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Influence of the length of CFRP tape reinforcement adhered to the bottom part of the bent element on the distribution of normal stresses and on the elastic curve

IZABELA BURAWSKA[1)], ANDRZEJ TOMUSIAK[1)], PIOTR BEER[1)]
Department of Construction and Technology of Final Wood Products, Warsaw University of Life Science, Nowoursynowska 159, 02-776 Warsaw, Poland

Abstract: *Influence of the length of CFRP tape reinforcement adhered to the bottom part of the bent element on the distribution of normal stresses and on the elastic curve.* The paper analyses the influence of reinforcements made of CFRP tape on the distribution of normal stresses and on the elastic curve of a wooden beam that is being bent. It was a numerical analysis made in the Solidworks Simulation environment. The local reinforcement of the element permitted to reduce the elastic curve by up to 20% and to reduce the maximum normal stresses by 80% in the proximity of the opening, by using a 50 cm long CFRP tape. It has been concluded that CFRP tapes may be useful for local reinforcement of the tensed areas of bent wooden beams that are weakened due to openings produced by knots that fell out or rotted.

Keywords: bending, reinforcement, CFRP tape, normal stresses, elastic curve

INTRODUCTION

The intense development of technology creates new possibilities for designers and engineers. Lately, composite materials have become very popular, and especially the CFRP (carbon fibre reinforced plastic) tapes. This material started to be used in the construction in the 60s, with the development of the usage of resins. Composites have specific qualities that differentiate them from traditional construction materials, that is: low specific weight that goes together with very good physical parameters and high resistance. Table 1 shows the basic properties of chosen fibre types and steel.

Table 1. Chosen properties of fibres and steel [German, 2005]

		Fibre type				
Parameter	steel	E-glass	S-glass	graphite	kevlar 49	Boron
Diameter [μm]	-	16	16	7-8	12	100-200
Specific weight ρ [kN/m³]	78	25-25.5	24.5	13.8-18.6	14.1	25.5
Tensile strength R [GPa]	0.5	1.7-3.5	2.5-4.8	1.7-2.8	2.3-3.6	3.5
Specific strength R/ρ [km]	**6.4**	**68-136**	**102-196**	**123-163**	**163-255**	**137**
Young's Modulus E [GPa]	210	72	86	230-250	120-125	400-410
Specific modulus E/ρ [km·10³]	**2.7**	**2.8**	**3.5**	**12.4-18.1**	**8.5**	**16**

Most composites consist of a continuous phase, called the matrix, which surrounds the dispersed phase, called the reinforcement. Hence, the properties of the composites, which have anisotropic character, depend on the share and on the properties of the phases that they consist of, as well as on the geometrical features and the manner of arrangement of the reinforcement within the matrix. Thanks to the anisotropy of the composites, there is a possibility of adjusting the resistance value and the anisotropy directions to the stress state of the material [Dąbrowski, 2002].

Composite materials are used mostly to manufacture components of modern, light structures, sports and recreation equipment, as well as masts, posts, and above all reinforcements of constructions. Due to the above-mentioned advantages of composite materials, we decided to check whether it would be useful to locally reinforce a weakened, bent construction beam with a CFRP tape; the check was carried out numerically with the use of the Solidworks Simulation programme. It was also relevant to determine the optimum length of the local reinforcement of the weakened element.

NUMERICAL ANALYSIS

The CFRP tape was modelled as an orthotropic element, 1.2 mm thick, 50 mm wide and with a variable length – 20 mm, 50 mm, 100 mm, 150 mm, 300 mm and 500 mm. The tape was adhered on the bottom part of the bent element, covering its whole width. The bent element was designed as a pine beam, also with an orthotropic model and the dimensions of 50x100x2000 mm. The characteristic values of the resistance parameters were assigned as for the class C22 timber. The Table no 2 presents the resistance parameters of the timber and of the CFRP tape, which were applied during the numerical analysis.

Table 2. Chosen values of resistance parameters for the timber and for the CFRP tape

	Longitudinal flexibility ratio E [MPa]			Poisson's ratio ν [-]			Transverse flexibility ratio G [MPa]		
	E_x	E_y	E_z	ν_{xy}	ν_{xz}	ν_{yz}	G_{xy}	G_{xz}	G_{yz}
C22 timber	6700	330	330	0.4	0.4	0.025	630	630	630
CFRP tape	168000	10000	10000	0.3	0.3	0.03	5000	5000	500

The glue layer was not modelled, because of its high resistance. Constant displacements were assumed at the place of contact between the layers.

In order to carry out the simulation of reinforcement of the bent element, we prepared a model of real instruments applied during resistance tests. The virtual experimental workplace is in line with the recommendations of the PN-EN 408:2004 standard (Fig. 1.). The support and upper points of contact were designed as made of alloy steel. One of the support points of contact was defined as fixed, and the other one as mobile (Fig. 2.).

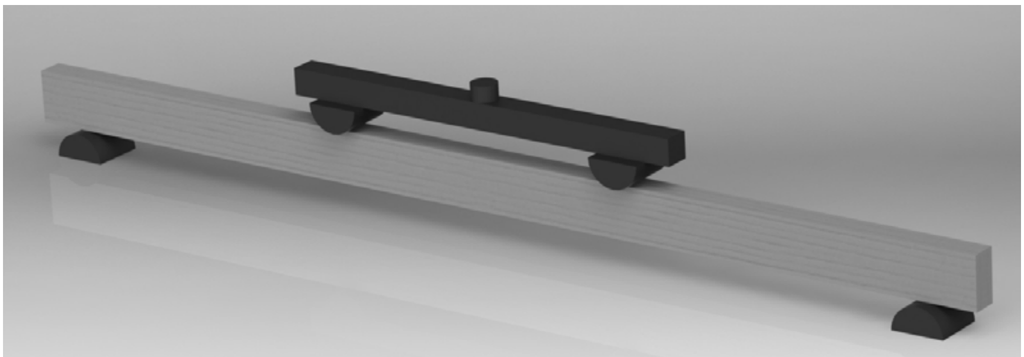

Fig. 1. Experimental workplace view

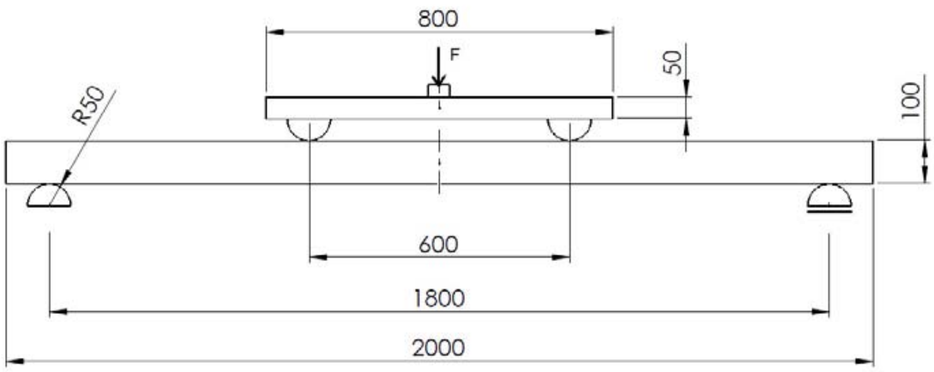

Fig. 2. View of the layout of the support and upper points of contact

We tested the bent element that was weakened by an opening left after a knot that fell out or rotted, whose diameter amounted to φ10, that was placed perpendicularly to the lateral surface of the beam and was located on its symmetry axis. Two positions of the opening were included in the assumptions (Fig. 3.):

- the middle of the opening located on the bottom surface of the element;
- the middle of the opening located 15 mm from the bottom surface of the element.

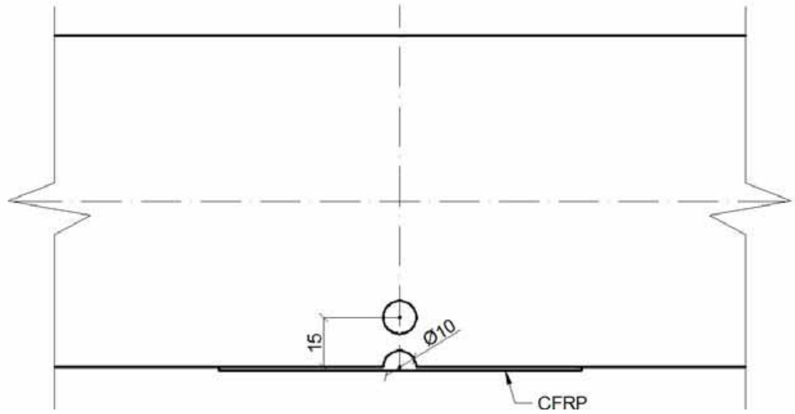

Fig. 3. Opening location in respect to the bottom surface of the beam (2 positions)

A load force amounting to P=6kN was applied to the beam, weakened by the φ10 opening in two positions. For the φ10 opening whose middle was located on the bottom surface of the element, the maximum normal stress was measured in point A (Fig. 4.), whereas for the opening placed 15 mm away, it was in point B, placed on the bottom part of the opening.

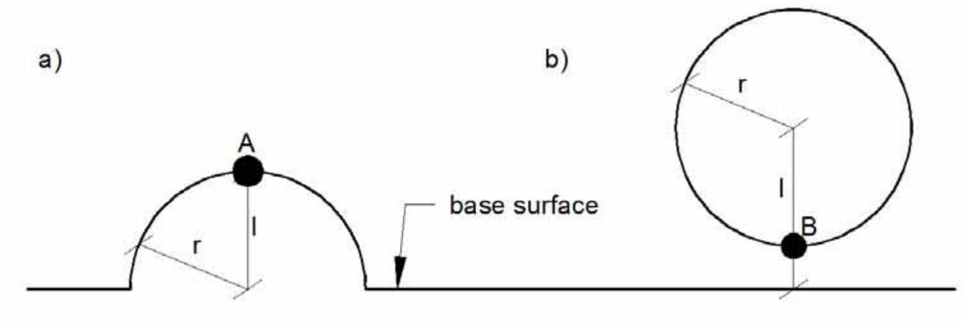

Fig. 4. Location of the measurement points a) when $l \leq r$, b) when $l > r$; where l – distance between the middle of the opening and the base surface, r – opening radius

DISCUSSION OF RESULTS

Figure no 5 presents a chart showing the maximum normal stresses reached for different lengths of the CFRP tapes, adhered to the bottom side of the element in accordance to the opening position, subject to a load force of P=6kN.

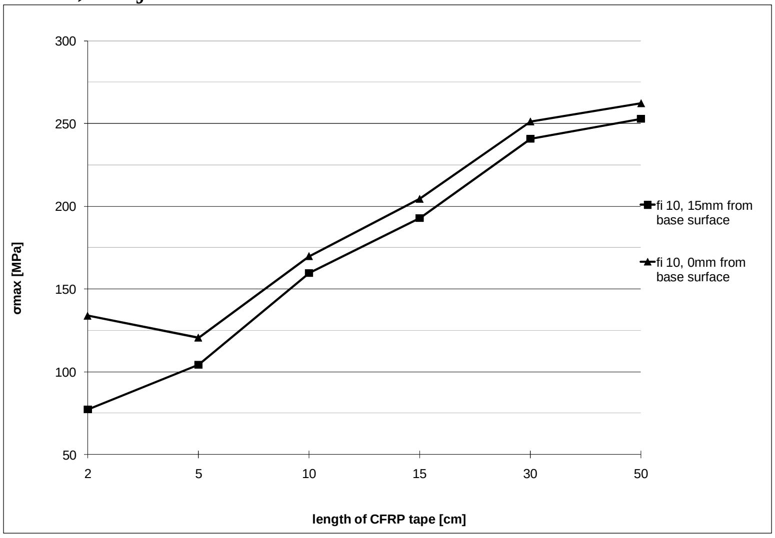

Fig. 5. Maximum normal stresses in the CFRP tape in accordance to its length and to the position of the opening in respect to the bottom surface of the beam

The simulations that were carried out showed that when the tape used to reinforce the section was longer, the normal stresses that were reached in that section were higher. This is natural, because a longer tape transmits a bigger part of the section stresses. The only exception occurs when the φ10 opening is placed on the bottom surface of the bent beam: in the case of a 2 cm tape the maximum normal stresses reach higher values than in the case of a 5 cm long tape. This may be due to the fact that the tape is too short and it is not sufficiently anchored in relation to the opening type, which results in higher normal stress values reached within the tape.

Figure no 6 shows the maximum normal stresses that were reached in the measurement points “A” and “B” of the openings, reinforced with the use of CFRP tape of different lengths.

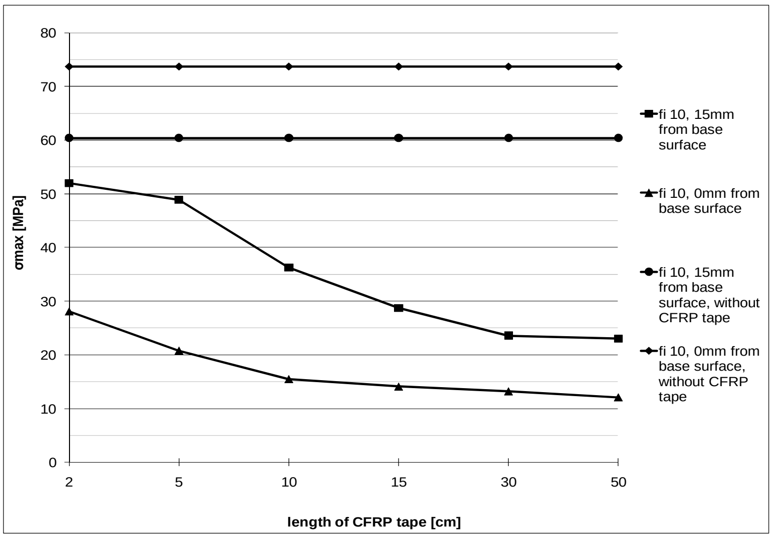

Fig. 6. Maximum normal stresses in measurement points “A” and “B” in accordance to the length of the reinforcement

On the basis of the Figure no 6 it may be concluded that the maximum normal stresses in the measurement points “A” and “B” were reduced after applying a CFRP tape reinforcement to the section. The longer the tape, the more significant the reduction of normal stresses. In case of a 50 cm tape reinforcing the element weakened by a φ10 opening, whose middle was placed on the bottom surface of the beam, the stresses were reduced by up to 80%, while for an analogous tape, but in case of an opening placed at the distance of 15 mm from the bottom surface, the reduction amounted to 60%. Therefore, it is more effective to reinforce beams that are weakened by openings located far away from the neutral axis of the element.

The value of normal stresses advances asymptotically to a certain value. Hence, it may be concluded that it is not economical to apply reinforcement to the whole length of the element. Moreover, in accordance to the Saint-Venant’s principle [Orłoś, 1977], the disturbances caused in a uniform stress field and the increase of normal stresses, which goes together with the weakening, have a local character; and at a distance equal to several times the diameter of the opening, that disturbance is negligibly small. This fact also speaks in favour of the local reinforcement of weakened elements. Therefore, it seems that the length of the reinforcement applied in the proximity of the weak point should amount to 5-6 times the diameter of the opening.

Figure no 7 shows the distribution of maximum normal stresses for a beam weakened with a φ10 opening, whose middle is placed on the bottom surface of the beam, reinforced with a 5 cm long CFRP tape.

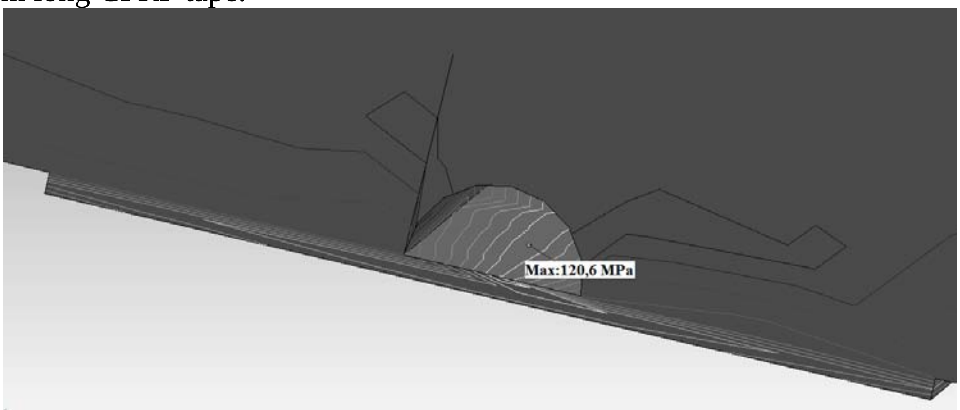

Fig. 7. Distribution of normal stresses for a test model example

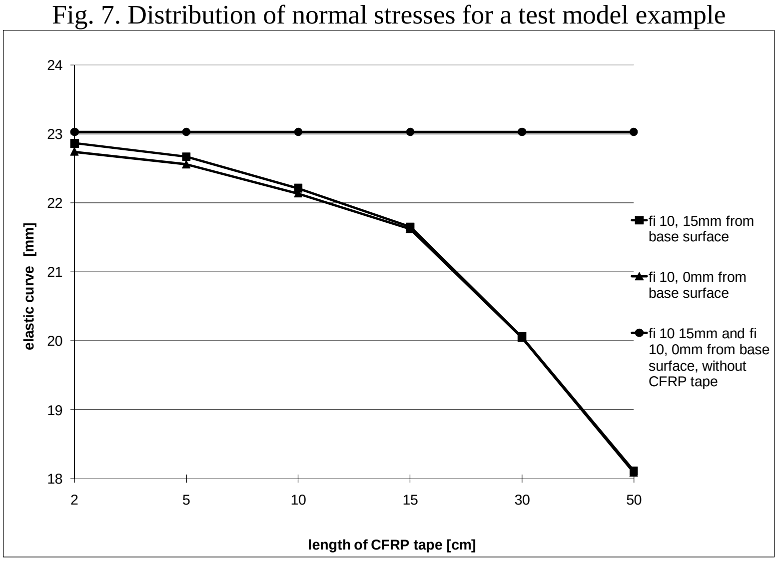

Fig. 8. Elastic curve in accordance to the length of the reinforcement

Fig. 8. shows the relation between the elastic curve and the length of the CFRP tape reinforcement. On this basis it may be concluded that the higher the length of the reinforcement, the smaller the elastic curve of the bent element. A longer CFRP tape reduces the importance of the opening position for the elastic curve values.

CONCLUSIONS:

1) The longer the tape, the higher the maximum normal stresses that are present in its section as a result of the operation of a constant force.
2) The longer the tape, the more significant the reduction of normal stresses that can be reached in the proximity of the opening. However, after exceeding a certain tape length, the reduction of normal stresses becomes very small.
3) The application of a CFRP tape provides a more significant reduction of normal stresses when the weak points are placed further from the neutral axis of the bent element.
4) The longer the reinforcing tape, the more significant the reduction of the elastic curve.
5) We have not observed any important influence of the position of the opening on the degree of elastic curve reduction as a result of the reinforcement.
6) CFRP tapes may be useful for local reinforcement of tensed areas of bent wooden beams that are weakened due to the presence of knots in their sections.

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Streszczenie: *Wpływ długości wzmocnienia w postaci taśmy CFRP przyklejonej od dołu zginanego elementu na rozkład naprężeń normalnych oraz ugięcie.* W pracy badano wpływ wzmocnienia w postaci taśm CFRP na rozkład naprężeń normalnych i ugięcie zginanej belki drewnianej. Analizę przeprowadzono numerycznie w środowisku Solidworks Simulation. Dzięki miejscowemu wzmocnieniu elementu uzyskano redukcję ugięć sięgającą nawet 20%, oraz 80% redukcję maksymalnych naprężeń normalnych w okolicy otworu przy zastosowaniu taśmy CFRP o długości 50cm. Stwierdzono, że taśmy CFRP mogą być przydatne do miejscowego wzmacniania stref rozciąganych zginanych belek drewnianych, osłabionych na skutek występowania otworów, jako pozostałości po sękach wypadłych lub zepsutych.

Corresponding authors:

1) Izabela Burawska, Andrzej Tomusiak, Piotr Beer
Department of Construction and Technology of Final Wood Products
Faculty of Wood Technology,
Warsaw University of Life Sciences – SGGW,
Ul. Nowoursynowska 159,
02-776 Warsaw,
Poland
e-mail: izaburawska@o2.pl
e-mail: andrzej_tomusiak@sggw.pl
e-mail: piotr.beer@wp.pl