Behaviour of Timber-Concrete Joints in Hybrid Members Subjected to Flexure

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Abstract. Possibility to develop rigid timber-concrete joint for hybrid timber-concrete specimens was stated. Behaviour of timber-concrete rigid and compliant joints were evaluated numerically and by experiment for the members subjected to flexure. Small scale hybrid timber-concrete specimens with the length, width and thickness equal to 400, 95 and 43 mm were investigated for case of three points bending. The small-scale hybrid timber-concrete 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. 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. Dimensions of the crushed granite pieces changes within the limits from 2 to 25 mm. The compliant timber-concrete joint was provided by the screws with diameter and length equal to 4 and 40 mm, correspondingly. The screws were placed under the angles equal to 45 and 90 degrees relatively to the direction of fibres of the timber layers. Load-carrying capacity and maximum vertical displacements were gotten for groups of small-scale hybrid timber-concrete specimens with rigid and compliant timber-concrete joints. It was shown that providing of rigid timber-concrete joint enables to decrease 1.86 - 3.50 times the maximum vertical displacements of hybrid timber-concrete specimens. Load-carrying capacity of the specimens grows by 16.5 – 50.0% at the same moment.

1. Introduction
Combination of timber and concrete becomes enough popular especially during the last years [1-7]. Timber is used in combination with the concrete for producing prefabricated and cast in place load-carrying hybrid composite members subjected to flexure mainly. It can be beams or panels of floors and roofs mainly (figure 1).

Combination of timber and concrete enables to increase load-carrying capacity of structural members, it fire resistance and sound insulation. Load-carrying capacity of structural members grows so as protective or finishing layers of concrete or another cement-based 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 play a role of protective covering in the case [8]. Sound absorption of timber and concrete hybrid members grows so as timber has approximately three-time higher sound absorption coefficient in comparison with the concrete.
At the present moments exist two major types of timber to concrete joints. This are compliant and rigid ones. The compliant joints usually are realized by the mechanical fasteners but the rigid ones by the adhesives. Investigations of behaviour of timber to concrete joints indicates, that the hybrid structural members realized by the compliant and rigid timber to concrete joints, are characterized by the comparable load-carrying capacity [4-8]. But hybrid structural members realized by the rigid timber to concrete joints, are characterized by the increased rigidity. But theoretically hybrid structural member realized by the rigid timber to concrete joints, possess a potential for increase of its 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 [4]. More rational materials use and probable increase of the load-carrying capacity 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 [4]. Information regarding behaviour of the hybrid timber-concrete panels with rigid timber to concrete joints, which are solved by the adhesives, is enough miserable at the present moment. Comparison of behaviour of the hybrid timber-concrete panels created by the mechanical fasteners and adhesives is another question, which cause a certain interest. So, aim of the current study is to evaluate experimentally possibility to increase load-carrying capacity of the hybrid timber-concrete panels subjected to flexure with the rigid timber to concrete joint in comparison with the analogous members with compliant once. Behaviour of timber to concrete joints in hybrid timber-concrete panels subjected to flexure should be investigated for the purpose.

2. Choice of specimen’s parameters

2.1. Choice of type of mechanical fasteners for compliant timber to concrete joint

Several types of mechanical fasteners so as cuttings with the different shapes are widely used for compliant timber to concrete joints. The major variants of compliant timber to concrete joints, realized by the mechanical fasteners, are shown on figure 2 [4].

![Figure 2. Timber to concrete joints by the mechanical fasteners: (a) steel bars and screws; (b) tooth steel plates and punched steel plates [4].](image)

So, straight and curved steel bars, screws, placed vertically and under the angles so as tooth steel plates and punched steel plates can be mentioned as the major types of mechanical fasteners, used for compliant timber to concrete joints. The major shapes of cuttings used in combinations with the mechanical fasteners for compliant timber to concrete joints are shown on the figure 3 [4].
Figure 3. Timber to concrete joints by the cuttings and mechanical fasteners: (a) round and trapezium cuttings; (b) trapezium cuttings and timber boards joined by the nails with steel plates [4].

So, specimens where compliant timber to concrete joint will be provided by the screws are chosen for the investigations. Three variants of the screw’s placement were considered. The screws were placed under the angles 90° and 45° relatively to longitudinal axis of the specimens, correspondingly, for the two first variants. Two screws were placed in each point under the angle 45° relatively to longitudinal axis of the specimens, for the third variant [9].

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.

Twelve small scale hybrid timber-concrete specimens were prepared with compliant timber to concrete joint provided by the screws with length and diameter equal to 40 and 4 mm, correspondingly. Three sub-groups by the four specimens in the each were prepared with the screw’s placement by the variants, which are shown in figure 4. Specimens have the length, width and thickness equal to 400, 95 and 43 mm, correspondingly. The small-scale hybrid timber-concrete 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/m3, correspondingly. Its strength class is C20 C.

Figure 4. Considered variants of screws placement: (a) screws were placed under the angle 90° relatively to longitudinal axis of the specimens; (b) screws were placed under the angles 45°; (c) two screws were placed in each point under the angle 45° [9].

2.2. Description of specimens with rigid timber to concrete joint

The rigid timber to concrete joint can be provided by the glue and different elements, which can be used to provide additional mechanical bonds between the timber and concrete. Possibility to obtain rigid timber to concrete connection by the glue only was investigated before [10]. Possibility to develop a hybrid timber to concrete member by the gluing together cross-laminated timber (CLT) panel and prefabricated panel from the cement base finishing mass Sacret BAM by the epoxy glue Sica Dur 330 was considered [10]. CLT panel consisting from three layers of С24 strength class timber with thickness in 20 mm each and total thickness in 60 mm was glued together with the prefabricated panel from the cement base finishing mass Sacret BAM with thickness in 30 mm. Length of the panels was equal to 2 m. The panels were freely supported with the span equal to 1.8 m and loaded by the three-point bending
scheme, as it is shown on the figure 5 c). Six such hybrid timber to concrete specimens were prepared and tested for getting it real load-carrying capacities (figure 5). The maximum vertical displacements of the specimens were predicted by the transformed section method as for the members with the rigid timber to concrete joint. The difference between the results obtained by the transformed section method and by the experiment does not exceeds 7 %. It enables to conclude, that rigid timber to concrete joint was obtained. But during the test and after failure of the prepared specimens it was stated, that the contact between the CLT panel and prefabricated panel from the cement base finishing mass was not obtained by all the surface. So, variant, when the bonds between the timber and concrete will be provided by the pieces of crushed granite joined with the surface of timber by the glue and playing the role of keys is considered in the current investigation. Existence of such keys should increase the effectiveness of the timber to concrete joint and load-carrying capacity of the hybrid member subjected to flexure.

Twelve small scale hybrid timber-concrete specimens were prepared with rigid timber to concrete joint. 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 with the different dimensions of the pieces of crushed granite, which are shown in figure 6.

The pieces of crushed granite were joined with the surface of the timber by the glue, as it is shown on figure 6. 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 specimens with rigid timber to concrete joint are the same as for the specimens with the compliant joints, which were explained above [9].
3. Description of laboratorian experiment

Twenty-four small scale hybrid timber-concrete specimens were tested by the scheme of three point bending at the action of static loading (figure 7). All of the twenty four small scale hybrid timber-concrete specimens of both considered groups have the same dimensions of cross-sections, what is necessary to evaluate behaviour of compliant and rigid timber to concrete joints and to have possibility for comparison of results. Values of the lengths and spans for all the specimens were also the same and equal to 400 and 300 mm, correspondingly (figure 7 (a)). The specimens were tested after twenty-eight days from the specimen’s formation.

Intensity of the concentrated force applied in the middle of the specimens span and maximum vertical displacements are two parameters, which were taken under the control during the experiment. The expected load-carrying capacities of the specimens were previously determined by the using of transformed section method [11]. The maximum vertical displacements were measured by two mechanical indicators placed in the middle of the span (figure 7 (a)).

![Figure 7](image1.png)

**Figure 7.** Testing of hybrid timber-concrete 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 [9].

Precision of the maximum vertical displacements measurements was equal to 0.01 mm. All the specimens were loaded till 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 [9]. All the specimens were loaded till the failure.

4. Behaviour of timber-concrete joints in hybrid members subjected to flexure

The experiment was carried out for two groups of specimens which are divided into three sub-groups each. Each from the six sub-groups consists from four specimens. The difference between the specimens of the sub-groups for rigid timber to concrete joint is joined with the dimensions of the granite pieces dimensions (figure 6). The difference between the specimens of the sub-groups for compliant timber to concrete joint is joined with the screw’s placement (figure 4) [9].

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. The maximum vertical displacements as a function from the vertical load for the all sub-groups of tested specimens which are differed by the screw’s placement and crushed granite pieces dimensions are shown on figure 8. The final point for each graph corresponds to the mean load-carrying capacity of the each sub-group of specimens. Each point on the graphical dependences was obtained as the mean value obtained for all specimens of the sub-group [9].

The values of scatters for the specimens with the compliant concrete to timber joints were observed within the limits from ± 0 to ± 0.07 mm. The scatters for the sub-groups of specimens where the screws were placed under the angles 90º and 45 º relatively to longitudinal axises, changes within the limits from ± 0 to ± 0.06 mm and from ± 0.03 to ± 0.07 mm, correspondingly. The scatter for the sub-groups of specimens where two screws were placed in each point under the angle 45 º relatively to longitudinal axis, changes from ± 0.03 to ± 0.06 mm [9].

The values of scatters for the specimens with the rigid concrete to timber joints were observed within the limits from ± 0.01 to ± 0.06 mm. The scatters for the sub-groups of specimens where the dimensions
of the pieces of crushed granite, changes within the limits from 2 to 5mm, 5 to 8 and 16 to 25 mm, were within the limits from ± 0.02 to ± 0.03 mm, ± 0.02 to ± 0.06 mm and from ± 0.01 to ± 0.03 mm, correspondingly [9].

**Figure 8.** The maximum vertical displacements as a function from the vertical load for the all sub-groups of tested specimens [9].

Comparison of the dependences shown on the figure 8 enables to conclude, that the most rigid specimens are sub-group with the rigid timber to concrete joint with the dimensions of the crushed granite pieces changes within the limits from 16 to 25 mm. The maximum mean vertical displacement for the specimens of this sub-group under the action of vertical concentrated force equal to 12 kN is equal to 2.34 mm. It is 5.13 and 7.26% less, than the vertical displacements of specimen’s subgroups, where dimensions of crushed stone pieces changes within the limits from 5 to 8 mm and from 2 to 5 mm, correspondingly. So, influence of the dimensions of the crushed stone pieces on the maximum vertical displacements of the specimens subjected to flexure is insufficient. But it can be stated, that using of the rigid timber to concrete joint instead of compliant ones, enables to decrease maximum vertical displacements of the specimens subjected to flexure from 62.55% to 3.39 times. These results confirm the conclusion regarding increased stiffness of the hybrid timber to concrete members with the rigid timber to concrete joint in comparison with the analogous members, where the joint is compliant [9].

The maximum load-carrying capacities obtained for the all sub-groups of specimens are shown on the figure 9. Each from the six load-carrying capacities was determined as the mean value obtained for the four specimens of the each sub-group. The values of load-carrying capacities for the sub-groups of specimens where the screws were placed under the angles 90° and 45 ° relatively to longitudinal axises, changes from 8.40 to 12.60kN and from 9.40 to 11.80kN, correspondingly. The mean values of load-carrying capacities for the sub-groups are equal to 10.8 and 11kN, correspondingly. The load carrying capacity for the sub-group of specimens where two screws were placed in each point under the angle 45 ° relatively to longitudinal axis, changes from 13.60 to 14.00kN, correspondingly. The mean value of load-carrying capacities for the sub-group was equal to 13.9kN (figure 9) [9].

The values of load-carrying capacities for the sub-groups of specimens where the dimensions of the pieces of crushed granite, changes within the limits from 2 to 5mm, 5 to 8 and 16 to 25 mm, were within
the limits from 11.20 to 12.80kN, from 12.00 to 13.40kN and from 15 to 17.8kN, correspondingly. The mean values of load-carrying capacities for the sub-groups are equal to 12.10kN, 12.90 kN and 16.20kN, correspondingly (figure 9) [9].

![Figure 9. Maximum load-carrying capacities obtained for the all sub-groups of specimens [9].](image)

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 hybrid timber to concrete 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%. So, possibility to increase load-carrying capacity of the hybrid timber-concrete members subjected to flexure with the rigid timber to concrete joint in comparison with the analogous members with compliant once was checked and confirmed experimentally.

5. Conclusions
Possibility to increase load-carrying capacity of the hybrid timber-concrete members subjected to flexure with the rigid timber to concrete joint in comparison with the analogous members with compliant once was checked and confirmed experimentally. It was stated, that using of the rigid timber to concrete joint instead of compliant ones, enables to increase the load-carrying capacity of the hybrid timber to concrete 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%.

It was stated, that using of the rigid timber to concrete joint instead of compliant ones, enables to increase the rigidity of the hybrid timber to concrete specimens subjected to flexure from 62.55% to 3.39 times. Increase of the crushed granite pieces from 2-5 to 16-25 mm enables to decrease maximum vertical displacements of considered specimens by 7.26 %.

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