TIMBER-CONCRETE COMPOSITE STRUCTURES WITH PREFABRICATED FRC SLAB

Roberto Crocetti¹, Tiziano Sartori², Mathias Flansbjer³

ABSTRACT: This study relates to the development of innovative composite structures, comprising timber beams and prefabricated concrete slabs, with high prefabrication level, high performance and good durability. For such a purpose completely dry shear connection systems were investigated. Moreover, innovative and very efficient materials, such as fibre reinforced concrete and modified wood were used for the manufacture of the specimens. The investigated shear connectors were; i) shear anchor-key of wood and ii) special inclined steel tubes. In both cases, the connectors are incorporated in the prefabricated concrete slab, which then easily is connected to the timber sub-structure only by means self-tapping screws. Both types of connectors exhibited a great performance, both in terms of strength, stiffness and ductility. The results from this project will allow the use of timber-concrete composite beams more effectively in large-span structures and also contribute to both simple and rapid manufacture and erection.

KEYWORDS: Shear connection, timber-concrete structure, dry connection, modified wood, FRC concrete

1 INTRODUCTION

Satisfactory strength and stiffness properties are among the most important prerequisites for a timber-concrete composite structure. However, only these properties are in general not enough to guarantee the success of the structure. In fact, besides strength and stiffness, also other aspects must be considered in the design of timber-concrete composite structures, such as i) ductility and ii) simplicity and rapidity of manufacture and erection.

A valid technique - for achieving both high strength and stiffness properties, which at the same time allows for a simple and rapid manufacture and erection - is the use of prefabricated concrete slabs. Only a few investigations have been performed on timber-concrete beams with prefabricated slab. These studies entail the use of concrete slabs with pockets (or holes) for the shear connectors. The empty pockets need then to be filled by adequate material, e.g. non-shrinking concrete. Therefore, the method may be quite time consuming due to the fact that the filling material needs time, both in order to be poured in the pockets, but also time for curing, before a paving layer/water-proof insulation can be applied on the top of it.

The investigation presented herein focus on the use of composite structure with high prefabrication level, high performance and good durability. For such a purpose completely dry connection systems are investigated, i.e. systems where the prefabricated concrete slab is connected to the timber sub-structure only by means of self-tapping screws. Moreover, the use of very efficient materials – such as modified wood (furfurylated) and fibre reinforced concrete (FRC) – is investigated.

1.1 BACKGROUND

The behaviour of composite timber-concrete beam is bounded by two extreme stiffness limits (see [1]), namely:

i) A lower limit, where no horizontal force transfer occurs between the two layers, i.e. “fully non-composite action”. In this case the two layers of the cross section, i.e. the concrete layer and the timber layer, move independently one to the other. The cross section will then have two individual neutral axes and discontinuous bending strain at the interface.

ii) An upper limit where the composite cross section has a single neutral axis and the bending strain at the interface between layers are identical, i.e. “fully composite action”.

During bending of a real composite timber beam, horizontal relative displacement (slip) occurs at the interface between the two materials. Slip reduces the efficiency of the composite structure with regard to both stiffness and strength. The structural behaviour of such a beam is something in between a fully non-composite situation and a fully composite situation. Such behaviour is referred to as “partial composite action”.

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1.2 AIM SCOPE AND LIMITATIONS

The principal aim of this study is to develop a new innovative timber-concrete composite structure with prefabricated concrete slabs that has a high prefabrication level, high performance and good durability. The scope is to perform both numerical and experimental investigation on the load-slip behaviour of innovative shear connectors between timber and fibre reinforced concrete (FRC) [2]. The investigation presented herein is limited to the study of load-slip behaviour of different shear anchor-keys and shear-loaded timber-concrete specimens.

2 STATE OF THE ART

The very first applications of timber-concrete composite concerned the refurbishment of existing timber floors. Several examples of this kind of intervention are reported in the literature. In [3] and in [4], for example, different types of shear connectors for refurbishment of ancient timber structures are shown, along with the achieved improvement in structural efficiency. During the last decades, several research studies have been conducted, with focus on design methods of new timber-concrete composite floor and bridges. These research works have provided a base of engineering data needed for practical applications. The competitive merit of such composite structures is borne out by several examples of successful projects decks both in Europe but also overseas.

In literature there are several studies that primarily focus on load-slip behaviour of different types of shear connector ([5] and [6]). However, the major part of these studies is based on the use of cast-in site concrete slab. A very few researchers have investigated on the possibility to using prefabricated concrete slabs connected to timber beams. On the other hand, this technique has been used both in USA and Europe in steel-concrete composite structures, since the beginning of the 1980’s. Experience has shown that steel-concrete composite structures with prefabricated decks offer several advantages, such as faster erection time, higher quality, better working environment and a dry bridge deck surface [7], [15]. When it comes to timber-concrete composite bridges, large amount of work has been conducted in Finland which included development of various tests methods for shear connectors. Recently some investigations [5], [12] have been performed at the technical University of Luleå, Sweden, focusing on the development of connector technologies for timber-concrete composite structures that are suitable only to prefabricated slabs. This research shows that the improvement perspectives of such a technique are enormous, but new possible solutions need to be tested. According to [5] and [12], the use of a prefabricated concrete slab implies several advantages such as a better material control, time saving and also, consequently money saving, etc.

3 PRELIMINARY INVESTIGATIONS

Before starting the investigations on timber-concrete systems, some preliminary tests were performed on “pure” shear anchor-keys in order to study the suitability of such shear connectors. Finite element analyses were carried out, before testing, in order to obtain a qualitative estimation concerning the behaviour of the connections.

3.1 INVESTIGATIONS ON WOODEN SHEAR ANCHOR-KEYS

A total of six specimens, each consisting of a piece of wood (shear anchor-key) connected to a timber member were tested, see Figure 1. For two specimens (G45_1, G45_2) the shear anchor-key was connected to the timber member by means of screws and glue together, whilst for the remaining four specimens (W45_A, F45_1, F45_2, F45_3) only screws were used.

![Figure 1: The shear anchor-key specimens](image1)

![Figure 2: Pictures of the test set-up for shear anchor-key tests](image2)
3.2 QUALITATIVE NUMERICAL ANALYSES

Three types of shear connections were investigated, namely:

- Connections with steel tubes, “T-system”, see Figure 3.
- Connections with wooden anchor-keys and “X-placed” self-tapping screws, “W30-system”, see Figure 4.
- Connections with wooden anchor-keys and self-tapping screws placed with an angle of 45°, “W45-system”, see Figure 5.

The Finite element analyses were performed with ABAQUS/Standard. For each type of connection a three dimensional model was created and every single part was modelled separately by solid elements. The model of the simulated systems are shown in Figures 3, 4 and 5, respectively.

The withdrawal behaviour of the screw was simulated by means of tie constraints placed between the outer surface of the screw and the inner surface of the hole in the timber.

The main findings obtained from the FE-analyses are:

- The connections type T with steel tubes showed less slip at the interface between timber and concrete than the other models. From the model it was also clear that a critical part can be the screw head where there is a stress concentration.
- The connection type W30 with “X-placed” screws indicated a significant rotation of the wooden shear anchor-key due to the inclination of the edge that is in contact with concrete.
- The connection type W45 with parallel screws with an angle of 45° showed a satisfactory behaviour and no significant local deformation in the wooden part.

4 LABORATORY TESTS ON TIMBER-CONCRETE SPECIMENS

Shear tests were performed on four series of different types of connectors, see Figure 6. A total of eight specimens were tested in order to investigate the load-slip behaviour of the connectors. The test set-up is shown in Figure 7.

<table>
<thead>
<tr>
<th>Property</th>
<th>[MPa]</th>
<th>Property</th>
<th>[-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_1$</td>
<td>12600</td>
<td>$\nu_{12}$</td>
<td>0.37</td>
</tr>
<tr>
<td>$E_2$</td>
<td>200</td>
<td>$\nu_{13}$</td>
<td>0.42</td>
</tr>
<tr>
<td>$E_3$</td>
<td>300</td>
<td>$\nu_{23}$</td>
<td>0.47</td>
</tr>
<tr>
<td>$G_{12}$</td>
<td>630</td>
<td>$\nu_{11}$</td>
<td>0.04</td>
</tr>
<tr>
<td>$G_{13}$</td>
<td>592</td>
<td>$\nu_{21}$</td>
<td>0.03</td>
</tr>
<tr>
<td>$G_{23}$</td>
<td>100</td>
<td>$\nu_{22}$</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Figure 6: The timber-concrete specimens
As it can be seen in Figure 7 an asymmetric test set-up was used for this study. Such a set-up is simpler to construct than a symmetric test set-up, in which two concrete slabs and a central timber element are used. On the other hand, a shortcoming of the asymmetric test set-up configuration is that it leads to an overestimation of approximately 10% both in terms of shear strength and of slip modulus, if compared to a symmetric test set-up [12].

The load was applied to the wood beam via a 10 mm thick steel plate with an area of 80x80 mm². The edge of the concrete slab was placed on an L shaped support. A thin strip of fibreboard was placed between the support and the concrete surface in order to evenly distribute the contact stresses. A low friction sliding support was used to minimize the vertical friction force at the upper horizontal support. The relative displacement between the beam and the slab was measured at mid-height of the specimen, at both side of the timber member. The load and the displacements were recorded continuously during the test with a frequency of 10 Hz.

The loading procedure was carried out according to EN 26891:1991 [10]. The first load cycle, up to 0.4F⁰est and back to 0.1F⁰est was carried out in load control and the subsequent loading to failure in displacement control. The load was maintained constant for approximately 30 s between loading and unloading phases.

4.1 MATERIALS AND GEOMETRIES

The specimens were designed taking into account the findings obtained in the preliminary study. The geometric properties of the specimens are resumed in Figure 8.

The amount of steel fibres used for the manufacturing of FRC slabs was 45 kg/m³. The aspect ratio of the fibres was l/d=6.3, where l is the length and d is the diameter. The shape of the fibres is shown in Figure 9.

Six standard cube tests with dimensions 150x150x150 mm³ were performed in order to measure the compressive strength of the steel fibre reinforced concrete. The results are resumed in Table 2. The first three specimens were tested 28 days after manufacturing of the cubes, whilst the last three specimens were tested later, i.e. at the same day when tests on the timber-concrete specimens were performed.

The timber used for all specimens was glulam L40 (similar to the European class GL32), which consists of laminations of Norway spruce with characteristic tensile strength parallel to the grain, fₜ₀,k ≥ 22 MPa and bending strength of the finger joints fₘ,j,k ≥ 39 MPa. The mean density of the specimens was ρₘ=490 kg/m³ and it was obtained at current moisture content MC = 13%.

The material used to manufacture the shear anchor- keys for specimens type W45, W30 and G45 was spruce with strength class C24. The moisture content was 14%. The material used for manufacturing the shear anchor-key of specimens type F45 was furfurylated beech. Furfurylation is a wood modification process, using furfuryl alcohol, obtained from renewable resources of corn cobs or sugar cane residuals. Due to its polarity, furfuryl alcohol can penetrate into the cell wall, where it polymerizes. Furfurylation of wood provides a high protection level against bio-degradation. Beside the biore sistance, wood properties like dimensional stability and hardness are significantly improved by the furfurylation of wood. These wood properties depend on the amount of furfuryl alcohol that is brought into the cell wall. Figure 10 summarizes the furfurylation process [9] and [13].

Figure 8: Geometry of the timber-concrete specimens

Figure 9: Steel fibres
The mean density of the furfurylated wooden shear anchor-keys was 885 kg/m³.

The material used for the manufacturing of the steel tubes for specimens type T12 and T14 was ordinary steel S355.

Full threaded screws with different dimensions were used in order to connect the concrete slab with the timber element, namely:

- Screws 11x250 for connections type T (i.e. connections with tubes).
- Screws 7x180 for connections type W, G and F (i.e. connections with wooden shear anchor-key).

The screws used in this study were laboratory tested at University of Trento, Italy, in March 2008 [14]. The mean value for the ultimate tensile strength was $f_u = 1256$ MPa.

### 4.2 CONNECTIONS TYPE T: SHEAR CONNECTORS WITH STEEL TUBES

For connections type T (see Figure 11), special steel tubes were applied in the formwork before the prefabricated concrete slab was cast. In order to achieve a better stiffness, the tubes had an inclination of 45° to the longitudinal axis of the beam. The principal dimensions of the steel parts of connections type T are shown in Figure 12.

**Figure 10: Product process of furfurylated wood**

The material used for the manufacturing of the steel tubes for specimens type T12 and T14 was ordinary steel S355.

**Figure 12: Steel tubes geometry**

Approximately one month after the concrete was cast, the prefabricated slab was placed on the top of timber members. Successively, self-tapping screws with dimensions $d=11\text{mm}$ and $l=250\text{mm}$ were driven in the steel tubes and tightened to the timber sub-structure using a torque wrench. The screws were pre-tensioned with a torque moment of 160 Nm.

Two types of configurations were adopted for the connections type T, namely:

- Connection type T12, with tube diameter of $12\text{mm}$.
- Connection type T14, with tube diameter of $14\text{mm}$.

Nominally identical full-threaded screws were used for both types of T-connections. However, fast setting cement (Quik-Rok® Fast Setting Cement) was poured into the tube for the case of connections type T14, immediately before the screw was tightened. This was done in order to fill the gap between the screw and the tube. On the contrary, no fast setting cement was used for connections type T12. The static principle of connections “type T” is shown in Figure 13.

**Figure 11: Steel tubes in the formwork before concrete casting**

**Figure 13: Illustration on the load path in the connection type T**

The shear force $V_T$ is transferred from the concrete slab to the timber beam both by shear action $F_s$ – in the direction of the force $V_T$ – and by tension action $F_T$ – in the direction of the screw axis. In the wooden part, shear is resisted by embedment capacity of the wood, while tension is resisted by withdrawal capacity. In the concrete slab, shear is resisted by contact pressure between the screw and the internal part of the tube, while tension is resisted by axial pressure of the screw head on the top of the tube, via a steel washer. Due to the
inclination of the screws, compression stresses will develop at the interlayer between timber and concrete. Such compression stresses generate friction between the two materials, which also contributes to increase the stiffness and the strength of the timber-concrete connection.

4.3 CONNECTIONS TYPE W: SHEAR CONNECTORS MADE OF WOODEN ANCHOR KEYS

For connection “type W”, see Figure 14, wooden shear anchor-keys were applied in the prefabricated slab before concrete was cast. Self-tapping double threaded screws with dimension 6.5x220 were driven in the anchor-keys, perpendicularly to the direction of the applied load, before concrete casting. Such screws have two main functions, namely:
- Proper anchorage of the shear anchor-key to the concrete slab.
- Reduce the risk for splitting of the anchor-key during loading of the specimen.

Approximately one month after the concrete was cast, the prefabricated slab was placed on the top of the timber members. Successively, self-tapping screws with dimensions $d = 7$ mm and $l = 180$ mm were driven through the shear anchor-key to the timber sub-structure.

![Figure 14: Wooden shear anchor-key before concrete casting. Left: W45-type. Right: W30-type.](image)

The geometry of connection type W45 along with the used screws, are shown in Figure 15.

![Figure 15: Illustration of the W45 system](image)

The static principle of connection type W45 is shown in Figure 16. The shear force $V$, is transferred from the concrete slab to the timber beam both by shear action $F_s$ – in the direction of the force $V$ - and by tension action $F_{tens}$ – in the direction of the screw axis. Both in the wooden shear anchor-key and in the timber member, shear is resisted by embedment capacity of the wood, while tension is resisted by withdrawal capacity. Due to the inclination of the screw, compression stresses will develop at the interlayer between timber and concrete. Such compression stresses generate friction between the slab and the timber member, which also contributes to increase the stiffness and the strength of the timber-concrete connection.

![Figure 16: Illustration on the load path in the W45 system](image)

The geometry of connection type W30 along with the used screws, are shown in Figure 17.

![Figure 17: Illustration of the W30 system](image)

The static principle of connection type W30 is shown in Figure 18 and it is rather similar to the static system of connection type W45. The main difference is that, during loading, in the connection type W30 two screws act in tension while the other two screws act in compression, see Figure 18. On the other hand – connection type W45- – all screws act in tension during loading.

![Figure 18: Illustration of the load path in the W30 system](image)
5 TEST RESULTS

The tests were carried out at SP Technical Research of Sweden, division Building and Mechanics during September 2009. The load-slip curves for the tested specimens are shown in Figures 19, 20, 21 and 22.

5.1 SPECIMENS WITHOUT CONCRETE SLAB

As it can be seen in Figure 19, the shear anchor keys made of furfurylated wood (specimens F45) exhibited higher stiffness and higher load capacity compared to similar shear anchor-keys made of spruce. An examination of the specimens after the tests revealed that – for the case of furfurylated shear anchor-keys – failure occurred due to reached withdrawal capacity of the screws at the timber member. Whereas, for the case of shear anchor-keys made of spruce, failure occurred due to reached withdrawal capacity at the wooden anchor-keys.

For the two specimens where the shear anchor-key was connected to the timber member by means of screws and glue together (specimens G45) the initial stiffness was very high, as it was expected, see Figure 20.

Both failure at the glue line and withdrawal failure of the screws, occurred at similar load level. Due to very high stiffness of the glue, the first failure occurred at the glue line. Successively, the load transmission from the anchor-key to the timber member was shifted from the glue line to the screws. From this point, the load-slip behaviour of these specimens was very similar to the behaviour of similar specimens where no glue was used (i.e. W45_A). The final failure, also for this case, occurred due to reached withdrawal capacity of the screws at the shear anchor-key.

5.2 SPECIMENS WITH CONCRETE SLAB

The load-slip behaviour of specimens type W45 was nearly linear up to approximately 30 kN, see Figure 21. On the other hand, the specimens type W30 exhibited almost immediately a nonlinear load-slip response. The discrepancy in behaviour between of these two types of specimens is mainly due to the rotation of the shear anchor-key in the slab, which takes place for the case of specimens type W30, as also explained in section 3.2. Specimens type W45 showed a significantly higher load-carrying capacity and a higher stiffness than specimens type W30. The final failure for specimens of type W45 occurred due to reached withdrawal capacity of the screws at the shear anchor-key. On the other hand, the final failure for specimens type W30 occurred mainly due to large rotation of the shear anchor-key.

Both highest failure load and highest stiffness of all tested specimens was obtained for the T-specimens, see Figure 22.
specimens occurred after rather large deformations, either i) due to splitting of the timber member into two pieces, along the direction were the screws were driven or ii) due to tensile failure of the screws.

5.3 STIFFNESS AND STRENGTH FOR THE DIFFERENT TESTED CONNECTIONS

During loading of the specimens, both stiffness and failure loads were recorded for each tested specimens. The procedure to obtain stiffness and failure load from the load-slip curves is indicated in Figure 23.

![Figure 23](image)

Figure 23: Procedure to obtain $K_{0.4}$, $K_{0.6}$ and $F_{\text{max}}$ from a load-slip curve

In Table 3, stiffness and failure load for a single connector are shown. For the case of G-type, F-type and W-type specimens, the values reported in the table are those for strength and stiffness of the entire system (i.e. anchor-key plus four screws). For the case of T-specimens, the values reported in the table are those for strength and stiffness of only a single screw.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>$K_{0.4}$ [kN/mm]</th>
<th>$K_{0.6}$ [kN/mm]</th>
<th>$F_{\text{max}}$ [kN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>F45_1</td>
<td>48</td>
<td>36</td>
<td>48</td>
</tr>
<tr>
<td>F45_2</td>
<td>57</td>
<td>43</td>
<td>46</td>
</tr>
<tr>
<td>F45_3</td>
<td>42</td>
<td>29</td>
<td>55</td>
</tr>
<tr>
<td>Mean F45</td>
<td>49</td>
<td>36</td>
<td>50</td>
</tr>
<tr>
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<tr>
<td>Mean T14</td>
<td>45</td>
<td>34</td>
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</table>

Table 4 gives an indication of stiffness and failure load that can be achieved for a meter of a hypothetical timber-concrete composite beam, if the tested shear connections were to be used. The following assumptions were made:
- Four shear anchor-key per meter, for F45, G45, W45 and W30 connections.
- Ten screws per meter, for T-connections.

Such assumptions were made on the basis of practical issues, when considering a possible application of the studied shear connectors in real floor structures.

<table>
<thead>
<tr>
<th>System</th>
<th>Anchor-key or screw/m</th>
<th>$K_{0.4}$ [kN/mm/m]</th>
<th>$K_{0.6}$ [kN/mm/m]</th>
<th>$F_{\text{max}}$ [kN/m]</th>
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<tbody>
<tr>
<td>F45</td>
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<td>199</td>
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<tr>
<td>T14</td>
<td>10</td>
<td>450</td>
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<td>438</td>
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</table>

6 DISCUSSION

The shear tests performed on specimens without concrete slab showed that shear anchor-key made of furfurylated wood behaved considerably better - both in terms of strength and stiffness - than anchor-keys made of spruce, see Figure 24.

![Figure 24](image)

Figure 24: Comparison between test on the specimen made of spruce (W45_A) and specimens made of furfurylated wood (F45_1)

The main reason for this discrepancy in behaviour between the two materials is the fact that density of furfurylated wood is approximately twice the density of spruce. Consequently, the withdrawal capacity is larger for screws that are driven in furfurylated wood than for screws driven in spruce. In the case of spruce, the screws were gradually pushed-in through the shear anchor-key during loading. Eventually, the specimen failed due to complete push-in (read: reached withdrawal capacity) of the screw through the shear anchor-key. In the case of furfurylated wood, on the contrary, no visible push-in of the screw through the shear anchor-key could be observed. Eventually, failure occurred in the timber
member, due to reached withdrawal capacity of the screw. Furfurylated wood has a rather brittle behaviour. However, no tendency to split was observed during testing. In the experiments, double threaded screws were driven in advance in the furfurylated wood – in predrilled holes – perpendicularly to the direction of the applied load. This precaution turned out to be very effective for preventing premature splitting.

Pure withdrawal tests on screws of the same type as the screws adopted for this study were performed at the University of Trento [14]. The screws tested at the University of Trento were driven in the wood both parallel and perpendicularly to the grain. It should be noted here that the load-testing machine used in Trento had some problems with the grip. In fact, a full action of this grip on the screw head was only achieved after an initial deformation in the order of magnitude 0.5-1 mm.

This is the reason why the curves for the pure withdrawal tests have a lower gradient during the initial phase of loading.

Figure 25 and Figure 26 show the load-slips curves for:

i) Laboratory withdrawal tests on single screws inserted perpendicularly and parallel to the grain. (These tests were performed at the University of Trento).

ii) For one screw of a W-type specimen (Figure 25) and a T-type specimen (Figure 26)

The screws in Figure 25 had a diameter of 7 mm and a penetration depth of 70 mm. On the other hand, the screws in Figure 26 had a diameter of 11 mm and a penetration depth of 176 mm.

Disregarding the initial phase of the load-slip curves for the “pure” withdrawal tests due to the abovementioned problems related to the grip of the testing machine, the following observation can be made:

- The stiffness of a single screw of W45-type specimens is similar to the stiffness of a similar screw that is tested for withdrawal capacity.
- The strength of a single screw of W45-type specimen is larger than the strength of a similar screw tested for withdrawal capacity.
- A single screw of T-type specimen has both larger stiffness and larger strength than that of a similar screw tested for withdrawal capacity.

The reasons for the abovementioned discrepancies can be attributed to the following reasons:

- During loading, the screws of either W45-type specimens or T-type specimen , are taking the applied load not only to pure axial stress, but also by shear, which increase both strength and stiffness of the connection.
- In both W45-type specimens and T-type specimens, compression stresses will develop at the interlayer between timber and concrete during loading. Such compression stresses generate friction between the slab and the timber member, which also contributes to increase the stuffiness and the strength of the connection (see section 4.2 and 4.3).

The very high stiffness observed at the initial stage of loading in T-type specimens can be attributed to the precompression generated by the applied torque moment on the screws. Such a precompression generates a large friction between the timber member and the concrete slab, which contributes to increase the stiffness.

7 CONCLUSIONS

In this study an analysis of properties of an innovative prefabricated timber-concrete composite system, with different types of shear connectors was presented. Preliminary shear tests were performed on specimens without concrete slab, i.e. consisting of solely i) a timber member and ii) a wooden shear anchor-key made either of spruce or furfurylated beech. Successively, shear tests
on timber concrete specimens with different shear connectors were performed. The investigated shear connectors in this case were:
i) Shear anchor-key of spruce with different geometries.
ii) Special steel tube (with and without fast setting cement filling).

On the basis of the obtained resultants, the following general conclusions can be drawn:
- Furfurylated wood has both mechanical and physical properties that make it suitable for applications for shear anchor-key connections.
- In all tests where shear anchor-keys of soft wood were used, failure occurred due to reached withdrawal capacity at the anchor-key. On the contrary, withdrawal failure occurred at the timber member, when furfurylated wood was used.
- Type-W30 connections are not completely suitable as shear connectors for timber-concrete structures, mainly due to the large rotations that occur at the anchor-key during loading.
- Type-T connections have revealed to be very suitable for applications in prefabricated timber-concrete composite structure, due to their extremely high strength and stiffness.
- In type-T connections, the use of tubes with larger dimension and then filling the gap between the tube and the screw with fast setting cement only slightly increases strength and stiffness of the connection.

It is worth to point out that all tested specimens are very easy to manufacture. It is believed, therefore, that the proposed shear connections are very suitable for applications in timber-concrete composite structures with prefabricated slab.

ACKNOWLEDGEMENT
The authors wish to gratefully acknowledge the financial support for the project granted by the Lars Erik Lundberg Scholarship Foundation and by SP, Technical Research Institute of Sweden, division Building and Mechanics, Borás, Sweden. The timber material was supplied by the glulam mill Moelven Töreboda AB, Töreboda, Sweden and the screws by the company Rotho Blaas srl, Cortaccia, Italy. Both companies are kindly acknowledged.

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