Development of new wood-concrete connectors

A. Khelil, C. Kiniagi and R. Boissière
IJL, UMRS CNRS 7198, Université de Lorraine, France
Email: abdel.khelil@univ-lorraine.fr

Abstract. The application of timber-concrete composites (TCC) connections in structures has increased over the past decades. The mechanical behaviour of these connections is largely influenced by the stiffness of the joints, both with regard to deformations and strength. This paper presents laboratory experiments and numerical simulations using ABAQUS performed on TCC with a new connector that has been developed in our laboratory. Collapse tests of Shear (push-out) tests, four-point bending tests on beams with different configuration and spacing are carried out within the serviceability load range to verify the slip modulus of connections which were derived from the push-out tests. Although the new connection is applied on notched timber, both experiments and 3D FEM simulations showed that the new connector exhibits stronger stiffness and has a significantly higher peak force performance in constructing both.

1. Introduction
The assembly of Timber-concrete composite (TCC) structures efficiently optimizes the structural performance of buildings and bridges by technically improving the strength and stiffness of the system as a whole thereby reducing construction cost of buildings and bridges, as well retrofitting and strengthening of existing structures [1, 2, 3]. Timber has to its lower density in compared to reinforced concrete, therefore this decreases the total weight of these hybrid structures hence having several advantages over reinforced concrete floors which include; better efficiency in terms of load applied increase in the rigidity which improves the seismic performance of the overall structure. Compared to concrete structures, TCC significantly reduce CO2 emissions through a sequestration process because Timber can act as a carbon store depending on its end of life treatment [4]. So generally the concrete slab increases the overall stiffness and reduces the structure’s vibrations, while the timber beam provides the resistance and improves the environmental impact and the aesthetic of the structures. This structural assembly is achieved by the union of a timber joist to a reinforced concrete slab through connectors, whereby the concrete slab and timber joist mainly resist compression and tension forces, respectively, and the connection provides a mechanism for the transfer of shear. The bond mechanical behaviour has a direct influence on the most important mechanical properties of the composite system, namely load-carrying capacity, stiffness and ultimate deformation capacity. Among the bond properties, the ones with the greatest influence on the mechanical behaviour of the composite system are the load-carrying capacity, stiffness and ductility. Experiments carried out by numerous researches cover various local and global aspects of this behaviour. Local aspects include the joints and connections which are effected by the connection type and the timber interlayers strength, ductility and stiffness of TCC beams [5], application of different types of concrete namely light-weight (LW) and normal-weight (NW) concrete [6] while global aspects are such as the various timber types in TCC beams which have been studied. [7]
2. Concept of a new composite connector
Over the past decades, there has been development of various new connectors and the analytical models for TCC beams which include discrete elements such as various types of dowels [8], coach screws, SFS-screws [9] [10], nails [11], connections with rebar [12] stud [3], sleeved connectors to mention but a few.

The new connector (fig.1) adopted is of steel that is used in notched timber but also has screws which are drilled into the timber. Therefore, it takes the advantages of screwed and notched timber connections. The screws are parallel to the grain of timber and also to the direction of the shear forces. It has a stud of 70 mm that gets embedded into the concrete after to achieve maximum liaison between the steel and concrete.

![Figure 1](image1.png)

**Figure 1.** (a) Conception of new connector, (b) Dimensions and corresponding (c) image of the new connector

3. Experimental programs
Push-out or shear tests always precede beam collapse tests in order to obtain important information of the mechanical properties of the connection. Strength, stiffness and post-peak behaviour of a connector are usually investigated by conducting symmetrical or asymmetrical shear tests. These are referred to push out tests, since they involve the “pushing out” of one of the components constituting the test specimens. Fig 2 shows the principal setup of a symmetrical push-out test, where the horizontal lines symbolize the shear connections.

![Figure 2](image2.png)

**Figure 2.** Side, and top views of the setup configuration of the push-out test of new connector, Specimen NC2
The aim of the experiment was to determine the sliding modulus \((K_{ser}, K_u)\) and the maximum force with shear failure \((F_{max})\) in order to be able to correctly size the concrete wood floor with the new connectors. The slip modulus of a connection system is got from calculating two ratios: the instantaneous slip modulus \((K_{ser})\) and the instantaneous slip modulus for ultimate limit states \((K_u)\), corresponds to the initial levels of loading obtained by the slope of the secant line through the beginning of the load–slip curve and the point corresponding to 40% of the rupture load. According to EUROCODE 5 [13], instantaneous slip modulus of a connection for ultimate limit states \((K_u)\) should be calculated according to: \(K_u = \frac{2}{3} K_{ser}\). The connectors were then sorted in relation to their stiffness or slip modulus: nails, screws, and dowels are the most flexible, whereas notches cut in the timber and continuous connectors glued to the timber are the most rigid.

Following the tests on the specimens of the new connector, the following results were obtained (Table 1).

| Mechanical property | Fmax(kN) | Kser(kN/mm), Initial slip modulus | Kser(kN/mm), Slip modulus at SLS | Ku(kN/mm), Slip modulus at ULS | Snax(max), Maximum slip | vi(mm), Initial slip | v0.1(mm), 10% secant shear modulus | v0.6(mm), Initial slip | v0.6(mm), Modified Initial slip | v0.6(mm), Slip for a load of 0.4 Fmax in the load branch until breakage | v0.6(mm), Slip at 0.8 Fmax |
|---------------------|---------|----------------------------------|---------------------------------|--------------------------------|------------------------|-------------------|-----------------------------|-------------------|-----------------------------|--------------------------------|---------------------|
| Specimen NC1        | 109.99  | 33.84                            | 36.66                           | 24.44                          | 2.52                   | 0.4               | 1.3                         | 1.20              | 1.46                        | 1.60                        | 1.34                |
| Specimen NC2        | 240.70  | 57.65                            | 82.06                           | 54.70                          | 4.82                   | 0.79              | 1.67                        | 1.17              | 1.70                        | 2.17                        | 1.64                |

The first pushout test of the new variant connector failed due to the splitting of the horizontal fibres of the timber element with some concrete crack failure on the adjacent side with the timber. The second variant failure generally because of cracking of the concrete around the internal areas of the connection. The crack propagation preceded downwards and outwards the inner assembly to the outsides producing more fissures in the concrete and the general assembly. The contact between the timber member and the concrete blocks was also reduced due to the sliding motion during charging hence reducing the friction between the composites therefore larger displacements. After removing with concrete to observe the state of the connector, little or no deformation of the connector and its screws were being observed.

Figure 3. Failure of new connector pushout of variants 1 and 2 showing cracks and development of gaps between the assemblies
4. Finite element simulation

The objective of the FEM simulation was to predict the mechanical behaviour of the timber-concrete joints under the two different types of connection. According to the standard practice, the load carrying capacity of a single fastener, per shear plane, loaded laterally, can be obtained according to the timber density, the fastener diameter and the geometry of the connection. This is method is the standard practice and is based on Eurocode 5 part 1 [13].

4.1. Materials modelling

The constitutive law of steel was assumed to be isotropic as well as the material yield criterion. The hardening rule was also assumed to be isotropic. The steel behaviour was simulated using a tri-linear behaviour corresponding to, respectively: initial elastic phase, hardening phase and yielding as presented. The connectors and the screws were assumed as isotropic elasto-plastic material with the following properties: $E = 200,000 \text{ MPa}$, $\nu = 0.35$ and $\sigma_y = 450\text{ MPa}$. The concrete material was modelled using the concrete damage plasticity model (CDPM) supported by the FEM package ABAQUS [14]. The model assumes that the uniaxial tensile and compressive response of concrete is characterized by damaged plasticity. It requires Concrete compression hardening, concrete tension stiffening, and isotropic elasticity.

4.2. Boundary conditions and meshing

Two types of external boundary conditions were considered: those due to the support and those due to symmetry considerations. In the model, the supports were simulated considering prescribed values of zero displacements for the three translations in all the nodes that correspond to support areas in the shear tests (the nodes in the timber elements base). Using this approach, a rigid connection was assumed between the specimen and the supports and at the same time no horizontal displacement was allowed in the bottom of the timber block. The loads were introduced by increasing controlled displacements applied on all the nodes in the top of the concrete element, as done in the laboratory tests. In ABAQUS, the material modelling of timber is complicated possibly because of natural imperfections like distortions in the grains or knots that can influence its structural behavior. In terms of elastic behavior, modelling the timber was first considered as isotropic material ($E = 11000 \text{MPa}$ and $\nu = 0.3$), but the results were not satisfactory and it was therefore modelled as an orthotropic material. The relations between the elasticity modulus in the various directions and between elasticity moduli and moduli of distortion were kept constant as given in EN 338 [15] for softwoods as given in Equation 1 and Equation 2. This was assumed as a first step, to be checked later with parametric simulations.

$$E_0 = Exx = 30Ezz = 30Eyy$$  \hspace{2cm} (1)

$$G_{xy} = G_{zx} = \frac{E_{xx} + E_{yy}}{2} \times \frac{1}{16}; G_{yz} = \frac{E_{zz} + E_{yy}}{2} \times \frac{1}{16}$$  \hspace{2cm} (2)

**Figure 4.** Pushout Failure in ABAQUS at 208 kN of load showing PEEQ values, displacement and stress, the experimental test collapsed at 240kN
The figure 4 shows the comparison between laboratory tests and FEM numerical simulations. The global load slip manner obtained in both tests shows similarity qualitatively. However, there was overestimation of the maximum load and the initial stiffness in ABAQUS. This could probably be explained by the perfect linear elastic behavior assumed for timber until the maximum strength is reached. The overestimation of the ultimate load carrying capacity of the joint was probably caused by the assumption of a yielding strength equal to the embedding strength of timber.

5. Conclusion
The new connector takes advantages of resisting more shear forces compared to the Tecnaria connector namely of the notched connection system, a head stud and screws. Further improvement of its design can be made for easy installation on structures especially when casting concrete. In the pushout tests, the notched connection was rigid enough that failure was due to crack propagation in the concrete members.

The system transferred the forces laterally downwards forcing cracking and high stress forces in the areas below the notches attached to the connector. The model used in ABAQUS shows that it has the capacity to describe the behavior of timber–concrete composite joints having screws and notches connections.

References
[1] A. Buchanan, B. Deam, M. Fragiacomo, S. Pampanin and A. Palermo, *Multi-Storey, Prestressed Timber Buildings in New Zealand,* vol. 18, no. 2, pp. 166-173, 28 March 2008.
[2] D. Yeoh, M. Fragiacomo, M. D. Franceschi and a. K. H. Boon, "State of the Art on Timber-Concrete Composite Structures: Literature Review," *Journal of Structural Engineering,* vol. 137, 1 October 2011.
[3] S. C. Auclair, L. Sorelli and A. Salenikovich, A new composite connector for timber-concrete composite structures, 2016 *Construction and Building Materials,* vol. 112,
[4] J. N. Rodrigues, A. M. P. G. Dias and P. Providencia, Timber-Concrete Composite Bridges: State-of-the-Art Review, *Bioresources,* vol. 8, no. 4, .
[5] L. Deam, M. Fragiacomo and A. H. Buchanan, Connections for composite con-crete slab and LVL flooring systems 2008 *Materials and Structures,* vol. 41, no. 3.
[6] L.F.Jorge, J.Schänzlin, S.M.R.Lopes, H.Cruz and U.Kuhlmann,Time-dependent be-haviour of timber lightweight concrete composite floors 2010 *Engineering Structures,* vol. 32,
[7] D. Yeoh, M. Fragiacomo and B. Deamc, Experimental behaviour of LVL–concrete composite floor beams at strength limit, 2011 *Engineering Structures,* vol. 33, no. 9,
[8] M.R.LeBorgne and R.M.Gutkowski, Effects of various admixtures and shear keys in wood–concrete composite beams, 2010 *Construction and Building Materials,* vol. 24, no. 9,
[9] M. Fragiacomo, Experimental behaviour of a full-scale timber-concrete composite floor with mechanical connectors, *Materials and Structures,* vol. 45, no. 11.
[10] L.F.Jorge, J.Schänzlin, S.M.R.Lopes, H.Cruz and U.Kuhlmann, Time-dependent behaviour of timber lightweight concrete composite floors, 2010 *Engineering Structures,* vol. 32, no. 12.
[11] D.D Djoubissie, A. Messana, E. Fournely and A. Bouchür, Experimental study of the mechanical behaviour of timber-concrete shear connections with threaded reinforcing bars, 2018 *Engineering Structures,* vol. 172, no. 1.
[12] E.P.Carvalho and E. V. M. Carrasco, Influence of test specimen on experimental characterization of timber–concrete composite joints, 2010 *Construction and Building Materials,* vol. 24, no. 8.
[13] EN. 1995-1-1, Eurocode 5: design of timber structures – part 1.1: general rules and rules for buildings. 2004 European committee for standardization, Brussels.
[14] SIMULIA,”Abaqus Documentation,” Dassault Systèmes, 2016. [Online]. Available: http://130.149.89.49:2080/v2016/index.html.
[15] C. EN 338, Structural timber-strength classes. 1995