CARBON FIBER REINFORCED AND PRESTRESSED TIMBER BEAMS

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SUMMARY

This research objectives the shear strength of carbon fiber reinforcement bonded into longitudinal openings of wood. Analysing the differential equation for sliding bond the stiffness of the bonded CFRP-sheet can be determinated.

Keywords: timber, carbon fiber reinforced plastic, epoxy adhesive, shear strength, k-value

1. INTRODUCTION

Naturally occurring fiber-reinforced composites like wood have been used for a long time. Wood differs from other construction materials because it is produced in a living tree. The mechanical properties (strength and stiffness) of the biological material wood differ very and depend on the quality of the tree, the humidity etc. It is necessary to grade the sawn lumber in different classes. In Austria exists visual and mechanical stress graded timber. There are three classes for visual graded timber (S 7, S 10, S 13) and four classes for mechanical stress graded timber (MS 7, MS 10, MS 13, MS 17). For glued-laminated timber beams (glulam-beams) four types are classified: BS 11, BS 14, BS 16 and BS 18. The beams consist of one class of lamination or are combinated of different classes of laminations. The combinated glulam beams are reinforced in the tension and/or pressure zones with timber of a higher quality. It is also possible to reinforce timber beams with steel or fiber reinforced plastics e.g. carbon fiber reinforced plastics: CFRP. By combining fibers and plastic matrix, a new sandwich material is produced with a strength and stiffness close of the carbon fibers and the chemical resistance of the plastic. The high tensile strength and Young`s modulus, low weight, resistance to corrosion and high fatigue strength are the advantage of carbon fiber reinforced plastics.

2. REINFORCED TIMBER BEAMS

Previous researchers have studied the feasibility of reinforcing glulam beams with metals and fiber-reinforced plastics. Recent works demonstrate the possibiltiy of high increase in bending stiffness and strength. Hernandez (1997) reinforced Yellow-Poplar glued-laminated beams with E-glass-fiber-reinforced plastic/vinylester (GFRP) composite sheets. At the IKI new developments with CFRP reinforced timber elements are carried out. Primarily shear tests on longitudinally reinforced timber elements were studied in order to define the shear-stiffness behavior. The possibility of reinforcements of glued-laminated beams are shown in Fíg. 1.

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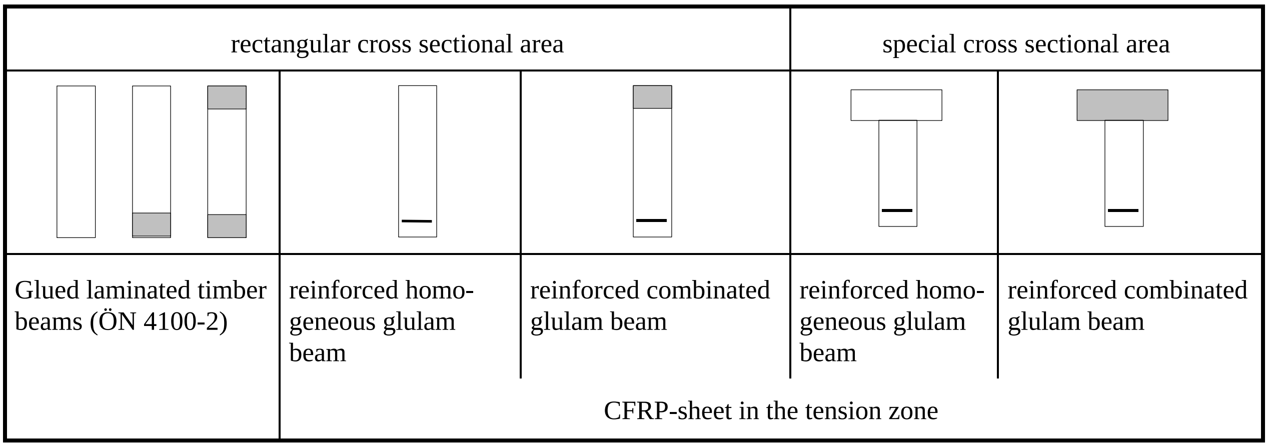
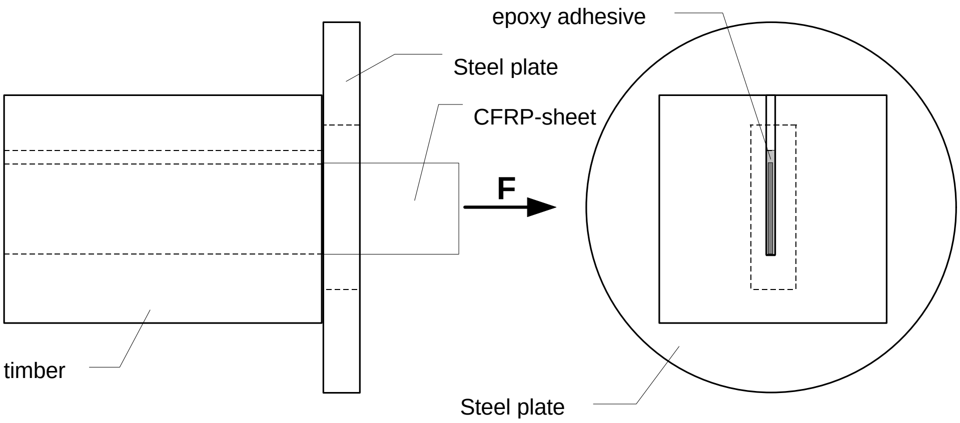


Fíg. 1: Illustration of traditional glulam beams and reinforced glulam beams

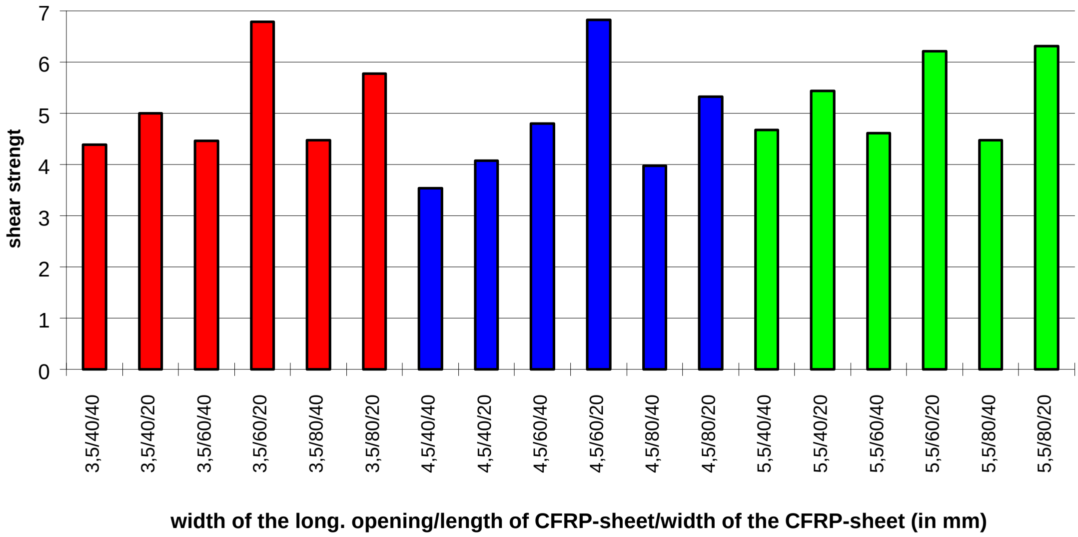
3. SHEAR TESTS - azv05.05.98

Epoxy adhesives are usually used to bond CFRP-sheets on the tension face of the glulam beam. Another possibility to apply the CFRP-sheets is to bond in longitudinal openings. The advantage of this application is the higher fire resistance. In order to improve the shear strength and stiffness of such an application several tests are carried out. Fíg. 2 shows the configuration of the shear tests (azv05.05.98). About 180 wood-CFRP specimens were tested with two diferent epoxy adhesives, different width of the longitudinal opening (3,5 - 4,5 - 5,5 mm), different width (20 mm and 40 mm) and different length (40 - 60 - 80 mm) of CFRP-sheets.



Fíg. 2: Configuration of the shear tests (azv05.05.98)

In the next figure are shown the results of the shear tests azv05.05.98.

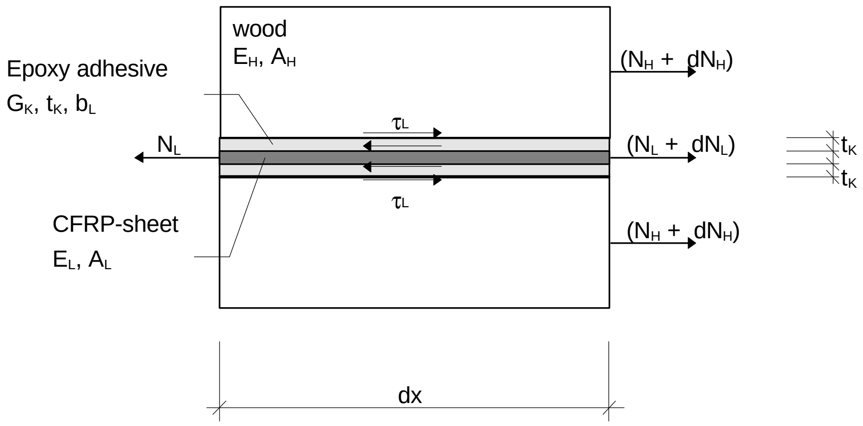


Fíg. 3: Results of the shear tests azv05.05.98 (adhesive F)

4. ANALYSIS

4.1 Differential equation for sliding bond for in longitudinal openings bonded CFRP-sheets

The analysis of differential equation for sliding bond presented in the following chapter is based on the theory of Volkersen (1953). Holzenkämpfer (1997), Pichler (1993) used also this differential equation for steel sheets bonded on concrete beams. The analysis bases on the assumption that the materials are linear-elastic and the governing deformation mode in the adhesive layer is shear.



Fíg. 4: Differential element

For the strain can be written:

$$\varepsilon_H = \frac{du_H}{dx} = u_H' \tag{1}$$

$$\varepsilon_L = \frac{du_L}{dx} = u_L' \tag{2}$$

For the stress and forces can be written:

$$\sigma_H = E_H \cdot \varepsilon_H \tag{3}$$

$$\sigma_L = E_L \cdot \varepsilon_L \tag{4}$$

$$N_H = \int_{(A)} \sigma_H \cdot dA_H = E_H \cdot A_H \cdot \varepsilon_H \tag{5}$$

$$N_L = \int_{(A)} \sigma_L \cdot dA_L = E_L \cdot A_L \cdot \varepsilon_L \tag{6}$$

Furthermore:

$$dN_H + dN_L = 0 \tag{7}$$

$$2 \cdot \tau_L \cdot b_L \cdot dx + dN_H = 0 \tag{8}$$

$$s_L = u_L - u_H \tag{9}$$

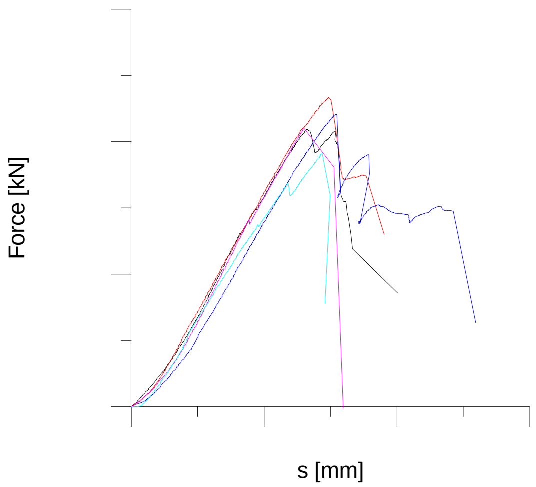
By combining we obtain:

$$s_L'' = \frac{2 \cdot \tau_L \cdot b_L}{E_L \cdot A_L} - \frac{2 \cdot \tau_L \cdot b_L}{E_H \cdot A_H} \tag{10}$$

with: $\tau_L = f(s_L)$, $\alpha_L = \dfrac{E_L}{E_H}$, $\rho_L = \dfrac{A_L}{A_H}$:

$$s_L'' - \frac{(1 + \alpha_L \cdot \rho_L) \cdot 2 \cdot f(s_L)}{E_L \cdot t_L} = 0 \tag{11}$$

The shear tests (Lang (1998)) in longitudianl openings with bonded CFRP-sheets have shown a nearly linear-elastic deformation (see Fíg. 5).



Fíg. 5: Typical stress-strain diagramm of the shear tests

For the shear stress can be written:

$$\tau_L = \frac{G_K}{t_K} \cdot s_L \tag{12}$$

with: $$\gamma_K = \tan\left(\frac{s_L}{t_K}\right) \approx \frac{s_L}{t_K} \tag{13}$$

$$\tau_L = \gamma_K \cdot G_K \tag{14}$$

$$s_L'' - \omega^2 \cdot s_L = 0 \tag{15}$$

with $$\omega^2 = 2 \cdot \frac{G_K \cdot (1 + \alpha_L \cdot \rho_L)}{t_K \cdot E_L \cdot t_L} \tag{16}$$

The solution of the differential equation may have the form of:

$$s_L(x) = A \cdot \sinh(\omega \cdot x) + B \cdot \cosh(\omega \cdot x) \tag{17}$$

By obtaining the constants A and B from the boundary conditions:

$$\text{BC 1: } x = 0: \qquad N_H = 0, N_L = 0 \tag{18}$$

$$\text{BC 2: } x = l: \qquad N_H = -F, N_L = F \tag{19}$$

The relation between stress and slip is given as:

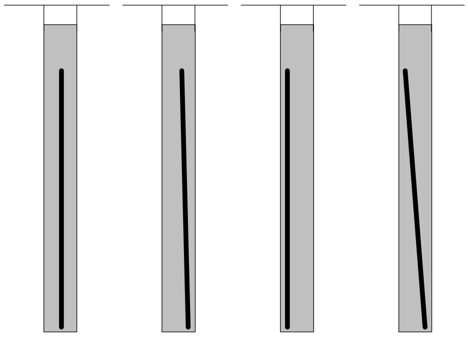
$$s_L(x) = \frac{F \cdot \omega \cdot t_K}{2 \cdot G_K \cdot b_L \cdot \sinh(\omega \cdot l)} \cdot \cosh(\omega \cdot x) \tag{20}$$

Finally for the shear stress may be obtained:

$$\tau_L(x) = \frac{F \cdot \omega}{2 \cdot b_L \cdot \sinh(\omega \cdot l)} \cdot \cosh(\omega \cdot x) \tag{21}$$

4.2 Shear-stiffness (k-value) for epoxy adhesive in longitudinal openings bonded CFRP-sheets

An exact centric position of the CFRP-sheets in the longitudinal openings of the wood specimens is almost impossible to produce. Therefore the CFRP-sheet is placed excentric or in a certain angle into the longitudinal opening. In order to describe eq. (20) in mechanical terms and to obtain numerical values a „shear volume stiffness“ is analysed.



Fíg. 6: Positions of the CFRP-sheets in the longitudinal openings

$$k = \frac{G_K}{t_K} \qquad [\mathrm{kN/cm^3}] \qquad (22)$$

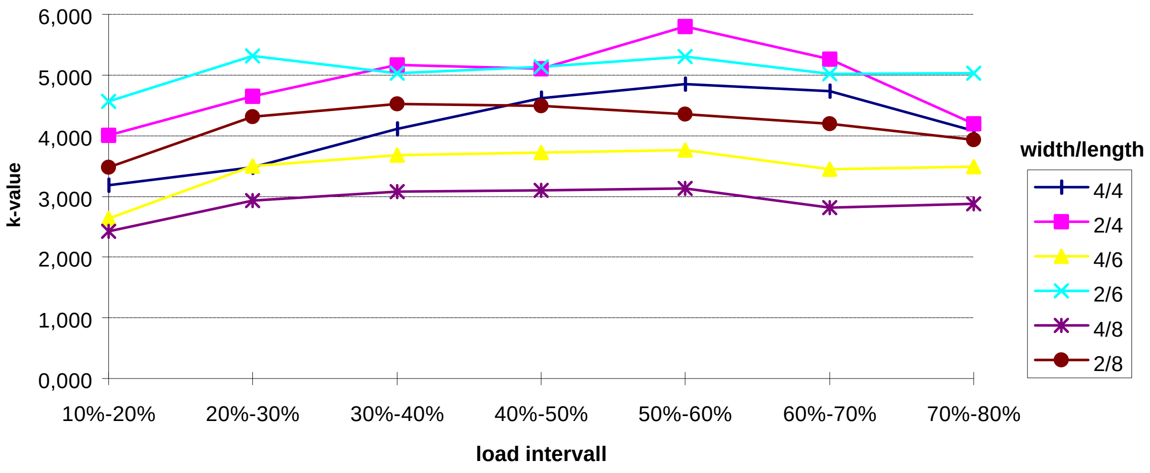
4.3 K-values from the shear tests azv05.05.98

From the shear tests azv05.05.98 the k-values can be calculated with the presented differential equation for sliding bond for in longitudianl openings bonded CFRP-sheets.

For the slip, we obtain at x = l:

$$s_L(x=l) = \frac{F \cdot \sqrt{\frac{2k \cdot (1+\alpha_L \cdot \rho_L)}{E_L \cdot t_L}} \cot gh\left(\sqrt{\frac{2k \cdot (1+\alpha_L \cdot \rho_L)}{E_L \cdot t_L}} \cdot l\right)}{2k \cdot b_L} \qquad (23)$$

For the width of the longitudinal opening of 3,5 mm the k-value is calculated at different load intervalls of the maximum of the shear stress. The test configuration results an increase of the k-value up to 20 % of the maximum of the shear strength. In the higher stage the k-value is nearly constant. Therefore the k-value is calculated in the load intervall of 20 % to 50 % of the maximum shear strength. In Fíg. 8 the k-value have been analysed for an epoxy adhesive type F.



Fíg. 7: Average k-values for epoxy adhesive F for different load labels

	width of the longitudinal opening		
	3,5 mm	4,5 mm	5,5 mm
	k-value (average) [kN/cm³] coefficient of variation [%]		
test C, O, ZA l = 4 cm, b = 4 cm	4,360 26,7	3,720 27,8	4,617 3,2
test D, P, ZB l = 4 cm, b = 2 cm	5,573 10,6	7,629 26,7	4,717 51,2
test G, S, ZE l = 6 cm, b = 4 cm	3,847 4,2	3,879 3,9	3,504 16,0
test H, T, ZF l = 6 cm, b = 2 cm	6,264 3,3	6,322 18,4	5,717 12,3
test K, W, ZI l = 8 cm, b = 4 cm	3,531 6,3	3,185 2,8	2,878 14,9
test L, X, ZJ l = 8 cm, b = 2 cm	4,649 11,4	4,528 7,33	4,678 9,9

Fíg. 8: k-values for epoxy adhesive F

5. CONCLUSION

The behavior of in longitudinal openings bonded CFRP-sheets was carried out in this study. An analytical model have been developed for the prediction of the stiffness (k-value). Future research should will be focused toward establishing the behavior of carbon fibr reinforced and prestressed glulam beams.

6. REFERENCES

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