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FOREWORD

The International Scientific and Professional Conference POLITEHNIKA 2023 represents the seventh edition of the POLITEHNIKA scientific and professional events, occurring biannually since its inaugural event in 2011. POLITEHNIKA 2023 upholds a distinguished tradition and commitment to integrating higher education and practical application across a diverse spectrum of disciplines represented by defined thematic scopes.

Organized with the patronage of the Ministry of Education of the Republic of Serbia, the Ministry of Environmental Protection of the Republic of Serbia, the Ministry of European Integration of the Republic of Serbia, the Directorate for Occupational Safety and Health, the Office for Dual Education and National Qualifications Framework, the Conference of Academies of Applied Studies in Serbia, the Chamber of Commerce of Serbia, the Chamber of Commerce of Belgrade, the Institute for Standardization of Serbia, the Association of Belgrade Architects, the City of Požarevac and the Tourist Organization of the City of Požarevac, POLITEHNIKA 2023 stands as a collaborative platform at the intersection of academia, governmental institutions and industry.

This year heralds a notable progression with its international status and the incorporation of 10 conference scopes. Expanding beyond the thematic domains featured in previous events, the Conference now encompasses Environment and Sustainable Development, Occupational Safety and Health and Fire Safety, Smart Management Systems, Graphic Engineering, Design, Traffic Engineering, Biotechnology and Healthcare, Mechanical Engineering, Ecotourism and Rural development, and Mechatronics. By engaging experts, emerging professionals, and practitioners from these domains, the conference unifies fields of study programs of the Academy of Applied Technical Studies Belgrade. The thematic scopes, coupled with the structure of the compiled papers in this Proceedings, exhibit a rich diversity and multidisciplinary approach, fundamentally contributing to a holistic examination and resolution of societal and scientific challenges.

Comprising over 220 peer-reviewed contributions, the Proceedings represent a substantial intellectual asset, aligning with the conference's overarching objective of fostering the exchange of knowledge, research findings, and professional experiences among experts from industry, research institutions, and higher education establishments.

The Proceedings of the International Scientific and Professional Conference POLITEHNIKA 2023 serve as a comprehensive snapshot of the current landscape within the thematic realms of the conference, offering both insights and directives for ongoing scientific and professional development. Moreover, they proffer concrete solutions to practical challenges grounded in contemporary trends and pertinent insights.

The Academy of Applied Technical Studies Belgrade extends its sincere appreciation to all conference supporters whose financial contributions played a pivotal role in its successful realization. Special acknowledgment is reserved for the authors of the papers, whose diligence and eagerness to present their work to a wider audience, alongside the reviewers and members of the International Scientific Committee, Program Committee and Organizational Committee, have collectively contributed to the triumph of the International Scientific and Professional Conference POLITEHNIKA 2023.

Belgrade, December 2023
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PANEL SHEAR PROPERTIES OF CARBON FIBER REINFORCED LVL BOAPANEL SHEAR PROPERTIES OF CARBON FIBER REINFORCED LVL BOARD

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Abstract: *Problem of rational use and lack of quality wood raw material for producing veneer boards, can be solved using poor quality wood raw materials for design composite veneer board. Poplar LVL panels do not have structural use because of its mechanical properties. Fiber reinforced composites can improve mechanical properties of wood-based panels, and thus enable the structural use of poplar panels. Synthetic fibers can reinforce panels, minimize the negative properties of wood raw material and improved dimensional stability of the board. This paper presents the results of experimental testing of the panel shear tests of unreinforced and reinforced seven-layer LVL (laminated veneer lumber) poplar veneer panels. The aim of the research is to determine the influence of woven carbon fibers on the improvement of the panel shear test of LVL, in order to test the potential of using this composite material as a structural element. The orientation of fibers has a strong influence on the reinforcement. The main research task is investigation the effects of orientation of the carbon fibers and their position in the panel construction on the shear properties of the panel. This research present possibility of applying poplar veneer to design structural elements in LVL using epoxy adhesive.*
Keywords: mechanical properties; LVL; CFRP; epoxy.

1. INTRODUCTION

Wood as a natural material used throughout history as one of the most commonly materials in construction. As natural material wood have great potentials for use in construction, due to its availability, easy processing and good physical and mechanical properties. The disadvantage of wood raw material is that not every type of wood is suitable for structural use, especially fast-growing soft species. Domestic wood species like poplar wood are very common in south Europe. The two leading countries that encourage the use of poplar in the construction industry and its structural application are Italy and Spain. With its 32,000 ha, Serbia is the 5th country in Europe in terms of the area of poplar plantations [1]. Lower load capacity and weaker mechanical characteristics compared to other species used for structural timber, make poplar is a less represented species in the construction industry. In order to make the best possible use of wood raw materials, wood-based products were made. Products based on veneer layers, plywood and laminated veneer lumber (LVL) are of special importance, and they stand out additionally due to their mechanical and aesthetic performance. Advantage of composite products like LVL and plywood is on distributing the errors through the panel and eliminating them in production. This reduce the variability in material properties, and equalize the mechanical properties of the product in the longitudinal and transverse direction. In order to improve mechanical properties of wood raw material and wood-based products, various

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strengthening techniques have been investigated throughout history. Strengthening timber construction with synthetic materials has been the subject of research studies since the 1960s [2].
The pioneers of using polymer composites - glass fiber reinforced polymers (GFRP) for strengthening of wood were Wangaard and Biblis [3]. During early 2000s, these authors continued to improve this idea, and examined the bending properties of three- and five-layer plywood reinforced with glass fiber fabric using phenol-based adhesives [4]. More intensive research in this area was made in the last ten years, and they mostly focused on bending properties of composite product created from wood veneer and fiber reinforced polymers. The research of mechanical propeties of reinforced veneer based panels or LVL, can be defined into two types of reinforcement - carbon or glass fibers. The flexural strength and modulus of elasticity were tested on three- and five-layer boards made of pine veneer, reinforced on the outside with two-way woven glass mesh in two layers, impregnated with polyester resin [4]. Examining the influence of the amount of fibers on the buckling of GFRP-reinforced veneer panels when exposed to compressive stresses and their behavior when exposed to different temperature conditions was investigated by Choi (S.W) and others [5, 6]. Investigation of the influence to mechanical and physical properties of panel using glass fabrics reinforcement with fibers oriented in two directions and their position in the veneer panel construction show significant improvements, especially to modul of elasticity and modul of rupture [7, 8]. An examination of the influence of the amount of carbon fibers in the strengthening of plywood with CFRP products on its mechanical properties and, above all, on its bending properties was presented in research by Brezović et al. [9]. Strengthening of veneer-based panels with carbon fibers oriented in two directions and analysis of their position in construction on the mechanical properties of the plywood [10] shows an increase in flatwise bending strength, tensile strength, and Young's modulus of elasticity. Just a few researches analyse the examination of the panel shear properties of composite LVL or plywood panel. For the structural application of these panels, it is very important to examine that mechanical properties.
Depending on the design and position in the construction, panels can be exposed to different types of loads, differ is primarily in their direction and position, which means that the elements are exposed to different type of stress. Panels used as diaphragm due to their small static height cannot accept bending perpendicular to the plane of the plate, and the diaphragms are designed as complex cross-sections of veneer plates and substructures. In these constructions, veneer based panels have the role of accepting shear forces perpendicular to the plane of the plate when the structure is exposed to a horizontal load, or shearing in the plane of the plate that occurs as a result of bending under the effect of gravity load. Potential of new reinforced material is to use panels as structural element, to unconventional way. This implies to use panel for folds, polygonal shells and structures formed in a constructive system of reciprocal constructions. To use panel as desribed, it needs to have exceptional resistance to in-plane compression and tension, as well as perpendicular to planar and panel shear.
This research investigates the possibility of producing composite panels based on veneer reinforced with CFRP. The aim of the research is to determine the influence of woven carbon fibers on the improvement of the panel shear test of LVL, in order to test the potential of using this composite material as a structural element. The main research task is investigation the effects of orientation of the carbon fibers and their position in the panel construction on the shear properties of the panel.
The focus is on the investigation of the possibility of applying this material as structural elements in architectural buildings, especially those exposed to forces in the plane of the plate, like beams, polygonal shells and folded structures.

2. MATERIALS AND METHODS

2.1 Veneer

In this study, constructive poplar veneers, produced by peeling (rotary-peeled veneers) at a thickness of 4 mm and humidity of 7 ± 1%, were selected for the formation of LVL panels. All veneers are cut to dimensions of approx. 550 × 550 × 4 mm. Reinforced and control LVL panels were formed from all veneers. Four set of sheets were formed using epoxy adhesive (EK panels). Three types of reinforced sheets and one type of non-reinforced sheet were formed. LVL panels were produced in the laboratory at the Faculty of Forestry.

2.2 Adhesives

Epoxy adhesive Mapei "MapeWrap 31" was applied in all layers, between the veneers as well as between the veneers and the fiber reinforced polymer (FRP). The adhesive was formed in a mass ratio of A:B = 4:1 (according to Technical sheet [11]). The same amount of adhesive was applied to each glueline and each layer of CFRP wood on both sides of the carbon fabric. Epoxy adhesive properties show in Table 1.

Table 1. Epoxy adhesive properties
Source: [11]

Technical properties	Epoxy	
	Resin – A	**Hardener - B**
Density ρ (20°C) (g/cm^3)	1.05	1.12
Brookfield viscosity (mPa·s (25°C))	17000	110

2.3 Woven carbon fiber

The unidirectional "plain-weave" type of knitting carbon fiber, MapeWrap C UNI-AX 300/40", weighing around 300 g/m^2, was used for reinforcement. The physical and mechanical properties of the CFRP fabric are shown in Table 2.

Table 2. Physical and mechanical properties of MapeWrap C UNI-AX 300.
Source: [12]

Technical properties	**MapeWrap C UNI-AX 300**
Mass (g/m^2):	300
Density (kg/m^3):	1800
Equivalent thickness of dry fabric (mm):	0.164
Load resistant area per unit of width (mm^2/m):	164.3
Tensile strength (MPa)	≥ 4900

2.4 Manufacturing LVL

All panels are produced as seven-layer panels with six veneer sheets oriented in the longitudinal direction, and the central, fourth veneer sheet oriented perpendicular to the grain of the outer veneer sheets. Reinforcements are placed between the veneer layers, according to the following scheme, shown in Figure 1:

- Combination 1 (K1) – reinforcement placed in the first and sixth glueline (S1‖6‖), unidirectionally oriented, carbon fibers placed longitudinally, parallel to the grain of outer veneer;
- Combination 2 (K2) – reinforcement placed in the first and sixth glueline, parallel-oriented as outer veneer, and the third and fourth glueline - perpendicular to the direction of orientation of the outer veneer sheets (S1‖3⊥4⊥6‖);
- Combination 3 (K3) – reinforcement placed in two layers perpendicular to each other, forming a mesh in two directions. The fabrics are placed in the first and sixth glueline (S1‖⊥6⊥‖), taking into account the symmetry of the cross-section;
- Combination 4 (K4) – unreinforced panels, i.e. control reference samples.

For each combination, 3 panels measuring 50×50 cm were formed. All plates were pressed in a laboratory press for 15 minutes from the moment of reaching a temperature of 100°C in the central layer at a pressure of 1.5 MPa. After that, they were stored for a week for additional curing. After that, 30-mm edges were trimmed off of the panels, and samples were cut from the panels. Samples dimensions 150x50 mm, were conditioned in standard climate (20±2)°C and (65±5)% relative humidity during 30 days.

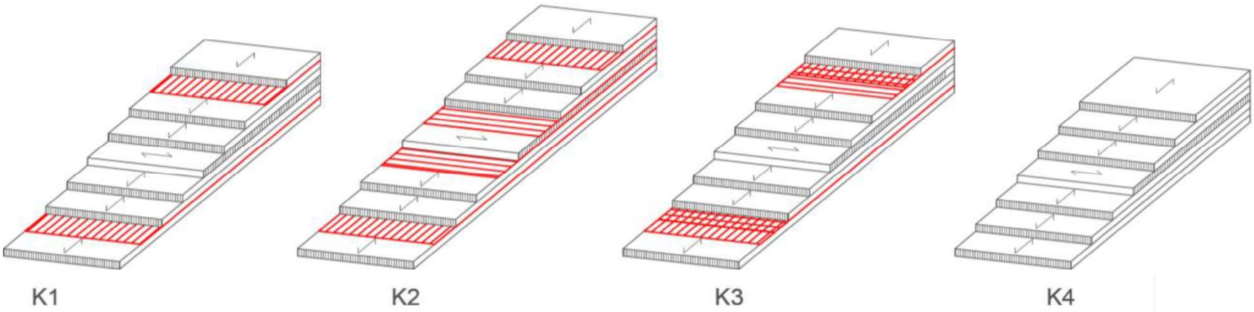

Figure 1. Strengthening configuration of reinforced and unreinforced LVL panels
Source: original copyright

Determination of shear strength perpendicular to the plane of the panel or panel shear test was performed according to the standard [13] SRPS CEN/TS 14966:2010 Wood-based panels - Small-scale indicative methods for testing certain mechanical properties using a small-scale indicator (Figure 2).

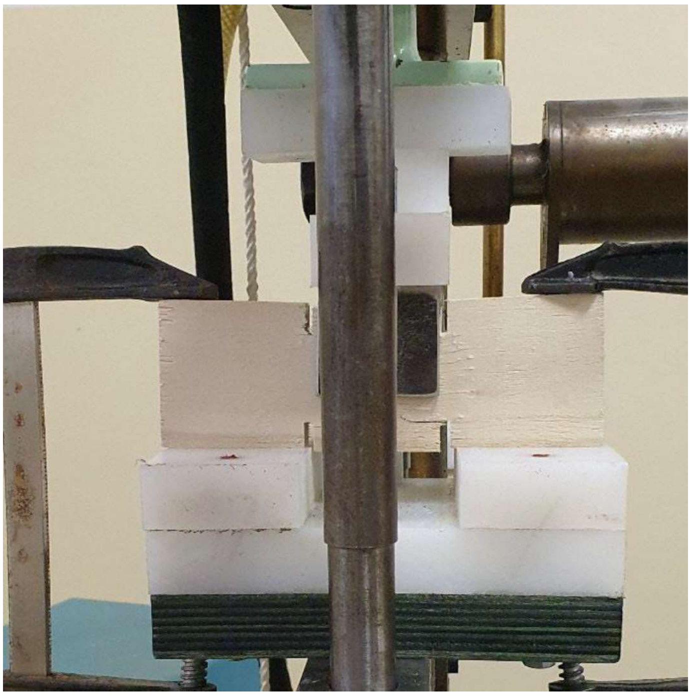

Figure 2. Fracture of the test sample due to shear stress.
Source: original copyright

3. RESULTS AND DISCUSSION

The test results for the test samples are shown in Table 3. For reinforce with two longitudinal, two longitudinal sheets and two perpendicular sheets, and sheets in disposition like a mash, the critical panel shear strength has increased by about 20.42%, 22.04%, 44.75%, respectively, compared to the untreated plate. These results show that higher panel shear load can be achieved using fiber reinforcement in two directions.

The best results are for combination K3, where carbon is oriented like mesh, in bi-directional orientation. In all tested samples, fracture occurred due to exceeding the shear stress. The fracture starts in the central sheet of veneer, whose wood fibers are transversely oriented in relation to the outer sheets of veneer, in the direction of the pressure force. In all other layers, shear occurs, which is manifested by the compression of fibers. Complete crush and cutting of the wood fibers does not occur, the fabric helps the test sample remains coherent (Fig.3).

Table 3. Shear properties of RLVL and LVL in edgewise directions, epoxy adhesive.
Source: original copyright

Combination	$f_{v,0,edge}$ (N/mm²)	x (%)
EK1	15.16	20.42%
EK2	15.36	22.04%
EK3	18.22	44.75%
EK4	12.59	

Note: $f_{v,0,edge}$ – average shear stress, x – increase of average shears stress relative to EK4

Figure 3. Panel shear test **-** characteristic fracture for EK1
Source: original copyright

For combination 2 the mechanical damage of the test samples is less expressed compared to EK1. All test samples have the same forms of damage. In this combination the possibility of splitting along the longitudinal fibers of the wood was reduced.
On all the test samples of Combination 3 the fracture occurred by shear stress, but the deformations on the samples are very small, and on some of them are noticeable. Plastic deformation occurred on the test samples due to compression and crumpling of the fibers at the point of weakening of the material.
In all test samples from the control, unreinforced plates of Combination 4, failure occurred as a result of shear stresses. In relation to reinforced samples, the fracture of the test samples is quite expressed. The fracture tends to complete fracture of the test sample EK4.

4. CONCLUSION

In this study, laminated veneer lumber and reinforced laminated veneer lumber were produced with poplar veneer bonded with epoxy adhesive (EK). Reinforced laminated veneer lumber was produced by inserting woven carbon fiber between veneers, and some of their mechanical properties were tested. Reinforcement of EK3 panels, where the carbon fabric is placed in the first and sixth glueline in two layers, like mesh, oriented perpendicularly to each other, shows a much higher degree of increase panel shear capacity. The force at which the fracture occurred increased by 57.05%, while the percentage of improvement in shear stress is 44.75% compared to the control sample (EK4). In the test samples from these plates, it was observed that the degree of damage is the lowest compared to all tested test samples. The conducted research confirmed the possibility of applying the newly obtained poplar veneer composite material for the design of structural elements in LVL using epoxy adhesive. In this way, the use of technically weaker wood in the construction industry is encouraged and the use of wood raw materials is rationalized.

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