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Influence of glueline parameters on the mechanical behaviour of CFRP reinforced wood - numerical analysis

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Abstract: *Influence of glueline parameters on the mechanical behaviour of CFRP reinforced wood – numerical analysis.* This work presents numerical investigation of wood strengthening technique in the aspect of glueline parameters. Described reinforcement method consists in application of CFRP tape (Carbon Fibre Reinforced Polymer) of a certain length in aim to increase load capacity and stiffness of reinforced wooden element. CFRP tape is bonded to the tensile area of bent beam with a glue, creating a system composed of wooden beam, glueline and reinforcement. However, depending on the parameters of the bond (rigid, elastic), differences in mechanical behaviour of the composite can be observed. Usage of the glue bond characterized by elastic properties leads to lower stress concentration within the composite, therefore the effectiveness of reinforcement could be increased.

Keywords: numerical analysis, mechanical properties, stress distribution, reinforcement

INTRODUCTION

CFRP tape (Carbon Fibre Reinforced Polymer) is a composite material, consisting of two phases- carbon fibres and a binding polymer, which in most cases is epoxy resin. Carbon fibres provide the strength, while the polymer warp renders FRPs resistance to corrosion and guarantees a low weight of the composite [Fiorelli, Dias 2003]. Because of specific properties of CFRP tape, it is commonly used in construction works as a reinforcement material (mostly in concrete and reinforced concrete structures).

In this context, CFRP is used in aim to increment the dead loads and reduce excessive displacements. Additionally, in wooden structures, CFRP reinforcement can be applied to compensate the degradation of wooden elements, manifested in significantly reduced mechanical parameters [de Jesus et al. 2012]. Moreover, reinforcement with CFRP tape guarantees lower variability of wood product properties, as well as allows to avoid the negative influence of wood defects, such as knots or grain deviation. Because of that, it is possible to reduce the oversized cross sections and use timber of lower quality in construction works.

Reinforcement effectiveness using FRPs has been investigated by numerous researchers. A lot of strengthening techniques have been developed, as a result of experimental works and modelling investigations [Sena-Cruz et al. 2013; Romani, Blaß 2001; Plevris, Triantafillou 1992; Kim, Harries 2010; Brunner, Schnueriger 2005; Burawska et al. 2012]. One from the developed technique is local, externally bonded horizontal reinforcement. Experience has shown, that the application of CFRP tape with the length lower than beam span, prompts the stress concentration at the end of the reinforcement [Burawska et al. 2011]. High values of shear and normal stresses (peel) leads to delamination of CFRP, which dictate the failure. This phenomenon has been profoundly investigated in case of concrete and reinforced concrete structures, but quite perfunctorily for timber elements. A lot of factors could be described as having impact on reinforcement efficiency. The length of reinforcement, its shape and position, as well as bond parameters could be mentioned e.g..

This paper presents the results of numerical investigation of mechanical behaviour of solid timber beam reinforced locally with CFRP. Effect of variability of the glueline parameters was taken into account, bonding reinforcement (CFRP tape) with the reinforced material (pine wood).

FEM ANALYSIS

Numerical analysis was performed using Abaqus 6.13 software, enabling complex FEM investigations.

Pine beam in technical scale, with dimensions 50 mm x 100 mm x 2000 mm was modelled. Beam was modelled as an orthotropic, elastic material, with different material properties and strength in different orthogonal directions. Strength parameters were selected according to EN 338:2012, self-performed tests and literature review (Bodig, Jayne 1982). Input data for pine wood, used in numerical calculations are presented in table 1. Local coordinate system was set as shown in figure 1. To be able to investigate the mechanical behaviour of pine beam, virtual test stand was modelled as well. The test stand was in line with the recommendations of EN 408:2012. Wooden beam was subjected to four point bending test, with the test regime presented in figure 2.

Tab. 1 Input data used in FEM analysis for a pine wood

Mechanical parameter	E_1 MPa	E_2 MPa	E_3 MPa	μ_{12} -	μ_{13} -	μ_{23} -	G_{12} -	G_{13} -	G_{23} -
	15000	1200	750	0.42	0.37	0.47	1070	1007	107

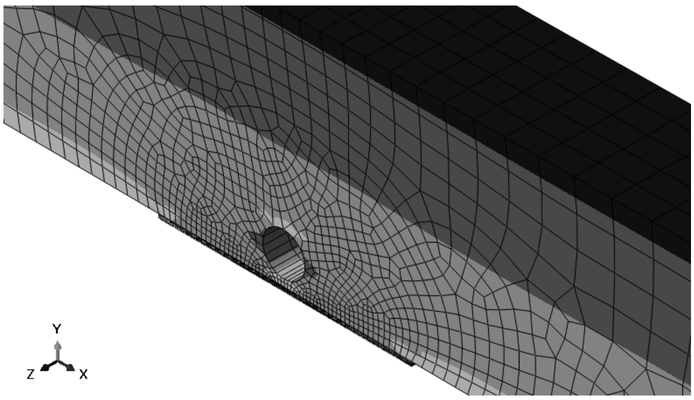


Figure 1. Local coordinate system in FEM analysis

a) b)

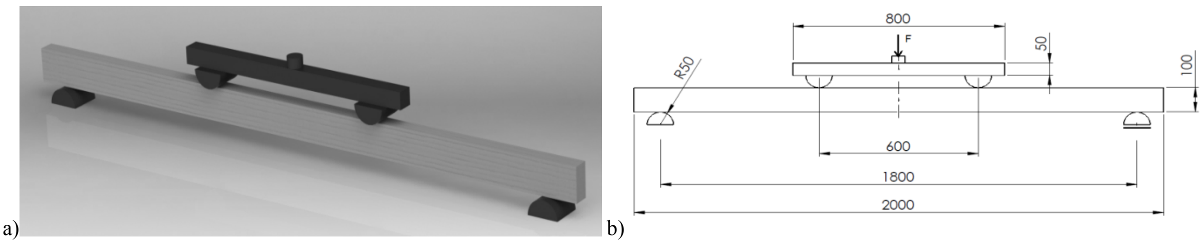


Figure 2. View of the test stand regime

Wooden beam was weakened with a borehole of 18mm in diameter to simulate a knot, the most common wood defect, negatively influencing the strength of wood (Baňo 2009). The borehole was placed in one of the most unfavourable positions – in the midspan, in the tensile zone of the bent beam. The location of the middle of the hole guaranteed the 3mm thick layer of wood secured under the knot. The grain deviation around the knot was not modelled.

Wooden beam was strengthened with a flat horizontal reinforcement made of CFRP tape (1.4 mm thick and 50 mm wide) of a limited length. The length of reinforcement was determined in accordance with previously published literature (Burawska et al. 2011, Orłoś 1977), at a value six times longer than the diameter of the weakening (figure 3). CFRP tape was attached to the reinforced beam with a glue bond. Two kinds of the glueline were analysed – rigid (e.g. epoxy resin) and elastic (e.g. polymer resin), differing mainly in Young's modulus (table 2). Various thickness of the glue bond was investigated (0.5 mm, 1.0mm, 1.5mm, 2.0mm) in aim to determine its influence on the mechanical work of the whole composite.

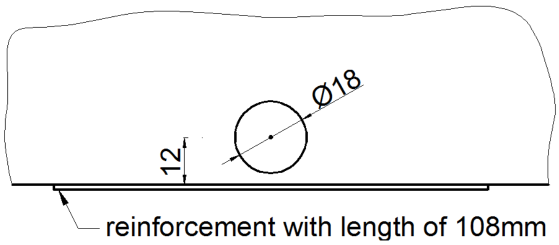


Figure 3. Local reinforcement in form of CFRP tape

Tab. 2 Input data used in FEM analysis for a CFRP tape and a glue bond (data obtained from producers)

Mechanical parameter	E_1 MPa	E_2 MPa	E_3 MPa	μ_{12} -	μ_{13} -	μ_{23} -	G_{12} -	G_{13} -	G_{23} -
CFRP	165000	10000	10000	0.3	0.3	0.03	5000	5000	500
Epoxy	3000	3000	3000	0.25	0.25	0.25	-	-	-
Polymer	500	500	500	0.3	0.3	0.3	-	-	-

The elastic model of reinforced wood was consisted of almost 42000 nodes. The wood, adhesive and CFRP tape were modelled by 20-node quadratic brick elements with reduced integration (C3D20R). The continuity of displacements was assumed at the interfaces. Contact points were solved with the tie option used.

RESULTS AND DISCUSSION

Based on numerical analysis, normal and shear stress distribution for the bent composite was obtained (for load 10kN). Exemplary results of the modelling are presented in figures 4, 5 and 6.

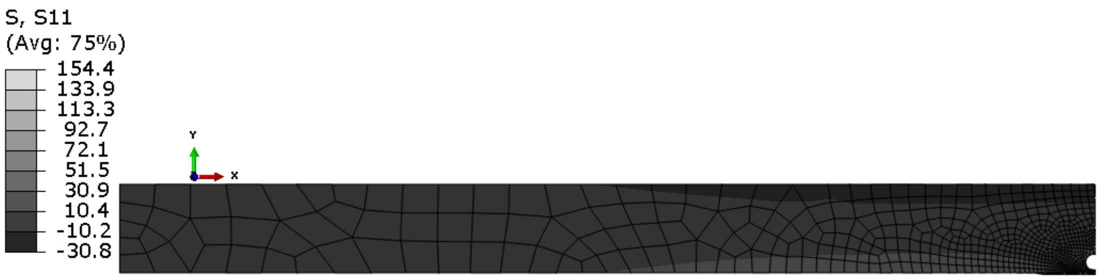


Figure 4. Normal stress distribution (σ_{11}) and the mesh of ½ of the reinforced beam

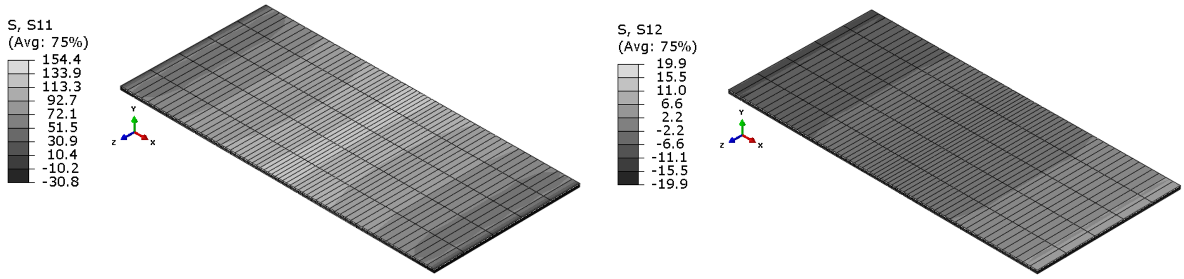


Figure 5, 6. Normal stress distribution (left) and shear stress distribution (right) in the CFRP tape, glued with a rigid adhesive to the reinforced element

Numerical investigation showed differences in stress distribution, obtained in case of using various thickness of adhesive (0.5mm, 1.0mm, 1.5mm, 2.0mm), as well as various adhesives properties.

Based on numerical analysis it can be observed (figure 7), that very thin (0.5mm) rigid glue bond results in high normal stress concentration at the edge of the connection (for x distances equal 0 and 108mm). Thinner glue bond (1.5mm, 2.0mm) cause more uniform stress distribution, as well as lower normal stress values in the reinforcement (figure 8). The same dependence can be observed in case of elastic adhesive. Thickness of the glueline affect the normal stress distribution in the reinforcement, and especially the value of the stresses in the middle of the reinforcement.

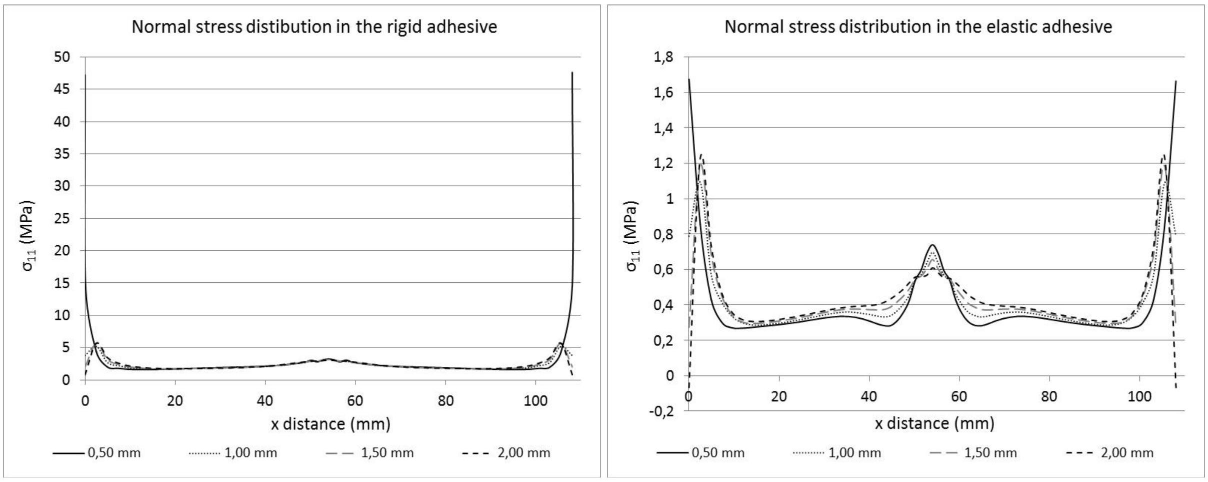


Figure 7. Normal stress distribution in rigid adhesive (left) and elastic adhesive (right)

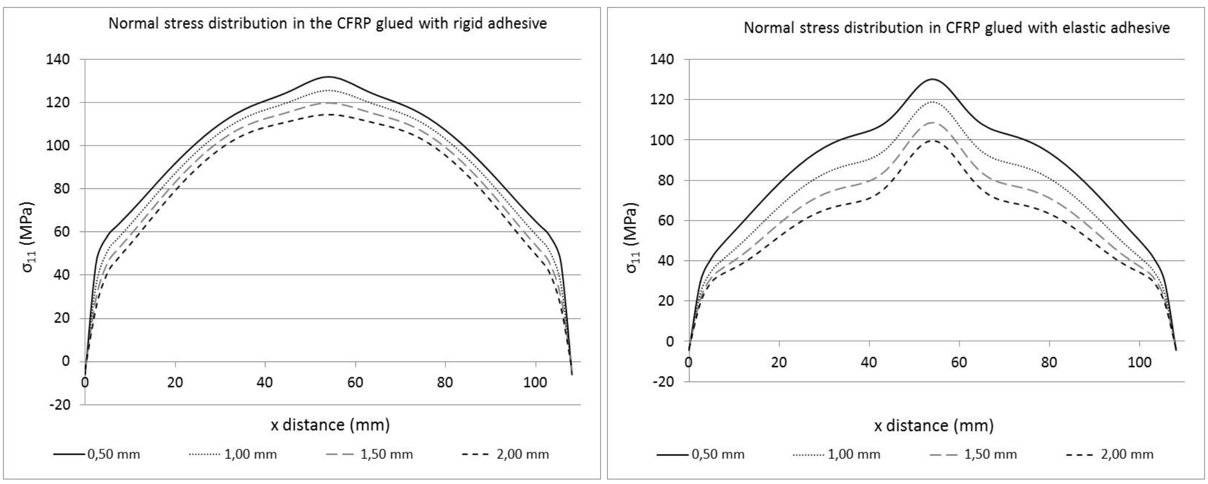
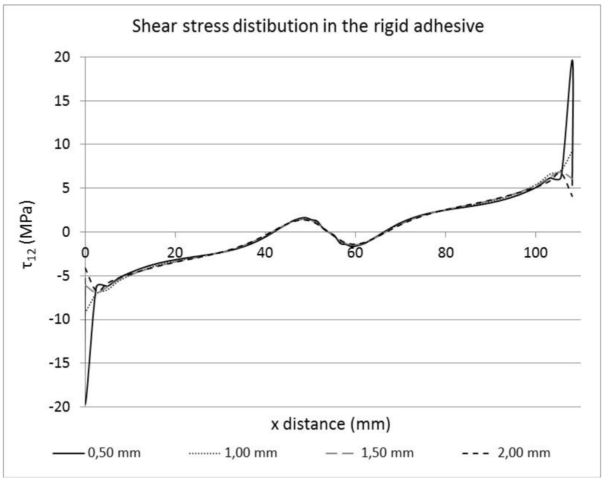


Figure 8. Normal stress distribution in the CFRP tape bonded with rigid adhesive (left) and elastic adhesive (right)

Influence of the glue bond thickness (rigid or elastic adhesive) on the shear stresses in the adhesive itself and in the reinforcement is similar to its impact on the normal stresses. Lower thickness of the glueline results in higher stress concentration at the ends of connection and edge of the CFRP tape (figure 9, 10).



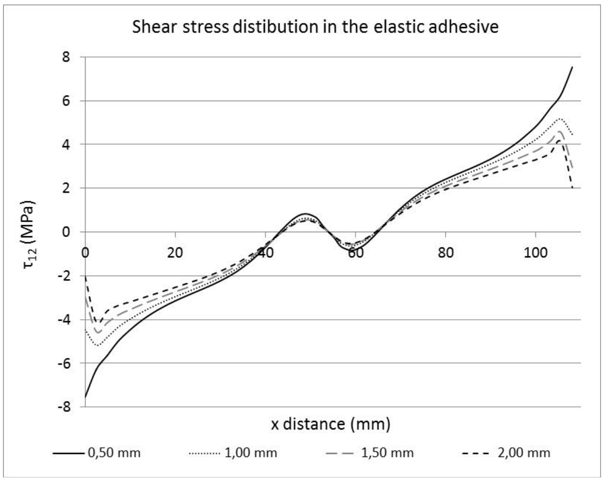
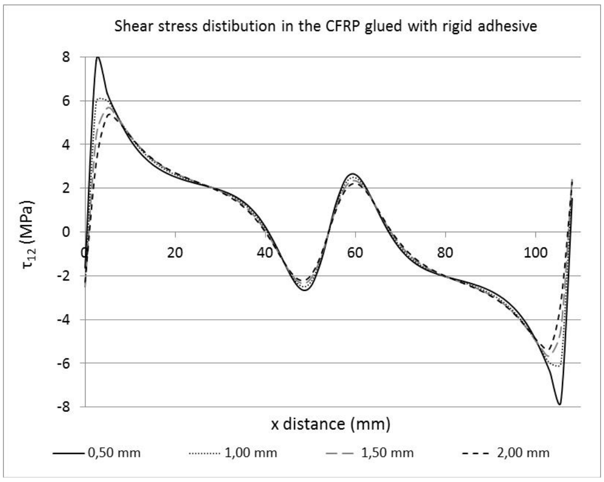


Figure 9. Shear stress distribution in rigid adhesive (left) and elastic adhesive (right)



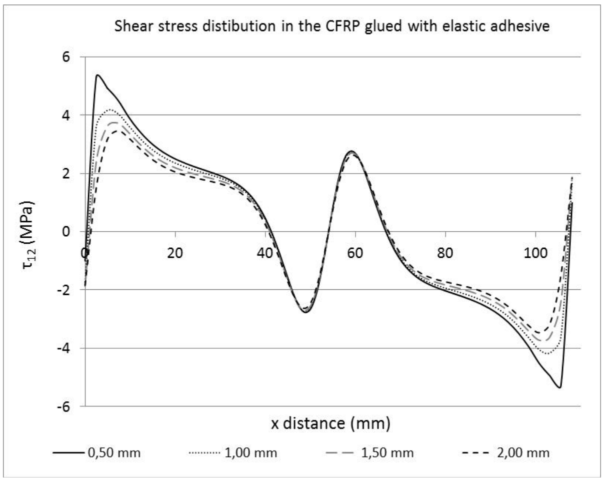


Figure 10. Shear stress distribution in the CFRP tape bonded with rigid adhesive (left) and elastic adhesive (right)

On the basis of the results (figure 7 – 10) it can be seen that significantly lower stress values (in the glueline and reinforcement) are obtained when the glue bond is characterized by lower MOE. Usage of the elastic glueline leads to even 80% reduction of normal stresses values in the bond, and around 50% reduction in shear stress values at the ends of the reinforcement.

CONCLUSIONS

Based on the performed studies, it can be concluded:

- The effect of the lower MOE of the glue bond is demonstrated by more uniform stress distribution (in the glueline itself and the reinforcement). Lower values of normal and shear stresses are obtained, therefore the effectiveness of the reinforcement could be increased.
- The thickness of the glueline has significant influence on the stresses values at the ends of wood-adhesive-CFRP interfaces. Lower thickness of the glueline leads to higher stress concentration, which often results in crack initiation and failure.

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Streszczenie: *Wpływ parametrów spoiny klejowej na pracę drewna wzmocnionego taśmą CFRP- analiza numeryczna.* W pracy przedstawiono wyniki analizy numerycznej, dotyczącej techniki wzmocnienia drewna w aspekcie parametrów spoiny klejowej. Wspomniana metoda wzmocnienia polega na zastosowaniu taśmy CFRP (Carbon Fibre Reinforced Polymer) o określonej długości, w celu zwiększenia nośności i sztywności wzmocnionego drewnianego elementu. Taśma CFRP przyklejana jest do strefy rozciąganej zginanej belki za pomocą kleju, tworząc system składający się z belki, spoiny klejowej i zbrojenia. Jednakże, w zależności od parametrów spoiny klejowej (sztywna, elastyczna), zauważalne są różnice w pracy kompozytu. Zastosowanie spoiny klejowej charakteryzującej się właściwościami elastycznymi prowadzi do zmniejszenia koncentracji naprężeń w obrębie kompozytu, a zatem efektywność wzmocnienia może zostać zwiększona.

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