25th Australasian Conference on Mechanics of Structures and Materials (ACMSM25)
Edited by C.M. Wang, J.C.M. Ho and S. Kitipornchai
Brisbane, Australia, December 4 – 7, 2018

SHEAR STRENGTH OF CROSS LAMINATED TIMBER-CONCRETE CONNECTIONS REINFORCED WITH CARBON FIBRE POLYMER COMPOSITES

S.A. Hadigheh*, and D. Dias-da-Costa

School of Civil Engineering, The University of Sydney, NSW 2006, Australia
Emails: ali.hadigheh@sydney.edu.au, daniel.diasdacosta@sydney.edu.au
*Corresponding author

Abstract. *This paper presents an experimental study on the mechanical behaviour of four different timber concrete composite (TCC) connections. Experimental shear tests were conducted to assess the strength and stiffness of the composite connection system. A new type of connection based on carbon fibre reinforced polymer (CFRP) was also proposed to achieve enhanced performance at the cross laminated timber. The stiffness and strength for each type of connection were identified by assessing the load-slip behaviour and load capacity. In addition, the relationship between applied force and slip characteristic of each type of connecting system was also established. Results showed that the addition of CFRP to the connection can effectively improve the maximum shear capacity and stiffness of the connection.*

Keywords: Timber concrete composite; Cross laminated timber; CFRP; Notch joint; Shear strength

1 INTRODUCTION

The application of timber concrete composite (TCC) connections has been growing due to different benefits including reduction in cost, weight as well as energy consumption in the course of manufacturing (Manaridis, 2010). The use of TCC connections started in the 1930's when there was a shortage of steel that drove builders to search for alternative materials (Rodrigues et al., 2013). Throughout the years, the application of TCC has been extended from bridges to multi-storey buildings where it has been employed for construction of low rise commercial, industrial and residential buildings.

In TCC members, the connection system plays a significant role towards the stability and performance of the whole composite structure. To achieve an efficient structural system, the connection is deemed to demonstrate high composite action. The TCC connection relies on the capability of the concrete to resist compression forces whilst the timber section carries tension. As a result, the structural efficiency of the composite system is highly dependent on the stiffness (Yeoh, 2010), load carrying capacity, deformation and ductility of the connection. For floor systems, a connection with an optimum composite action can allow a significant reduction of the slab depth and longer span length.

The mechanical performance and level of composite action in TCC connections are influenced by the quality of the shear connectors. A longer span with shorter beam depth can be achieved through high composite action. High composite action results in a more efficient shear stress transfer between two components of the connection which subsequently reduces the relative movements/interlayer slip (Yeoh, 2010). This is only likely to be attained by designing an effective connection system where the joint is strong enough to transfer shear loads and has a high slip modulus (Shan et al., 2017, Dias, 2005, Ceccotti, 2002).

Fibre reinforced polymer (FRP) composites have been widely used in construction due to their high tensile strength and durability performance, light weight, and ease of installation. FRP as a sheet or laminate can be used in shear or flexural strengthening of the beams, joints or slabs, in which the FRP contributes to transfer the load between two surfaces (Hadigheh et al., 2015). The use of FRP as the connecting element could be a potential option to achieve higher composite action in TCC systems. This paper focuses on the development of alternative TCC connections with improved structural performance. Various connections are designed and tested using cross laminated timber (CLT) panels. A combination of more traditional notch system and advanced fibre reinforced polymer sheets are used to achieve composite action. During the tests, photogrammetry is used for monitoring of the joint.

2 DESIGN OF TIMBER-CONCRETE CONNECTIONS

Four types of timber-concrete connections were tested in this research: one control connection with a notch (C-N), one connection with notch and FRP (40-N), and two connections without notch using Carbon FRPs (CFRP) of different length (40-NN and 60-NN). Three identical samples were made for each type of connection. The details of the test specimens are presented in Table 1 and Figure 1.

2.1 Materials

For the samples with a notch, the design included a circular notch in the centre of the timber with a diameter of 50 mm and depth of 60 mm which was filled with concrete during concrete casting. Portland cement and 10 mm and 14 mm coarse aggregates used to achieve a target compressive strength, f'_c, 32 MPa for concrete. After casting, the specimens were left to cure for 28 days in room temperature. The concrete section was water sprayed during curing and covered by a damp hessian sack to provide consistent moisture conditions.

Each timber sample was cut from cross laminated timber (CLT) at a size of 200 mm by 200 mm. CLT panels were made of bonded softwood boards with C30 strength class and modulus of elasticity of 12.5 GPa. Each layer of softwood was stacked perpendicularly to the lower/upper layer. In this experiment, the CLT sections consisted of three layers with a total thickness of 120 mm. The species for this type of wood was the European spruce or equivalent softwood with a density of approximately 500 kg/m^3.

The carbon fibres and epoxies used for these experiments were SikaWrap 231C and Sikadur 330, respectively. The tensile modulus of dry carbon fibres was 230 GPa with a tensile strength of 4900 MPa. Carbon fibres were saturated and attached onto the substrates by a two-part epoxy adhesive. Sikadure 330 was produced by mixing two parts of thixotropic epoxy at a ratio of 4:1 by weight. The reported tensile modulus and strength of the epoxy were, respectively, 4500 MPa and 30 MPa, with an elongation at break of 0.9 percent.

Table 1 Test matrix.

Specimen ID	Notch Diameter (mm)	Notch Depth (mm)	Length of CFRP embedded in Concrete (mm)	CFRP Length attached on Timber (mm)
C-N	50	60	---	---
40-N	50	60	60	40
40-NN	---	---	60	40
60-NN	---	---	40	60

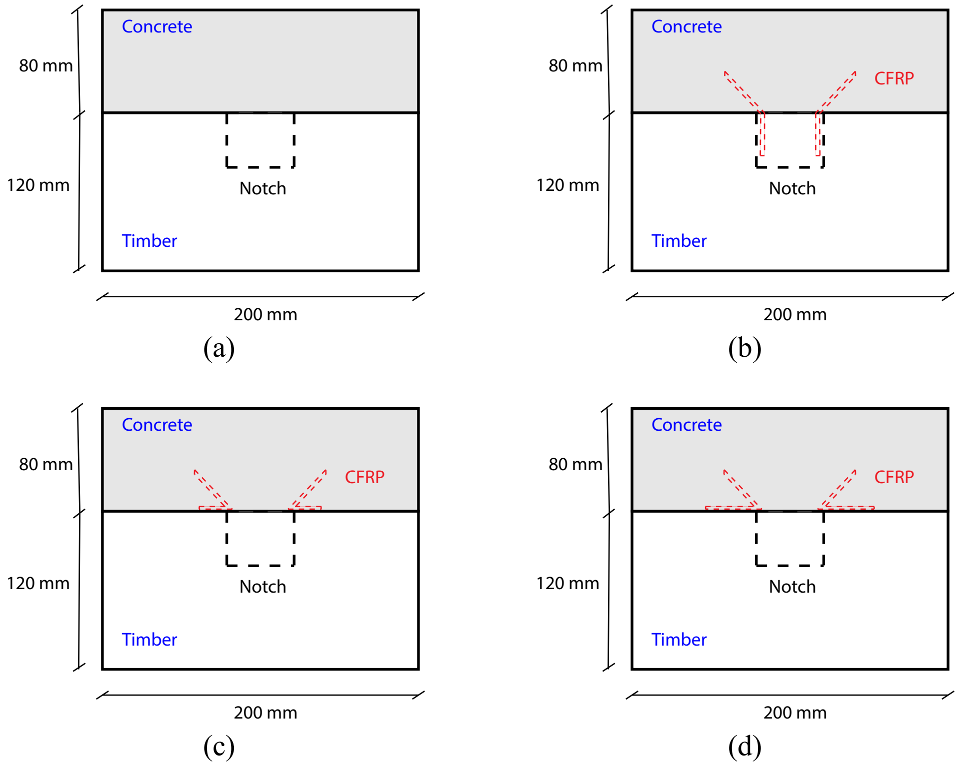


Figure 1 Schematics of tested specimens (a) C-N, (b) 40-N, (c) 40-NN, and (d) 60-NN.

2.2 Instrumentation and measurements

Shear force was applied on the timber section under displacement control at 1 mm/min using an Instron testing machine, while the concrete block was fixed in the test rig (Figure 2). A steel plate was placed over the timber element and used to uniformly apply the load.

Figure 2 (a) experimental instrumentation, (b) monitoring of the response.

Two linear variable differential transformers (LVDT) were used to measure the global displacement of the lower corner of the timber section. L-shaped steel plates were pre-attached to the timber, with the LVDTs pointing directly to them. The local slippage between the timber and concrete was monitored by photogrammetry using a Nikon D810 camera. A light source was placed right behind the camera to avoid shadows and adequate exposure conditions to the region of interest. Pre-loading of the specimens was conducted and reference images were taken for error assessment. Data was acquired throughout the test and until the failure of the specimens.

3 RESULTS AND DISCUSSION

During the test, all specimens showed similar behaviour even though with different failure modes. A cracking sound was heard at approximately 20% of the applied load which was assumed to be from the timber. This indicated the start of slippage in the connection which was then followed by a louder screeching sound associated with further plasticisation in the connection due to presence of notch and/or CFRP. This observation indicated that failure occurred at the interlayer connection. The TCC samples then failed due to fracture in the connection. The failure of the C-N specimens was quick with the complete separation of timber and concrete sections (Figure 3a). N and NN samples with CFRP incorporated into the connection, failed long after the C-N specimens, also showing higher ductility. Failure in both N and NN series happened with either the rupture of the CFRP or interface (cohesive) failure (Figure 3b-c). It was decided to terminate the test after a maximum slip of 15 mm.

(a) (b) (c)

Figure 3 Failure of the specimens: (a) C-N, (b) 40-N, and (c) 40-NN.

The load versus slip relationship for each specimen was evaluated and is reported in Figure 4 and Table 2. In the C-N notched connections, a linear elastic behaviour was found until the maximum load, which was followed by a sharp reduction and a sudden brittle failure. For 40-N connections, the load-slip curves showed improved mechanical performance with an average maximum load of 25.3 kN. This was due to the presence of both the notch and CFRP which provided further shear strengthening to the connection. During the test, the carbon fibres acted as a reinforcement and were able to contribute to the shear transfer in the connection even after the failure of the concrete counterpart. All three replicated samples showed similar behaviour at the initial loading and until 15 kN after which they experienced nonlinearity until the maximum load. Although both 40-NN and 60-NN specimens showed higher maximum shear force than the C-N specimens, they had far less capacity than the 40-N specimens. This indicates that inserting CFRP into the notch could significantly increase the load carrying capacity of the joint without compromising the ductility of the connection. The failure pattern and behaviour of the 40-NN and 60-NN specimens were quite similar, while the 60-NN specimens showed higher maximum shear load due to using a longer CFRP length. Figure 5 shows the crack opening in the 40-NN specimen before and after failure.

The specimens with a notch showed high stiffness but reduced plastic deformation capacity. On the other hand, glued-in CFRP joints with/without notch provided a more ductile behaviour since the CFRP and concrete notch both contribute towards further plasticisation of the connection.

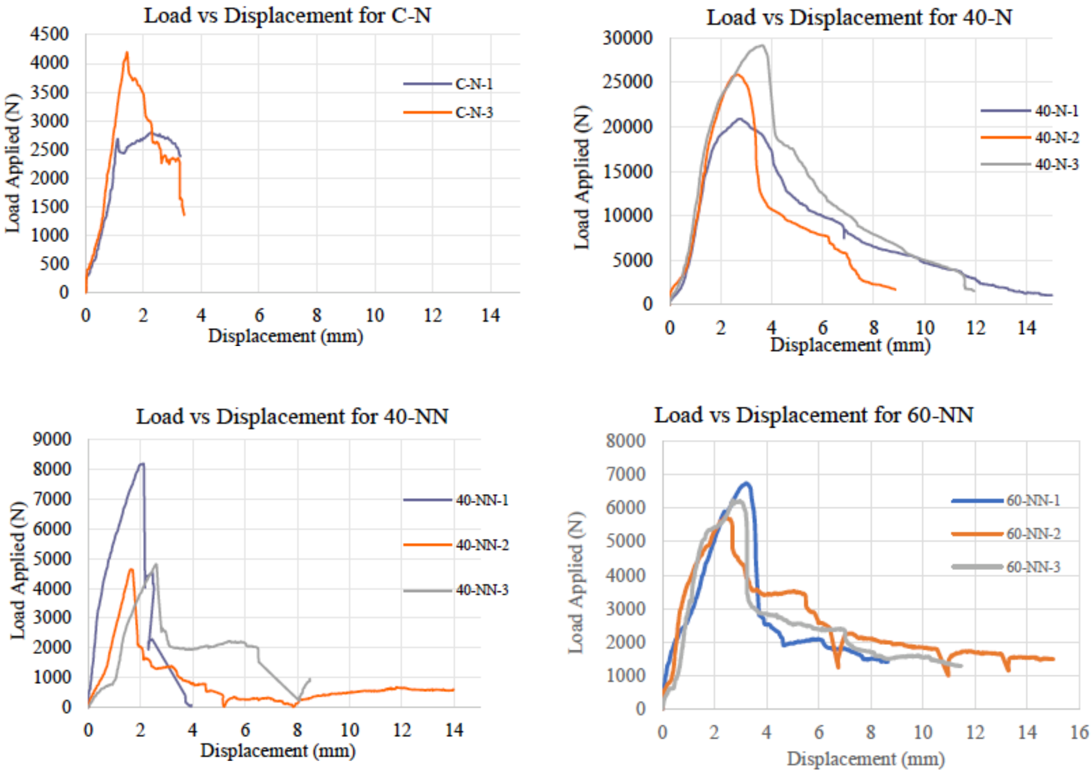
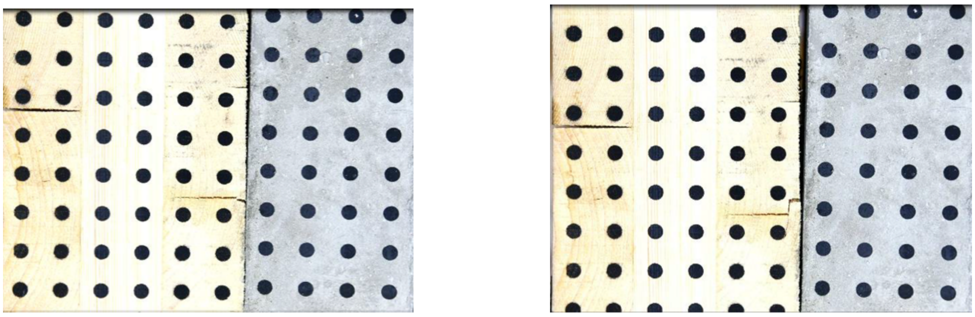


Figure 4 Load-displacement curve for the tested samples.



(a) (b)

Figure 5 Crack opening between timber and concrete elements for the 40-NN-2 connection.

Table 2 Test results.

Connection	Average maximum shear force (kN)	Average maximum displacement (mm)
C-N	3.5	3.3
40-N	25.3	11.9
40-NN	5.9	8.8
60-NN	6.2	11.7

4 CONCLUSION

This paper investigated the performance of four different composite timber-concrete connections. The connections developed incorporated both traditional methods such as the ones using a notch and an advanced system based on carbon fibre reinforced polymer (CFRP) sheets. The carbon reinforcement provided further strength and stiffness to the TCC system. The load-displacement results during the tests showed that the specimens with CFRP inserted inside the notch could carry the highest shear stresses due to the combined contribution of concrete in shear and CFRP in tension. The was also able to increase ductility and prolong the post yielding stage before failure.

5 ACKNOWLEDGEMENT

The authors would like to acknowledge the support from the School of Civil Engineering at the University of Sydney and the Australian Research Council through its Discovery Early Career Researcher Award (DE150101703) and ARC Projects (DP140100529, LP140100591).

REFERENCES

Ceccotti, A. (2002), Composite concrete-timber structures. Progress in Structural Engineering and Materials, 4, 264-275.

Dias, A. M. P. G. (2005), Mechanical behaviour of timber-concrete joints, PhD thesis.

Hadigheh, S.A., Gravina, R.J., Setunge, S. (2015), Identification of the interfacial fracture mechanism in the FRP laminated substrates using a modified single lap shear test set-up, Engineering Fracture Mechanics, 134 (2015), 317-329.

Manaridis, A. (2010), Evaluation of timber-concrete composite floors. TVBK.

Rodrigues, J. N., Dias, A. M., Providência, P. (2013), Timber-concrete composite bridges: State-of-the-art review. BioResources, 8, 6630-6649.

Shan, B., Xiao, Y., Zhang, W., Liu, B. (2017), Mechanical behaviour of connections for glubam-concrete composite beams. Construction and Building Materials, 143, 158-168.

Yeoh, D., Fragiacomo, M., De Franceschi, M., Buchanan, A. H. (2010), Experimental tests of notched and plate connectors for LVL-concrete composite beams. Journal of Structural Engineering, 137, 261-269.