the analysis presented above is only preliminary and is to verify the accuracy of the above results obtained. Experimental tests should be carried out on similar models and the assumptions adopted for the calculations should be verified.

Acknowledgments

The authors are grateful for the access granted to the computing infrastructure built in projects No. POIG.02.03.00-00-028/08 „PLATON - Science Services Platform” and No. POIG.02.03.00-00-110/13 „Deploying high-availability, critical services in Metropolitan Area Networks (MAN-HA)”.

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Analiza numeryczna różnych sposobów wzmacniania belek z drewna klejonego warstwowo kompozytami włóknistymi CFRP

STRESZCZENIE:

Ze względu na korzystne właściwości coraz szerzej wykorzystywanym materiałem w budownictwie są materiały kompozytowe. Szczególnie często używa się ich przy wzmacnianiu elementów konstrukcyjnych wykonanych z tradycyjnych materiałów budowlanych. W artykule przedstawiono obliczenia numeryczne belek z drewna klejonego warstwowo wzmocnionych kompozytami włóknistymi CFRP w postaci taśm i prętów, zastosowanych w różnym układzie geometrycznym. Analizę wykonano w zakresie liniowo-sprężystym w programie ANSYS. Na podstawie obliczeń numerycznych określono, że najbardziej efektywne jest wzmocnienie z wykorzystaniem poziomej taśmy wklejonej pomiędzy ostatnią a przedostatnią lamelę.

SŁOWA KLUCZOWE:

drewno klejone warstwowo; FRP; wzmacnianie; kompozyty włókniste