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Shear strength of the joint wood – carbon lamella after moisture and heat conditioning

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Abstract: Application of carbon lamella on wood parts gives us the possibility to improve mechanical properties of wood construction. Glued carbon lamella increases load capacity of wood construction and decreases deformation. Shear strength of the joint wood – carbon lamella was tested. Glued joint was subjected to moisture and heat stressing. One component polyurethane adhesive Jowapur 686.60 was used and glued joints were tested according to the standards STN EN 301, STN EN 302 a STN EN 14257. Tested adhesive was suitable for gluing of wood with carbon lamella, glued joint met the standard in the field of application number I.

Keywords: carbon lamella, gluing of wood, gluing of wood with carbon lamella, shear strength

INTRODUCTION

Wood as construction material has been used for ages. Popularity of wood constructions has been increased also thanks to glued layered wood. Requirements for wood construction quality are constantly increasing; longer span and load capacity of wood construction is required. Wood historical objects need to be strengthened.

In those situations, usage of a combination of materials is very advantageous. If glued layered wood is connected with composite materials reinforced by fibers, new materials with improved mechanical properties are created.

Carbon fibers are characterized by high strength, modulus of elasticity, and heat resistance, together with low weight. In layers of graphite, the atoms are bound in aromatic rings by strong covalent bonds. The structure is available in carbon fibers; the basal aromatic rings are oriented parallel to the longitudinal axis of a fiber. Graphite micro crystals are turned on each other by small angles; the belt of parallel aromatic layers is slightly wavy. Graphite fibers are made from polyacrylonitrile fibers (PAN) in three stages: stabilization, carbonization, and graphitization (Jančář, 1999).

Carbon lamella is a composite material based on unidirectional oriented carbon fibers linked by epoxy resin. Mechanical properties of lamella are determined by type, number, and orientation of carbon fibers in the cross-section of lamella. If carbon fibers are oriented in the longitudinal direction of lamella, good mechanical properties are reached; namely high tensile strength and module of elasticity. Composite materials reinforced with carbon fibers are used in construction industry to strengthen reinforced concrete structures.

Application of carbon lamella onto wood parts increases load capacity of the wood construction and decreases deformation. Carbon lamellas are applied in the tensile or in the shear part of the structure, parallel to the longitudinal direction of a beam. Carbon lamella takes over the tensile stress, neutral axis is moved towards the glued line and wooden part of a cross-section takes over the compressive stress. Lamellas are characterized by a multiple higher value of tensile strength when compared with wood. When a beam is fastened with glued lamella on tensile stress side, it can carry/suffer higher tensile stress/tension, while the cell walls are collapsed in the compressive zone (Štefko, Grniak, 2004).

The reasons for strengthening wood constructions with carbon lamellas are:
- to increase load capacity,
- to reduce a cross-section of a beam (required by architectural design),

- to decrease deformation of the construction,
- to eliminate potential construction defects,
- rehabilitation and reconstruction of historic wooden constructions.

The important factor in the process of strengthening is the strength of the joint wood – carbon lamella. Problems can be caused by shear properties on the edge of wood and composite material, by unequal dimensional stability of wood in comparison with dimensional stability of lamella, and by shear at moisture changing. Moisture changing in the environment does not influence dimensions of the lamella; but wood swelling gives rise to shear stress on the edge wood – carbon lamella. Depending on kind of wood and used adhesive, the joint can collapse spontaneously without any external power (Tingley and Cegelka, 1996).

Similarly, the thermal stability of glued joint is an important criterion to determine a suitability of the adhesive in the field of new technologies and engineered wood. During product life, glued joint can be exposed to high temperature in various ways (direct exposure to the sun, fire, etc.). Clauß (2010) investigated different adhesive systems and the influence of temperature (20 °C to 220 °C) on the shear strength of glued wood joints. The strength of bonding changes under thermal load, there were big differences in thermal stability and failure behavior between tested adhesive systems.

The strength of glued joint is closely related to the surface machining. At gluing of carbon lamella to wood, wood surface should be machined according the standard STN 49 0231 in the level 3 (cutting – clean) and the level 5 (milling) (Rohanová, Dubovský 2004).

MATERIAL AND METHODS

There is no standard method for reinforcing wood constructions; therefore we chose a procedure according to the standards STN EN 301, STN EN 302-1 and STN EN 14257.

Test specimens for measuring of shear strength of wood – wood (BK–BK) joint were made from beech wood (*Fagus sylvatica*) with density 700 kg/m^3 and moisture content 12 ± 1 % according to the standard STN EN 302-1. Another set of samples were made from spruce wood (*Picea abies*), marked as SM.

The shape and dimensions of test specimens for measuring of shear strength of beech wood – carbon lamella (BK–C) and spruce wood – carbon lamella (SM–C) joints are shown in Fig. 1.

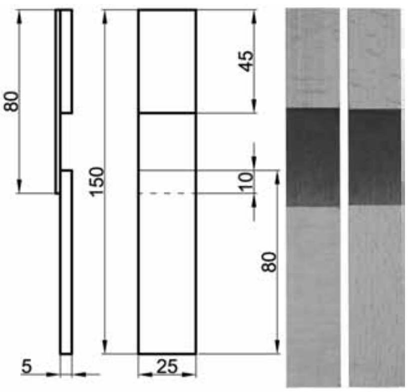

Fig. 1. Test specimen for measuring of shear strength of wood – carbon lamella joint

We used lamella reinforced by carbon fibers in epoxy resin matrix *Sika® CarboDur® S 512* (50 mm wide and 1,2 mm thick).

Technical data of the *Sika® CarboDur® S 512* lamella are:
- density [g/cm^3] 1,6
- heat resistance [°C] 150
- fiber volume [%] > 68
- minimal tensile strength [MPa] > 2800

Adhesive *Jowapur 686.60* is a polyurethane one-component adhesive suitable for structural applications – wood construction for indoor and outdoor use. According to the standard STN EN 301, according to suitability for use in climatic conditions, the adhesive is classified as type I adhesive. Glue line with thickness of 0,1 mm was tested. Moisture content of glued wood should not be lower than 9 %, optimal moisture content is 9 – 13 %. The adhesive cures by a reaction with bound water of wood.

Shear strength was measured and evaluated using a tensile testing machine LaborTech 4.050 with 5 kN head. The speed of the jaws was 5 mm/min, the joint collapsed after 30 to 90 seconds. Glued joint quality is determined by the standard STN EN 301 according to the shear strength values. Ways of specimens conditioning (from A1 to A5) before measuring of shear strength are defined in the standard STN EN 302-1.

Heating test was carried according to the standard STN EN 14257 (WATT 91). Test specimens were warmed in a preheated fan oven at 80 °C for 60 ± 2 minutes and then tested to fracture in a tensile testing machine.

RESULTS AND DISCUSSION

Average values of measured shear strength of test specimens (after preliminary conditioning A1- A5 and after heat stressing according to WATT 91) are listed in the tables 1 and 2. We give also the view on the pattern of the break, i.e. break surface covered with wood fibers.

Table 1. Shear strength of test specimens after preliminary conditioning (A1 – A5) according to EN 302

Method	Test specimen	Required shear strength [MPa]	Average shear strength [MPa]	Standard deviation[MPa]	Coefficient of variation [%]	Wood failure [%]
A1	BK–BK	10,0	**15,3**	1,38	9,0	98
A1	BK–C	10,0	**14,0**	1,90	13,6	50
A2	BK–BK	6,0	**6,7**	0,69	10,5	0
A2	BK–C	6,0	**7,3**	0,86	11,8	0
A3	BK–BK	8,0	**15,5**	2,19	14,1	95
A3	BK–C	8,0	**15,5**	1,63	10,5	37
A4	BK–BK	6,0	**7,0**	0,87	12,5	10
A4	BK–C	6,0	**8,5**	1,17	13,7	0
A5	BK–BK	8,0	**13,5**	2,19	16,2	10
A5	BK–C	8,0	**11,1**	2,98	26,8	0

Table 2. Shear strength of test specimens after heat stressing according to EN 14257 (WATT 91)

WATT 91	BK–BK	7,0	**14,0**	1,58	11,2	70
WATT 91	BK–C	7,0	**9,7**	1,36	14,1	30
WATT 91	SM–C	7,0	**9,5**	1,08	11,4	100

The obtained results were processed by statistical methods, by two-factor analysis of shear strength. The differences between BK–BK shear strength and BK–C shear strength of all samples after moisture conditioning are statistically evaluated in the Fig. 2 (95 % confidence intervals for each preliminary conditioning method). Differences between average shear strength of BK–BK and BK–C are statistically insignificant.

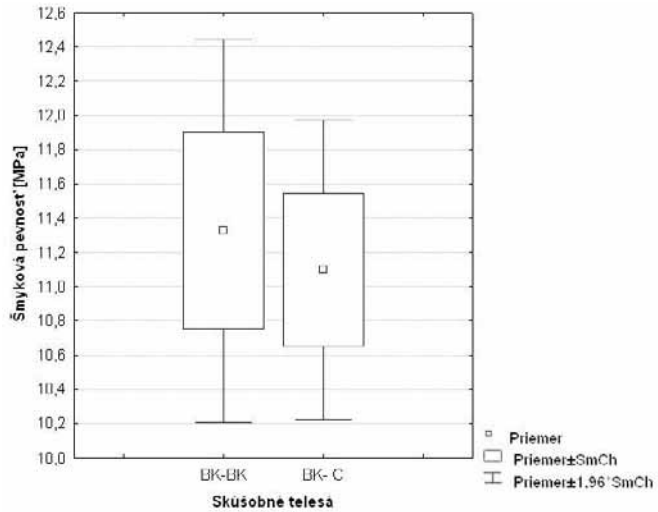

Fig. 2. Graph 95 % confidence intervals for each preliminary conditioning method at measuring of shear strength of glued joint

After preliminary conditioning A2 and A4, BK–C joint shear strength was higher than BK–BK joint shear strength. The adhesive bond BK–BK is exposed to water on both sides, whereas the adhesive bond BK–C is exposed to water on one side only, as water can not permeate through the carbon lamella. Surprising situation was observed at test A3, when carbon fibers were broken. Tensile strength and module of elasticity of carbon lamella is several times higher when compared with the strength and elasticity of beech wood. The failure can be explained by the possibility of failure of lamella surface, if carbon fibers were not strongly bound to the matrix epoxy resin.

In complex statistical evaluation, we can conclude that glued joints BK–BK and BK–C are equivalent.

At heat stressing test WATT 91, the difference between shear strengths was statistically high significant. The shear strength of BK–BK joints was much higher than the shear strength BK–C, or SM–C respectively. Glued joint BK–BK showed higher thermal stability; both types of joints met the required strength value above 7 MPa. The carbon lamella, when compared to wood (following chemical structure), is less reactive with polyurethane adhesive.

When comparing the shear strength of BK–BK and BK–C joints from the point of view of heat stressing or moisture stressing, we can see that the shear strength of the joint BK–C is much more influenced by heat stressing (worse strength) than by moisture stressing.

CONCLUSION

The examined adhesive meet the requirements defined by the standard for gluing of wood load constructions; when gluing two pieces of wood together and gluing carbon lamellas to wood.

Adhesive *Jowapur 686.60* can be classified as type I proper for using at temperatures higher than 50 °C in a climate with relative humidity more than 85 % at 20 °C. The adhesive is applicable at outdoor conditions – at unlimited climatic influences.

Good adhesive properties of polyurethane adhesive result from its chemical structure; high polarity of izokyanate group enables reacting with the functional hydroxyl groups of wood and the epoxy resin (matrix in carbon lamella) and so creating the strong chemical bond.

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Streszczenie: *Wytrzymałość na ścinanie połączeń drewna i włókna węglowego po wygrzewaniu oraz nawilżaniu.* Zastosowanie laminatu z włókien węglowych wzmacniającego drewno daje możliwości zwiększenia wytrzymałości mechanicznej konstrukcji. Wzmocnienie drewna nakładką z włókien węglowych zwiększa wytrzymałość oraz sztywność. Testowano wytrzymałość na ścinanie połączeń drewna i laminatu z włókien węglowych. Używano jednoskładnikowego kleju poliuretanowego Jowapur 686.60 przy procedurze testowej zgodnej z STN EN 301, STN EN 302 oraz STN EN 14257. Testowany klej okazał się odpowiedni do połączeń drewna i laminatu węglowego, połączenia spełniały wymogi normatywne.

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