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Load-carrying capacity of timber-concrete composite panels

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Abstract. Timber-concrete composite panels, due to its benefits, are one of the most popular alternatives to common slabs of pure timber or concrete. In the analyse of load-carrying capacity for timber-concrete composite panels, subjected to flexure, the important component is connection system between concrete layer and timber, which affects the stress distribution and the deformations of the structure. Possibility to increase effectiveness of structural materials use and load-carrying capacity of the timber-concrete composite structural members, with the rigid timber to concrete joint, was evaluated in this research. Consequently, possibility to develop rigid timber to concrete joint by the using of the crushed granite pieces as the keys was checked by the experiment. Development of rigid timber to concrete joint enables to increase effectiveness of the structural materials use in timber-concrete composite panels in comparison with the compliant once. Behavior of the timber-concrete composite panels were analysed by the transformed section method, finite element method and by experiment for the purpose of this study. Four timber-concrete composite panels were statically loaded till the failure by the scheme of three-point bending. Variants of composite panels with the rigid and combined timber-concrete joints were investigated. The rigid timber-concrete joint was provided by the pieces of crushed granite, which were strengthened on the surface of the timber boards by epoxy glue. Dimensions of the crushed granite pieces changes within the limits from 16 to 25 mm. Moreover, the combined timber-concrete joint was provided by the screws and by the crushed granite pieces. The screws were placed under the angles equal to 45 degrees relatively to the direction of fibres of the timber layers in accordance with the literature recommendations. As a result, it was stated, that load–carrying capacity of timber-concrete composite panels is up to 1.9 times higher than the same of cross-laminated timber panels. The maximum load-carrying capacity in 43 kN was obtained for the variant of timber-concrete composite panel with the rigid timber to concrete joint at the same time.

1. Introduction

Timber-concrete composite structures become enough popular during the last years as an alternative to reinforced concrete structures. Timber-concrete composite structures are mainly subjected to flexure and combine advantages of pure timber and pure concrete structures [1–13]. It can be beams, panels or slabs of floors and roofs mainly. Timber-composite structures cause interest of researchers during the last years. Different variants of concrete to timber joints so as several variants of structural solutions, which enables to increase the load-carrying capacity of timber-concrete composite structure are the major directions of the investigations at the present moment [14–17].

Timber-concrete composite structures possess the following advantages in comparison with the pure timber structures:

– Increased stiffness;

– Increased load carrying capacity;

– Increased fire resistance;

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- Improved sound insulation;
- Reduced sensitivity concerning vibrations;
- Simplified possibility to realize the horizontal bracing of the structure [13].

Load-carrying capacity of structural members grows also so as protective or finishing layers of concrete or another cement-base composite are involved into common work with the timber members and take up a part of the applied load. The fire resistance grows so as concrete layer plays a role of protective covering [10, 11]. Sound absorption of timber-concrete composite structures grows so as timber has approximately three-time higher sound absorption coefficient in comparison with the concrete.

Timber-concrete composite structures possess the following advantages in comparison with the pure concrete structures:

- Reduced dead load;
- Increase of re-growing materials and therefore less CO_2 emissions;
- Increase of prefabricated elements leading to a faster erection of the structure and therefore, to a lower influence of the surrounding conditions during the erection phase;
- Reduced volume of concrete, which leads to a faster building process and less volume to be transported on site;
- Reduced effort for the props/formwork since the load carrying capacity and the stiffness of the timber cross section is higher than the related properties of the prefabricated concrete elements [13].

Behaviour of timber-concrete composite structural members strongly dependent from the type of timber to concrete joint. Compliant and rigid once are two types of timber to concrete joints in timber-concrete composite structures existing now. Investigations of behaviour of timber to concrete joints indicates, that the timber-concrete composite structural members realized by the compliant and rigid timber to concrete joints, are characterized by the comparable load-carrying capacity [4, 5]. Studies shows, that the adhesive composite connection of the timber-concrete structural members is very effective, it provides higher bending stiffness [4] and leads to smaller deflections and a better composite behaviour [18] in comparison with mechanical fasteners. Theoretically timber-concrete composite structural members realized by the rigid timber to concrete joints, possess a potential for increase of it load-carrying capacity in comparison with the analogous members realized by the compliant joints due to the more rational structural materials use in the first case [5]. More rational materials use and probable increase of the load-carrying capacity in timber-concrete composite structural members is joined with the normal stresses distribution between the joined layers caused by the different compliances of the joints in the both mentioned above cases [5].

So, aim of the current study is analyse of load-carrying capacity for timber-concrete composite members subjected to flexure. Possibility to increase load-carrying capacity of the timber-concrete composite structural members subjected to flexure with the rigid timber to concrete joint in comparison with the pure timber member should be evaluated for the purpose. Behaviour of timber to concrete joints in timber-concrete composite members subjected to flexure should be investigated.

2. Methods

2.1. Realization of rigid timber to concrete joint

A hypothesis that using of the pieces of the crushed granite joined with the timber by the epoxy glue as the keys, enables to obtain a rigid timber-to concrete joint, was checked by experiment. The suggested type of timber-to concrete joint is close to grooved joint with the using of epoxy adhesives [4, 5]. However, suggested timber-to concrete joint enables to avoid deformations of the timber keys working in grooved joint in local compression in zones of contacts with the concrete. Additional rigidity of the suggested timber-to concrete joint should be provided as a result. The suggested timber-to concrete joint is characterized by the decreased workability and is simpler in realisation in comparison with the grooved joint.

Two groups of small-scale timber-concrete composite specimens were prepared and tested in laboratorian conditions. The first group include twelve small-scale timber-concrete composite specimens where the rigid timber-concrete joint was provided by the pieces of crushed granite, which were strengthened on the surface of the timber boards by epoxy glue Sica Dur 330. The epoxy glue Sica Dur 330 has modules of elasticity and shear strength equal to 12800 and 15 MPa, correspondingly. Dimensions of the crushed granite pieces changes within the limits from 2 to 25 mm. Three sub-groups by the four specimens in the each were prepared within the first group with the different dimensions of the pieces of crushed granite, which are shown in Figure 1.

Figure 1. Granite pieces with different dimensions joined with the timber board by the epoxy glue: *(a)* 2-5 mm; *(b)* 5-8 mm; *(c)* 16-25 mm [19]

The pieces of crushed granite were joined with the surface of the timber by the glue, as it is shown on Figure 1. The hardening of the glue was provided in course of two days and then the cement base finishing mass was casted into the moulds. So, the pieces of crushed granite work as a dowel, which are involved into the layer of the cement composite. Geometrical parameters of hybrid timber-concrete composite specimens with rigid timber to concrete joint are the same as for the specimens with the compliant joints, which were explained above [19]. Specimens have the length, width and thickness equal to 400, 95 and 43 mm, correspondingly. The small-scale hybrid timber-concrete composite specimens consists from the layers of cement base finishing mass Sacret BAM and timber boards of strength class C24 with thicknesses equal to 25 and 18 mm, correspondingly. Thickness of cement base finishing mass layer was equal to 25 mm so as it is a maximum size of the crushed granite pieces used for the specimens with the rigid timber to concrete joint. The cement base finishing mass Sacret BAM has modulus of elasticity and density equal to 30000 MPa and 20 kN/m^3, correspondingly. Its strength class is C20. The timber-concrete composite specimens were tested after twenty-eight days from the specimen's formation.

Second group include twelve small scale hybrid timber-concrete specimens, which were prepared with compliant timber to concrete joint provided by the screws with length and diameter equal to 40 and 4 mm, correspondingly. Three variants of the screw's placement were considered. The screws were placed under the angles 90º and 45º relatively to longitudinal axis of the specimens, correspondingly, for the two first variants. Two screws were placed in each point under the angle 45 º relatively to longitudinal axis of the specimens, for the third variant [19]. So, third variant of the screw's placement is characterized by the two times increased amount of screws in comparison with the two first variants. Three sub-groups by the four specimens in the each were prepared within the second group with the three variants of the screw's placement, which are shown in Figure 2.

Figure 2. Considered variants of screws placement: *(a)* screws were placed under the angle 90º relatively to longitudinal axis of the specimens; *(b)* screws were placed under the angles 45º; *(c)* two screws were placed in each point under the angle 45º [19]

Intensity of the concentrated force applied in the middle of the specimen's span and maximum vertical displacements are two parameters, which were taken under the control during the experiment. The expected load-carrying capacities of the timber-concrete composite specimens were previously determined by the transformed section method [16]. The maximum vertical displacements were measured by two mechanical indicators placed in the middle of the span (Figure, 3(a)).

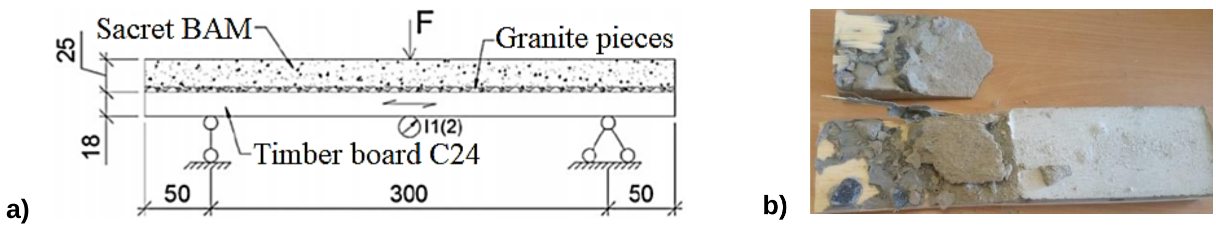


Figure 3. Testing of timber-concrete composite specimens: *(a)* scheme of the specimens testing; *(b)* failure mode of the specimen with the rigid timber to concrete joint and granite pieces dimensions changing within the limits from 16 to 25 mm [19]

Precision of the maximum vertical displacements measurements was equal to 0.01.mm. All the specimens were loaded until the failure to determine their load-carrying capacities. The vertical load was applied with the steps equal to 2 kN with the speed equal to 2 mm/min [19].

2.2. Approach for the load-carrying capacity analyse for timber-concrete composite panels

2.2.1 Experimental analyze of load-carrying capacity for timber-concrete composite panels

Four timber-concrete composite panels with the different timber to concrete joints were analysed analytically and by experiment. Two panels were prepared with the combined timber to concrete joint, which is provided by the granite pieces with dimensions changing within the limits from 16 to 25 mm and by the couples of screws, which are placed under the angles in 45° relatively the longitudinal axises of the panels. The diameters and lengths of the screws were equal to 4 and 40 mm, correspondingly (Figure 4(a)). Adding of the screws enables to increase reliability of the panels and provide a common work of the layers in case of defects of the glued joint [5].

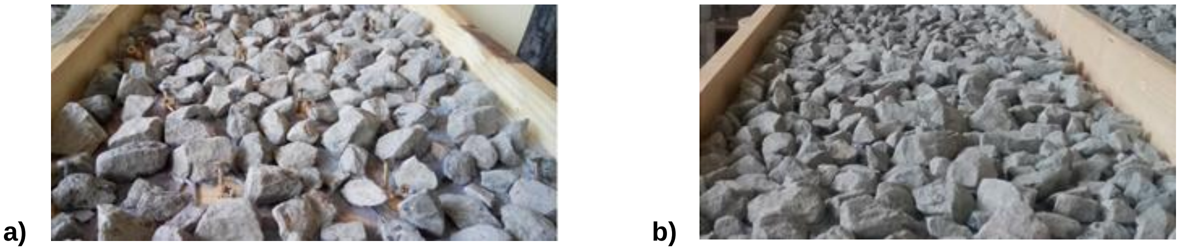


Figure 4. Placement of the granite pieces and screws, providing timber to concrete joint in the timber-concrete composite panels: *(a)* granite pieces and screws; *(b)* granite pieces only [19]

The screws were placed in accordance with the requirements of EN 1995-1-1 [20]. Timber to concrete joint in another two panels was provided by the granite pieces with dimensions changing within the limits from 16 to 25 mm only (Fig.3. (b)). The granite pieces were joined to the surface of the timber by the epoxy glue Sica Dur 330. Timber-concrete composite panels consist from the cross-laminated timber (CLT) components, which are strengthened by the carbon fiber reinforced plastic tape in the tensioned zone and with the layer of finishing mass Sacret BAM with thickness in 30 mm in compressed zone. Shrinkage of the finishing mass was not taken into account so as it was equal for all the specimens. The cross-laminated timber base consists from the three layers of strength class C24 timber boards with thickness in 20 mm. Fibers of outer layers are oriented parallel to the longitudinal axis of the panels. The panels have length, width and thickness equal to 2000, 350 and 60 mm, correspondingly (Fig.5. (b)). The panels were produced by the Sconto enterprise, Ltd, Jelgava, Latvia.

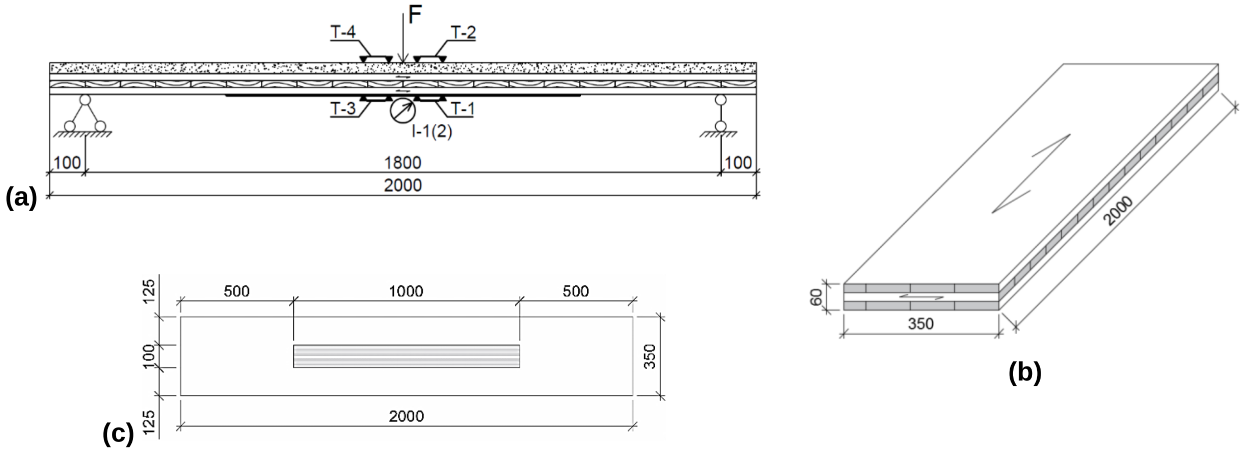


Figure 5. The design scheme and measuring devices placement for the timber-concrete composite panels (a); cross-laminated timber component of the timber-concrete composite panels (b); placement of the carbon fiber reinforced tape on it surface in the tensioned zone (c) [19]

The carbon fiber reinforced tape Mapei Carboplate E250 has the modulus of elasticity, tensile strength and thickness equal to 250000 MPa, 2500 MPa and 1.4 mm, correspondingly [21]. The carbon fiber reinforced tape was strengthened to the surface of the cross-laminated timber panel by the epoxy glue Sica Dur 330 (Figure 4(c)). The design scheme and apparatus placement for the timber-concrete composite panels is shown on the Figure 4 (a). Two couples of strain measuring devices and one couple of deflectometers were used during the static loading of the timber-concrete composite panels. Strain measuring devices T-2 and T-4 were placed on the surface of the finishing mass Sacret BAM in compressed zone. Strain measuring devices T-1 and T-3 were placed in tensioned zone on the surface of the cross-laminated timber. A couple of the deflectometers I-1 and I-2 were placed in the middle of the span. Precision of the maximum vertical displacements and absolute deformations measurements was equal to 0.01.mm and 0.001 mm, correspondingly. All the specimens were loaded until the failure to determine their load-carrying capacities.

The process of loading of each panel takes up until 20 minutes and the loading can be classified as the short-term once. The vertical load was applied with the steps equal to 2 kN with the speed equal to 2 mm/min [19].

2.2.2 Analytical analyze of load-carrying capacity for timber-concrete composite panels

Load-carrying capacity of timber-concrete composite panels was carried out analytically by the transformed section method and by the FEM [22], which was realized by the software RFEM 5.13. The plate finite elements were used to develop the FEM model of the timber-concrete composite panels.

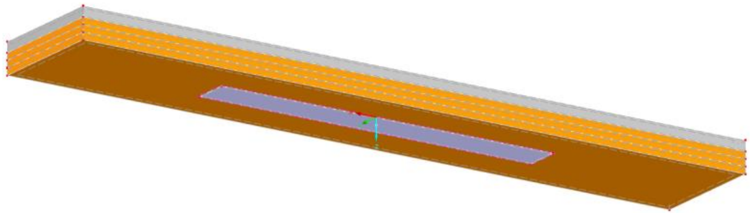


Figure 6. The FEM model of the timber-concrete composite panel developed by the software RFEM 5.13 [19]

The model was divided into the finite elements by the rectangular mesh (Figure 6). Timber-concrete panels analyze by the software RFEM 5.13 include following stages: development of the model, applying of loads, solution of the task and analyze of obtained results. Analyzed timber-concrete panels were considered as the structural members made of orthotropic structural material and the dependence between the internal forces and deformations has the following shape [23]:

$$\begin{Bmatrix} m_x \\ m_y \\ m_{xy} \\ v_x \\ v_y \\ n_x \\ n_y \\ n_{xy} \end{Bmatrix} = \begin{bmatrix} D_{11} D_{12} D_{13} & 0 & 0 & D_{16} D_{17} D_{18} \\ D_{21} D_{22} D_{23} & 0 & 0 & D_{26} D_{27} D_{28} \\ D_{31} D_{32} D_{33} & 0 & 0 & D_{36} D_{37} D_{38} \\ 0 \quad 0 \quad 0 & D_{44} & D_{45} & 0 \quad 0 \quad 0 \\ 0 \quad 0 \quad 0 & D_{54} & D_{55} & 0 \quad 0 \quad 0 \\ D_{61} D_{62} D_{63} & 0 & 0 & D_{66} D_{67} D_{68} \\ D_{71} D_{72} D_{73} & 0 & 0 & D_{76} D_{77} D_{78} \\ D_{81} D_{82} D_{83} & 0 & 0 & D_{86} D_{87} D_{88} \end{bmatrix} \begin{Bmatrix} k_x \\ k_y \\ k_{xy} \\ \gamma_{xz} \\ \gamma_{yz} \\ \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} \qquad (1)$$

where: m_x, m_y are bending moment that creates stresses in direction of the local axis x and y, correspondingly; m_{xy} is torsional moment; v_x, v_y are shear force acting relatively axis x and y, correspondingly; n_x, n_y are axial force in direction of the local axis x and y, correspondingly; n_{xy} is shear flow; stiffness matrix elements: $D_{11} - D_{33}$ are bending and torsion, $D_{16} - D_{38}$, $D_{61} - D_{83}$ are eccentric effects, $D_{44} - D_{55}$ are shear, $D_{66} - D_{88}$ are membrane; k_x, k_y are bending about the local member axis x and y, correspondingly; k_{xy} is torsional deformation in plane xy; $\varepsilon_x, \varepsilon_y$ are strain in direction of the member axis x and y, correspondingly; $\gamma_{xz}, \gamma_{yz}, \gamma_{xy}$ are shear deformation in plane xz, yz and xy, correspondingly.

Transformed section method was chosen for analytical analyze of load-carrying capacity for timber-concrete composite panels so as it is characterized by the simplified design procedure and comparable precision in comparison with the k-method, gamma method and shear analogy method. Transformed cross-section method is joined with the replacement of the real cross-section of element by the equivalent transformed cross-section [24–26]. Transformation of cross – section is based on the ratios of moduli of elasticity of the layers to the modulus of elasticity of the outer layers of CLT panels, which were oriented in the longitudinal direction. The widths of the internal layer of the CLT panels, layer of finishing mass Sacret BAM and carbon fiber reinforced tape Mapei Carboplate E250 must be multiplied by the relations of modulus of elasticities. Obtained transformed cross-section then is considered as glued homogenous cross-section. Checks of ultimate limit state (ULS) and serviceability limit state (SLS) must be conducted based on the recommendations of [20].

3. Results and Discussions

3.1. Behaviour of rigid timber to concrete joint

Two groups of small-scale timber-concrete composite specimens, explained in detail before, were tested by the experiment. The dependences of the maximum vertical displacements of the hybrid timber-concrete specimens subjected to flexure on the intensity of the vertical applied load were obtained together with the load-carrying capacities for all the specimens of six sub-groups. The maximum vertical displacements as a function from the vertical load for six sub-groups of tested specimens are shown on Figure 7.

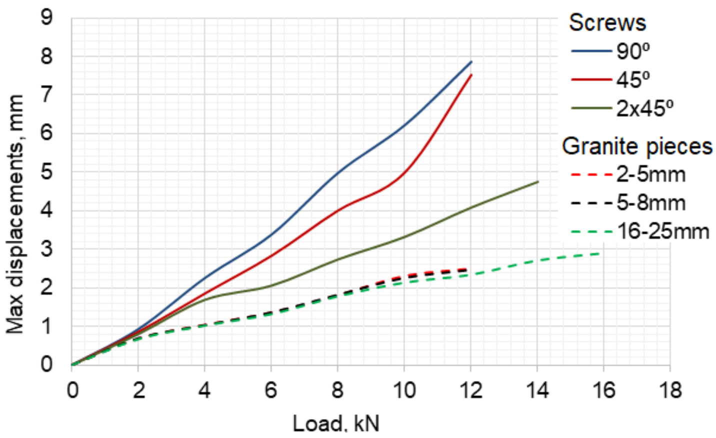


Figure 7. The maximum vertical displacements as a function from the vertical load for six sub-groups of tested small-scale timber-concrete composite specimens [19].

The maximum mean load-carrying capacities for small-scale timber-composite specimens of the first group with the dimensions of crushed granite pieces changing within the limits from 2 to 5 mm, from 5 to 8 mm and from 16 to 25 mm are equal to 12.1, 12.9 and 16.2 kN. The maximum mean load-carrying capacities for small-scale timber-composite specimens of the second group where the screws were placed under the angle 90º and 45º relatively to longitudinal axis of the specimens so as for the sub-group, where two screws were placed in each point under the angle 45º, are equal to 10.8, 11.00 and 13.2 kN. The values of load-carrying capacities of the first and second groups of small-scale specimens, obtained by the transformed section method, were equal to 10 and 12 kN, correspondingly [19].

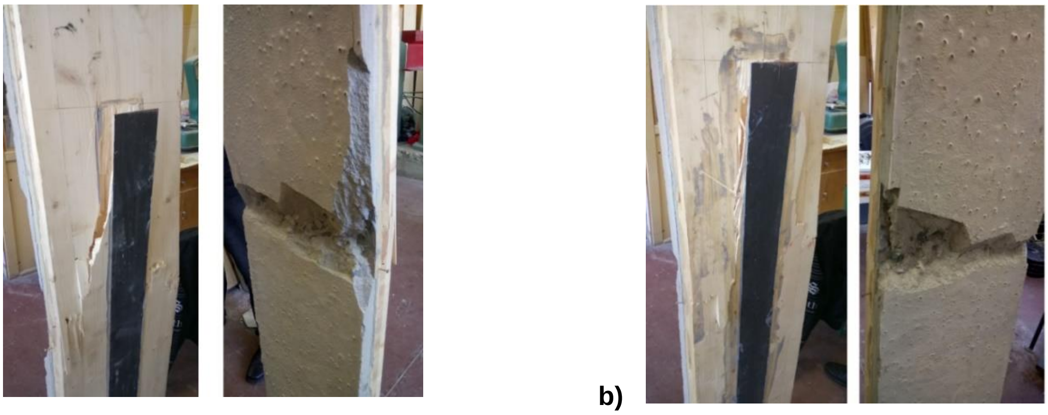
The values of maximum load-carrying capacities of twelve tested small-scale timber-concrete composite specimens of the first group are 25.92 % bigger than the values, obtained by the transformed section method and 18.52 % than the maximum load –carrying capacities of twelve tested specimens of the second group. It enables to make a conclusion, that the using of the pieces of the crushed granite joined with the timber by the epoxy glue as the keys, enables to obtain a rigid timber-to concrete joint.

The obtained results enable to conclude, that using of the rigid timber to concrete joint instead of compliant ones, enables to increase the load-carrying capacity of the small-scale timber-concrete composite specimens subjected to flexure from 16.55 to 50 %. Increase of the crushed granite pieces from 2–5 to 16–25 mm enables to increase load-carrying capacity of considered specimens by 33.88 % [19].

3.2. Behaviour of timber-concrete composite panels

The stresses, acting in the outer top and bottom fibers of the four timber-concrete composite panels, explained before, its maximum vertical displacements and load-carrying capacities were evaluated by the experiment and analytically by FEM. Maximum vertical displacements of the timber-concrete composite panels were evaluated by the transformed section method also. Four timber-concrete composite panels were divided in to two sub-groups. The first sub-group include the specimens, which were created with the combined timber to concrete joint, which is provided by the granite pieces and by the couples of screws, as it was explained before. These specimens will be mentioned next as first and second once. The second sub-group include the specimens, which were created with the timber to concrete joint, which is provided by the granite pieces only. These specimens will be mentioned next as third and fourth once. The failure mode for the specimens from the first and second sub-groups is shown on Figure 8.

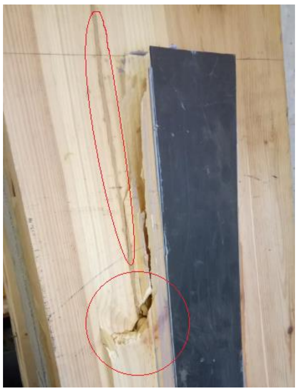
a)



b)

Figure 8. The failure mode for the specimens from the first and second sub-groups: *(a)* second specimen; *(b)* fourth specimen [19]

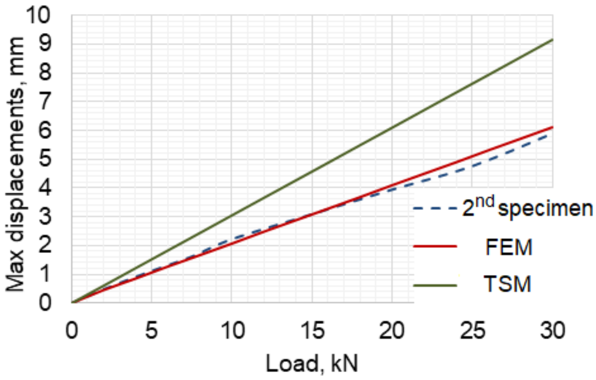
The failure of all four specimens starts from the timber in the contact zone with the carbon fiber reinforced tape in the tensioned zone of the specimen. Then occur breaking of cement composite in compressed zone and cross-laminated timber base. The maximum load-carrying capacities of all four specimens are equal to 33, 38, 43 and 39 kN, correspondingly. It was shown, that adding of the screws did not effects on the load-carrying capacities of the timber-concrete composite panels. The load-carrying capacity decrease for the first specimen can be explained by the defects – knots in the contact zone of cross-laminated timber base with the carbon fiber reinforced tape in the tensioned zone of the specimen. But existence of the defects did not effects on the failure mode of the first specimen (Figure 9).

a) 

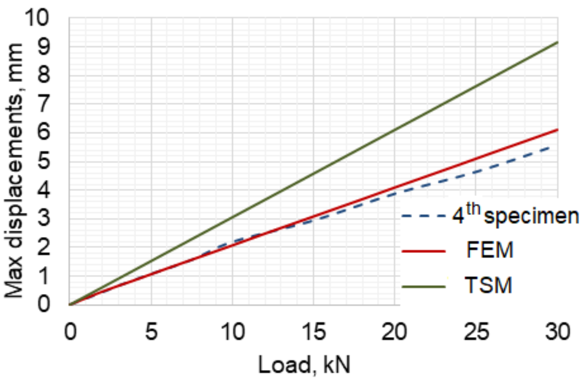
b) 

Figure 9. Defects and failure mode of the first specimen: *(a)* knots in the contact zone of cross-laminated timber base with the carbon fiber reinforced tape in the tensioned zone of the first specimen; *(b)* failure mode of the first specimen [19]

The dependences of the maximum vertical displacements of the specimens on the intencity of applied vertical load were obtained by the transformed section method, by the FEM, which was realized by the software RFEM 5.13. and by the experiment for the both sub-groups of the specimens. The dependences for the second and fourth specimens are shown on the Figure 10. The dependences obtained for the first and third specimens, have the similar shapes.



(a)

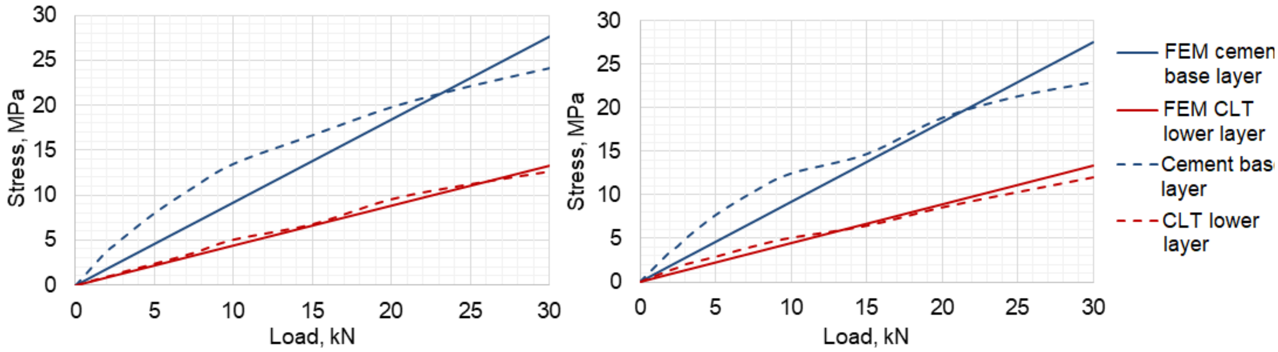


(b)

Figure 10. The dependences of the maximum vertical displacements of the specimens on the intensity of applied vertical load: *(a)* second specimen; *(b)* fourth specimen; FEM – dependence, which is obtained by the finite element method; TSM – dependence, which is obtained by the transformed section method [19]

The obtained dependences are linear for the both sub-groups of the specimens and existence of the screws as the members providing additional bonds between the cross-laminated timber base and the layer of cement composite did not effect on the behaviours of the specimens. So, the maximum experimental vertical displacements of the first and second sub-groups of the specimens obtained at the vertical load equal to 30 kN are equal to 6.71, 5.87, 5.37 and 5.56 mm, correspondingly. Maximum vertical displacements, observed for the first specimen, can be explained by the defects of it cross-laminated timber base. The maximum differences obtained between the results, got by the experiment, FEM and TSM were equal to 11.96 and 41.31%, correspondingly [19].

The dependences of the maximum normal stresses acting in the compressed and tensioned zones of the specimens on the intensity of applied vertical load were obtained by the by the FEM and by the experiment for the both sub-groups of the specimens. The dependence for the second and fourth specimens are shown on the Figure 11. The dependences, obtained for the first and third specimens, have the similar shapes.



(a) ***(b)***

Figure 11. The dependences of the maximum normal stresses acting in the compressed and tensioned zones of the specimens on the intensity of applied vertical load: *(a)* second specimen; *(b)* fourth specimen, other designations as on Figure 10 [19]

The dependences obtained by the experiment are characterized by the shapes, which is closed to linear. The values of the maximum normal stresses, obtained by the experiment in the cement base finishing mass layer at the value of the vertical load in 30 kN, were equal to 27.70, 24.13, 21.05 and 22.90 MPa for the first, second, third and fourth specimens, correspondingly. The values of maximum normal stresses, obtained by the experiment in the cross-laminated timber base, were equal to 13.29, 12.60, 11.43 and 12.04 MPa for the first, second, third and fourth specimens, correspondingly. The difference between the maximum normal stresses obtained by the experiment and by FEM, which was realized by the software RFEM 5.13., exceed 9.54 % for the cement base finishing mass layer, placed in the compressed zone and 17.06 % for the cross-laminated timber base, placed in tensioned zone [19].

It can be concluded, that involving of the layer of cement-based finishing mass into the common work with the cross-laminated timber panel by the development of the rigid timber to concrete joint enables to obtain timber-concrete composite panel with increased load-carrying capacity. Load-carrying capacity of the cross-laminated timber panel, considered as the base of the timber-concrete composite panel, which was investigated in the current work, is equal to 22.60 kN in case, if the panel is loaded by the scheme, which is shown on the Figure 5 [24]. So, involving of the layer of cement-based finishing mass into the common work with the cross-laminated timber panel by the development of the rigid timber to concrete joint enables to increase the load-carrying capacity of the panel from 1.46 till 1.90 times.

4. Conclusions

Load-bearing capacity of timber-concrete composite panels subjected to flexure was study. The improvement of load-bearing capacity from the common work of the layer of cement-based finishing mass and CLT panel which is provided by the development of the rigid timber to concrete joint was analysed analytically and by experiment. Possibility to develop rigid timber to concrete joint by the using of the crushed granite pieces as the keys was checked by small-scale timber-concrete composite specimens subjected to flexure.

The results showed that:

1. The common work of timber-concrete panels provided by rigid joints enables to obtain composite panel with increased up to 1.9 times load-bearing capacity in comparison with CLT panel;
2. The using of the rigid timber to concrete joint instead of compliant ones enables to increase the load-bearing capacity of the small-scale from 16.55 to 50 %;
3. The increase of the crushed granite pieces from 2–5 to 16–25 mm enables to increase load-carrying capacity of considered specimens by 33.88%.

5. Acknowledgement

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Несущая способность деревобетонных композитных панелей

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Ключевые слова: жесткое соединение бетона с древесиной, испытание на изгиб, композитные конструкции, расчет конструкции, элемент крепления, материалы, армированные волокном, разрушение (механическое)

Аннотация. Деревобетонные композитные панели, благодаря своим преимуществам, являются одной из самых популярных альтернатив обычным плитам из чистого дерева или бетона. При анализе несущей способности деревобетонных композитных панелей, подверженных изгибу, важным компонентом является система соединения между слоем бетона и древесиной, которая влияет на распределение напряжений и деформации конструкции. Данное исследование включает в себя проверку возможности увеличения эффективности использования бетона и древесины, а также увеличения несущей способности деревобетонных композитных панелей путем создания жесткого соединения древесины с бетоном. Экспериментально проверена возможность образования жесткого соединения древесины с бетоном при использовании гранитного щебня в качестве шпонок. Работа под нагрузкой деревобетонных композитных панелей исследована при помощи метода приведенных сечений и метода конечных элементов, а также экспериментально. Четыре деревобетонные композитные панели были загружены статической нагрузкой до разрушения по схеме трехточечного изгиба. Варианты панелей с жестким и комбинированным соединениями древесины с бетоном были рассмотрены. Жесткое соединение бетона с древесиной было обеспечено при использовании гранитного щебня, приклеенного на поверхности поперечно ламинированных деревянных панелей при помощи эпоксидного клея. Размер частиц гранитного щебня менялся в пределах от 16 до 25 мм. Комбинированное соединение бетона с древесиной было обеспечено при использовании шурупов и гранитного щебня. Шурупы были размещены под углом 45 градусов относительно продольных осей поперечно ламинированных деревянных панелей, направление которых совпадает с направлениями волокон наружных слоев. Показано, что несущая способность деревобетонных композитных панелей в 1,9 раз превышает таковую для поперечно ламинированных деревянных панелей, использованных в качестве основы. Наибольшая несущая способность в 43 кН была получена для деревобетонной композитной панели с жестким соединением древесины с бетоном.

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