Acta Polytechnica CTU Proceedings **53**:97–101, 2025
https://doi.org/10.14311/APP.2025.53.0097

FLEXURAL BEHAVIOR OF TIMBER-HIGH-PERFORMANCE CONCRETE EXPERIMENTAL SLABS

Tomáš Vlach*, Jonáš Klimt, Eliška Kafková, Jan Macháček, Věra Kabíčková, Jakub Hájek

Czech Technical University in Prague, Faculty of Civil Engineering, Thákurova 7, 166 29 Prague 6, Czech Republic

* corresponding author: tomas.vlach@cvut.cz

Abstract. In general, one of the possible future paths of the building construction industry is the development of robotization and prefabrication of individual building components. Presented article continues the development of prefabrication using traditional effective combination of two often used materials in construction – timber and concrete in the form of a slabs. The traditional concept of combining these materials is used for ceiling structures – slabs, panels, floor panels, where timber is most often in the form of beams and a concrete slab is applied over the beams as a material transmitting compressive stress. The key to functionality for this system is the shear connection of both materials. The presented study presents a thin concrete layer made of high-performance concrete, which is connected to a wooden board from glulam using an adhesive bridge. The aim of this presented study is to improve the bending load-bearing capacity and bending stiffness of the glulam slab with a small amount of high-performance concrete and thus achieve a more favorable environmental profile of the ceiling panel. The individual variants differ in thickness, the presence and number of ribs. These variants are compared with a variant of the same thickness of glulam slab without the layer of concrete.

Keywords: Timber-concrete, high-performance concrete, timber-high-performance concrete, composites, timber composites, timber-concrete composites, composite slabs.

1. Introduction

In the construction sector of civil engineering, it is common to use solid reinforced concrete slabs with steel reinforcement. Reinforcement serves to transfer tensile stresses in concrete, which is the weak point of concrete. Timber-Concrete Composites (TCC) offer a sustainable and more environmentally friendly building elements option due to timber's recyclability, reusability, sustainability and high tensile and bending strength. It works in combination with concrete, which transmits predominantly compressive stresses, where high-performance concrete (HPC) with high compressive strength finds very effective potential of applications [1]. TCC offer many different applications in civil engineering. The first applications were applied more than 50 years ago as a modification of existed floors [2]. The traditional concept of combining these materials is the use of timber in the form of beams. This study presents timber slabs – massive glulam board. The solid plate can be further optimized and lightweighted in different shapes. The advantage of this solution is a larger contact area between the materials and a reduction in contact stress. In the traditional concept, various steel shear connectors [3], composite shear connectors [4, 5], or various locking notches [6] or bonding systems [7–9] are used for connections of TCC. For shear connection in this study is used adhesive bonding with epoxy resin in combination with notch shear connections – system of ribs. The goal of presented study is to enhance the bending strength and stiffness of a glulam slab by incorporating a small amount of HPC, ultimately improving the environmental footprint. The different variants vary in thickness and the presence and quantity of ribs. These variants are compared to a version of the glulam slab with the same thickness but without the concrete layer.

2. Materials used for experiment

A recipe of HPC was developed by the Department of Architectural Engineering, Faculty of Civil Engineering, Czech Technical University in Prague [10]. HPC mixture design utilizes predominantly local raw materials and is detailed presented in Table 1. The HPC mixture is self-compacting and fine-grained. It combines two types of quartz sand and silica flour with silica fume. The maximum grain size is 1.2 mm. Dispersed alkali resistant glass fibers were designed into the mixture to eliminate shrinkage microcracks. The water cement ratio was 0.28 and the water binder ratio was 0.24.

A reference mixture without any fibers was also mixed. The compressive strength tested on three cubes $100 \times 100 \times 100\,\mathrm{mm}^3$ was 131.1 MPa according to the standard CSN EN 12390-3. The flexural strength tested on six prisms $40 \times 40 \times 160\,\mathrm{mm}^3$ was equal to 16.2 MPa according to standard ČSN EN 12390-5. The compressive strength was verified on the prism

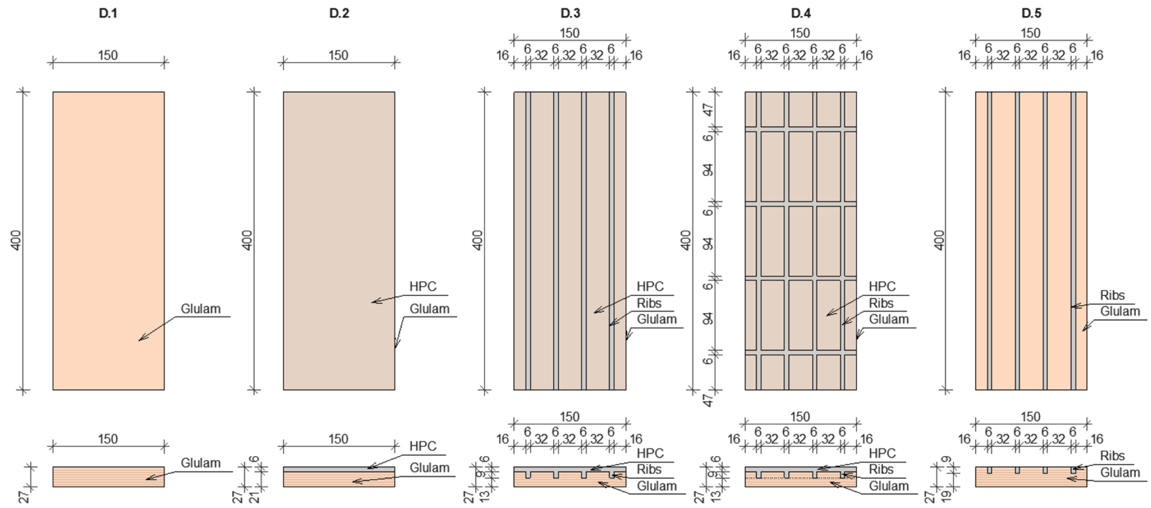

Figure 1. Specimen dimension of glulam slabs, scheme of all five types including HPC part and system of longitudinal and transverse ribs.

Mix content	**kg m^{-3}**
Cement I 42.5R	650
Technical silica sand	1 200
Silica flour (ground quartz)	235
Silica fume (microsilica)	100
Fibres – AR glass	20
Superplasticizers	24
Water	180
Total	2 409

Table 1. Recipe of HPC mixture.

Paramater	**Glulam**
Bending Elasticity Modulus E_m ∥ [N mm^2]	6 672
Bending Elasticity Modulus E_m ⊥ [N mm^2]	5 329
Bending Strength f_m ∥ [N mm^2]	59.6
Bending Strength f_m ⊥ [N mm^2]	50.5

Table 2. Basic mechanical parameters of used glulam.

fragments, and it was 133.8 MPa.

A mixture with dispersed AR Glass fibers was mixed for the determination of basic mechanical parameters. It was used for TCC presented in this article. The compressive strength tested on three cubes $100 \times 100 \times 100\,\mathrm{mm}^3$ was little bit lower 113.3 MPa according to the standard ČSN EN 12390-3. The flexural strength tested on six prisms $40 \times 40 \times 160\,\mathrm{mm}^3$ was equal to 17.9 MPa according to standard ČSN EN 12390-5, little bit higher in comparison with reference mixtures as expected. The compressive strength was verified on the prism fragments, and it was 126.1 MPa.

In the presented article only one type of glulam was selected. Glue-laminated technology allows different structural products to be manufactured in different sizes and shapes. The manufacture of glue-laminated timber as engineered products for structural uses requires careful procedures for material preparation. For this experiment glulam boards were selected adhesively bonded by birch plywood plates. Basic table values of the flexural mechanical parameters of the wood used are presented in the Table 2.

The adhesiveness in this article to create a bridge in the interface between HPC and glulam was selected epoxy resin Sikafloor 150/280 based on the previous successful experience with this epoxy resin in similar research projects. The basic material parameters of the epoxy resin are the flexural strength of 15 MPa and the modulus of elasticity of 2.0 GPa. The specific gravity of the resin is 1 100 kg m^{-3} according to the technical data sheet of the Sika company [11, 12].

3. Specimen design and preparation

The production process presented is slightly different from the others. If glue is used to transfer shear stress between TCC materials, the wooden and concrete parts are usually manufactured separately and finally glued together. In this experiment, HPC is carried out directly on the glulam part using an adhesive bridge, which facilitates the technological production process. First, a glulam board is prepared for the designed specimen dimensions of 150×400 mm in the variants presented in Figure 1. In sum three specimens were prepared for each of the five groups. The first is a reference for comparison – a glulam board without any HPC layer with a thickness of 27 mm. The other boards have a thickness of glulam 21 mm, where a layer of HPC was added so that the total thickness is also approximately 27 mm for better comparison. Furthermore, a system of longitudinal ribs is designed for the glulam board to lighten the contact area, another variant combines longitudinal and transverse ribs. The last group are glulam boards with only HPC ribs, without a continuous HPC layer. The geometry of all specimens is visible in Figure 1. Specimen groups are named D.1 to D.5, as visible in the same Figure 1.

Specimen	Number	Weight [kg]	Thick [mm]	Width [mm]	Length [mm]	$F_{cf,max}$ [kN]	$\phi F_{cf,max}$ [kN]
Glulam 27	D.1.1	1.061	26.47	148.8	400.0	21.96	21.98
	D.1.2	1.045	26.56	148.7	400.0	21.67	
	D.1.3	1.047	26.68	149.0	402.0	22.31	
Glulam 21 + HPC 6	D.2.1	2.015	26.65	150.1	400.0	28.09	28.96
	D.2.2	1.914	26.25	152.3	399.0	28.75	
	D.2.3	2.013	26.63	152.2	399.0	30.04	
Glulam 21 + HPC 6 + ribs longitudinally	D.3.1	2.028	27.54	152.7	402.0	28.19	28.37
	D.3.2	1.896	27.34	151.8	401.0	27.06	
	D.3.3	2.201	28.33	152.2	402.0	29.87	
Glulam 21 + HPC 6 + ribs longitudinally + transversely	D.4.1	2.069	28.12	152.2	402.0	33.97	31.91
	D.4.2	2.111	27.78	151.0	403.0	30.61	
	D.4.3	2.078	27.25	151.5	401.0	31.15	
Glulam 27 + ribs longitudinally	D.5.1	1.223	26.57	148.4	402.0	23.99	22.96
	D.5.2	1.221	26.42	148.7	400.0	22.51	
	D.5.3	1.286	26.47	148.8	401.0	22.37	

TABLE 3. List of samples, individual weights and dimensions, measured maximum force value.

The next step, after preparing the glulam boards, was to apply a bonding bridge to transfer shear stress at the interface of both materials. This was done in two stages. The first stage involved applying a coat of epoxy resin, which sealed the wood structure. After it hardened, a second coat was applied, followed by the addition of sand with a grain size of 0.6–1.2 mm. The sand was spread loosely over the surface. After hardening, as specified in the technical sheet, the sample was ready for concreting. The bonding bridge effectively transfers shear loads [8], while the epoxy also protects the wood from the wet concreting process. Finally, concreting was carried out. In addition to the specimens, as specified in the plan, the concrete support structures were also cast to determine the basic mechanical properties of the concrete, as listed above.

4. Experiment and results

The article focuses on the influence of a thin HPC layer on the load-bearing capacity and overall behavior of the slab. Loading is carried out using a four-point bending test. The distance between the supports was 300 mm and the distance between the loading supports was 100 mm. The loading process was carried out at a constant loading rate of 0.5 mm min^{-1} so that the total test length until failure was approximately 15 minutes. The experiment was created on a Galbadiny Quasar 100 hydraulic press with a maximum cylinder load capacity of 100 kN. Numerical values of maximum reached forces the results are given in Table 3. The table provides interesting results. The table provides interesting results with a visible positive influence of the HPC layer.

These differences between single groups are better visible in Figure 2, where the curves from the load tests are presented. The result of the reference group D.1 without a HPC layer shows similar results with group D.5, where only longitudinal thin HPC ribs are presented. This is quite a surprising result, and it may be due to the ribs being properly filled with HPC. The maximum flexural strength of group D.1 was 62.8 MPa. This result corresponds to the value of 59.6 MPa given in Table 2 so measurement was correct.

However, a significant influence of the HPC thin layer on the load-bearing capacity and a positive influence on the specimen stiffness in groups D.2, D.3 and D.4 are visible. All variants show similar values of strength and stiffness. Variant D.2 is the worst of the three mentioned, because it has a smaller interface contact area without any ribs. The concrete surface slipped at the end due to the shear stress. Variant D.3 is a little bit stiffer, achieves better results. Thanks to the longitudinal ribs the interface contact area is increased, however, there was also shear failure of the interface bond and then failure of the glulam. Group D.4 with longitudinal and transverse ribs achieved the best results and there was no slipping in the interface bond area. Furthermore, the ribs could be optimized in future work. In Figure 3 are presented views on the damaged specimens after the destructive loading tests.

5. Conclusions

The aim of this presented study was to improve the bending load bearing capacity and bending stiffness of TCC. It is a glulam by incorporating a small amount of HPC. To allow for a better comparison of the results, all samples were made with approximately the same dimensions and were compared to reference samples without HPC. The load bearing capacity of the glulam without HPC corresponds to the data provided in the technical data sheet. The HPC was applied directly to the glulam, with surface treatment involving an adhesive bridge of epoxy resin and silica sand before concreting process. The effect of the single longitudinal HPC ribs on the overall stiffness of the panel was not proven. However, a significant positive effect of the HPC layer in the compression zone was

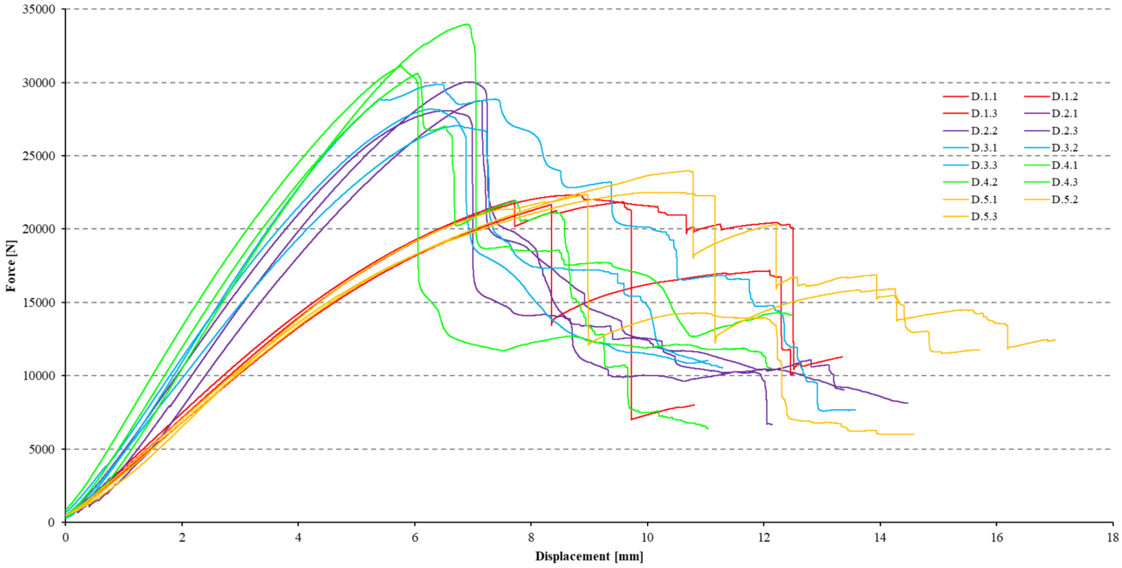

Figure 2. Force-displacement diagram for all specimen from groups D.1 to D.5. Visible significant influence of the concrete layer on the load-bearing capacity and especially the stiffness of the slab.

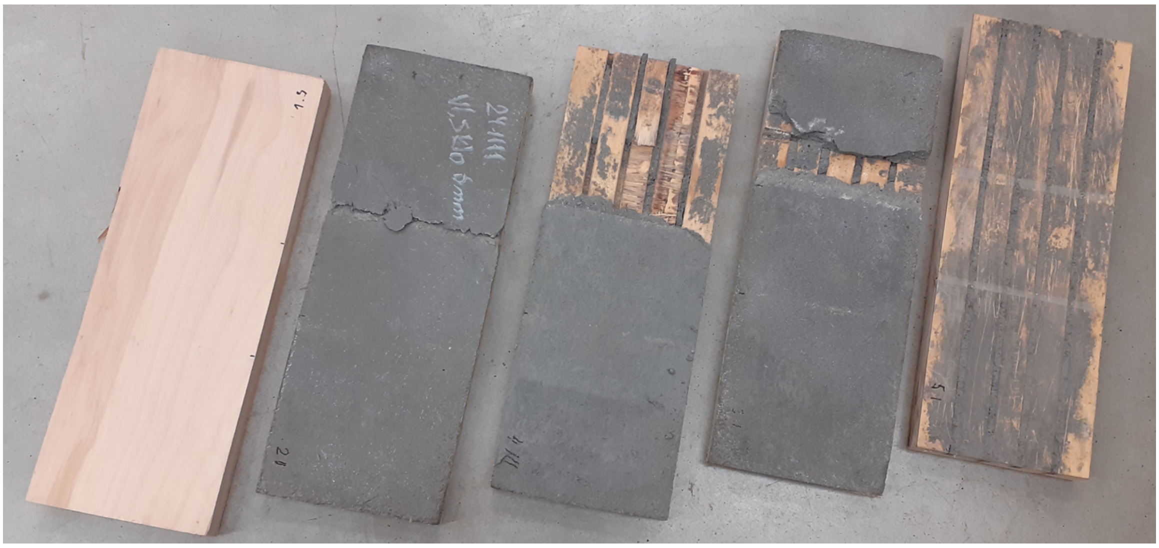

Figure 3. View on the damaged representative specimens after the loading test, one from each group D.1 to D.5. For group D.3 and D.4, the HPC was removed after the testing to see the ribs and the positive influence of the transverse rib.

demonstrated, as the bending load bearing capacity increased by approximately 45 %, and the stiffness was also improved. At the same load value, the deformation of the specimen was roughly halved. The ribs showed a positive effect on the shear capacity of interface between both materials.

Acknowledgements

The work on this paper was supported by Czech Science Foundation Grant No. 22-14942K entitled “Possibilities of using natural fibers for the production of hybrid textile reinforcement in concrete” The authors would like to acknowledge all financial assistance provided to support this research.

References

[1] A. Neville, P.-C. Aïtcin. High performance concrete – an overview. *Materials and Structures* **31**(2):111–117, 1998. https://doi.org/10.1007/BF02486473

[2] E. Lukaszewska, H. Johnsson, M. Fragiacomo. Performance of connections for prefabricated timber-concrete composite floors. *Materials and Structures* **41**(9):1533–1550, 2008. https://doi.org/10.1617/s11527-007-9346-6

[3] M. Fragiacomo. Experimental behaviour of a full-scale timber-concrete composite floor with mechanical connectors. *Materials and Structures* **45**(11):1717–1735, 2012. https://doi.org/10.1617/s11527-012-9869-3

[4] S. C. Auclair, L. Sorelli, A. Salenikovich. A new composite connector for timber-concrete composite structures. *Construction and Building Materials* **112**:84–92, 2016. https://doi.org/10.1016/j.conbuildmat.2016.02.025

[5] L. Marchi, L. Pozza. Timber-concrete composite connections using GFRP notches fastened with self-tapping screws: Conceiving, numerical modelling and testing. *Construction and Building Materials* **294**:123579, 2021. https://doi.org/10.1016/j.conbuildmat.2021.123579

[6] K. Müller. *Timber-concrete composite slabs with micro-notches*. Ph.D. thesis, ETH Zürich, 2020. https://doi.org/10.3929/ETHZ-B-000474874

[7] Q. Fu, L. Yan, N. A. Thielker, B. Kasal. Effects of concrete type, concrete surface conditions and wood species on interfacial properties of adhesively-bonded timber – concrete composite joints. *International Journal of Adhesion and Adhesives* **107**:102859, 2021. https://doi.org/10.1016/j.ijadhadh.2021.102859

[8] M. Novotná, C. Fiala, P. Hájek. Precast timber-concrete composite floor structures for sustainable buildings – experimental verification. In *CESB 13 Prague : Central Europe towards sustainable building 2013*, pp. 429–432. 2013. ISBN 978-80-247-5015-6.

[9] E. Appavuravther, B. Vandoren, J. Henriques. Push-out tests on adhesively bonded perfobond shear connectors for timber-concrete composite beams. *Journal of Building Engineering* **57**:104833, 2022. https://doi.org/10.1016/j.jobe.2022.104833

[10] M. Kynclova, C. Fiala, P. Hajek. High performance concrete as a sustainable material. *International Journal of Sustainable Building Technology and Urban Development* **2**(1):63–68, 2011. https://doi.org/10.5390/susb.2011.2.1.063

[11] T. Vlach, P. Hájek, C. Fiala, et al. Waffle facade elements from textile reinforced high performance concrete, 2016.

[12] T. Vlach, J. Řepka, J. Hájek, et al. Cohesion test of a single impregnated AR-glass roving in high-performance concrete. *Stavební obzor - Civil Engineering Journal* **29**(3):358–369, 2020. https://doi.org/10.14311/cej.2020.03.0032