1 Steel kerf plate solution for cross-laminated timber-concrete composite systems

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Abstract

An efficient and cost-effective solution for Timber-Concrete Composite (TCC) systems with steel kerf plates as shear connectors is presented in this paper. The stiffness, strength, and failure modes of small-scale TCC specimens comprised of 7-ply and 245mm thick CLT panels with 150 mm concrete topping connected with steel kerf plates were evaluated in quasi-static monotonic tests. In order to investigate the performance of steel kerf plates, the embedment depths of plates into the CLT were varied from 35 mm to 90 mm. A total of 18 tests were conducted with six replicates from each type. The load-deformations and connector slip at the CLT-concrete interfaces were measured. Results showed that load carrying capacity and stiffness of all test series were comparable and that the shallow 35 mm steel plate embedment depth into only the first layer of CLT resulted in sufficient composite action for the TCC composites. The steel kerf plates showed excellent performance and can be deemed a promising and economical solution for shear connectors in TCC members.

Keywords: Timber concrete composite, cross-laminated timber, timber connections.

2 Introduction

Timber-Concrete Composite (TCC) floors are an efficient and cost-effective alternative that can overcome some of the inefficiencies associated with conventional reinforced concrete or light wood frame floors regarding strength, section depth, stiffness, and vibration performance [1,2]. TCC floor systems are generally comprised of a timber floor connected to a concrete topping. The efficiency of TCC depends largely on the material properties of timber and concrete and the shear connections between the two materials. TCC

The findings from this research have been implemented in the design of "The Arbour", a 10-storey educational building located for George Brown College in Toronto, Ontario, Canada, that will host classrooms, lecture halls, and the Tall Wood Institute (Figure 1). To reflect the purpose of the building and to develop sustainable structural solutions, timber was chosen as the primary structural material. Each mass timber floor will be exposed from underneath, and structural concrete topping will be added to achieve the performance conducive to institutional programming.

These floors will be supported on glulam columns. From level 2 to 9, Cross-laminated Timber (CLT) panels are used as the primary floor system. To eliminate the use of beams and create more head clearance as well as the space for mechanical and electrical components, CLT panels span 9.2 m in north-south direction to act as slab bands on which thinner CLT panels bear in the transverse direction.

The typical 430 x 1178 mm columns, or "wallumns" supporting the main CLT "bands" are designed to resist their weak-axis.

Steel kerf plates were selected as TCC shear connector. The objective of the testing program presented herein was to investigate the performance of these connectors.

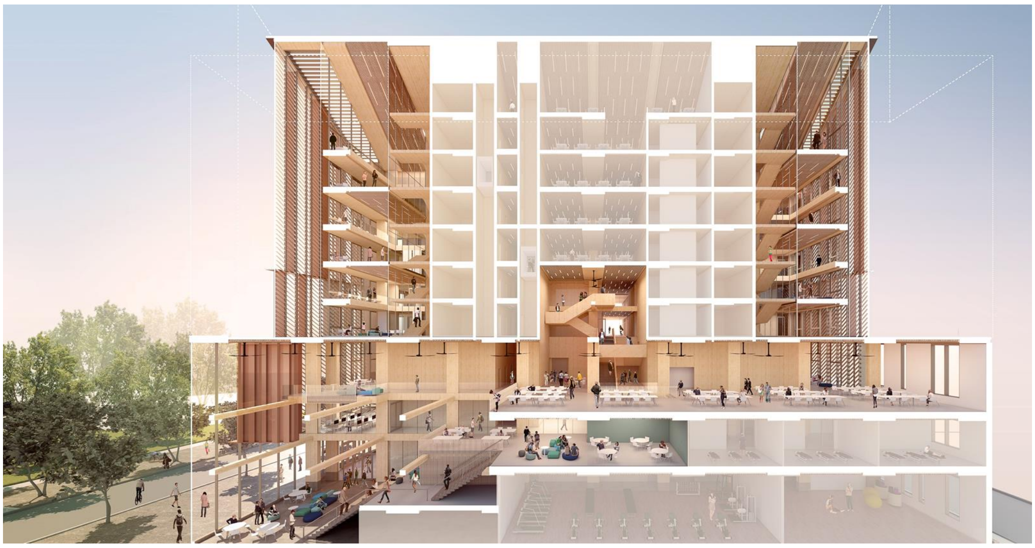

Figure 1. Rendering of "The Arbour" Building

3 Experimental Investigations

3.1 Materials

The composite floors were comprised of 245 mm thick, 7-ply CLT with 150 mm concrete topping. The CLT was manufactured from SPF lumber and was strength grade 2100 Fb-1.8E MSR according to CSA O86 [3].

The concrete compressive strength was 35 MPa minimum (specified strength). The concrete was made of Type I Portland cement with the maximum aggregate size of 10 mm and with superplasticizer to achieve a high slump of minimum 80 mm.

Grade A36 steel plate of 6 mm thick and 75 mm deep were used as TCC connectors.

The relevant material parameters are summarized in Tables 1, 2 and 3.

Table 1. Properties of CLT [MPa]

Direction	MOE	F_t	F_c	F_b	F_v	F_{cp}
Strong	12400	17.7	19.9	30.5	0.5	6.5
Weak	9500	5.5	11.5	11.8	0.5	5.3

Table 2. Shear Connector Description

Connector	Description
6 mm steel plates	Installed at 7 mm wide saw kerf with polyurethane adhesive

Table 3. Concrete Properties

Max Agg.	*Admixture*	*Additive*	*Air Content*	w/c ratio	Slump
[mm]	[-]	[-]	[%]	[-]	[mm]
10	Sika Air 260, Viscocrete 2100	Super-plasticizers	5	0.42	80±20

3.2 Connector tests

Steel kerf plates of 6 mm thick and 200 mm wide were installed in the CLT in a 7 mm wide saw kerf at 5^0 back bevel as shown in Figure 2. Three varying embedment depths into - a) 35 mm, b) 70 mm, and c) 90 mm were chosen to investigate the efficiency and failure pattern of steel plates embedment depth into the CLT, c.f. Table 4 and Figure 2. A total of 18 specimens were manufactured and subsequently tested at the University of Northern British Columbia Wood Innovation and Research Laboratory in Prince George.

Table 4. Test Series

Series	Connector depth [mm]	#of tests	L [mm]	b_c [mm]	b_t [mm]
A	35	6	1000	300	300
B	70	6	1000	300	300
C	90	6	1000	300	300

a)

b)

c)

Figure 2. a) Series A, b) series B, c) series C

The TCC specimens were tested from a compression load frame, shown in Figure 3. Test specimens were rotated by 12° as per EN-408 [4], so that the resultant forces of loading and support are aligned. The loads were applied according to a modified EN-26891 [5] protocol at a displacement-controlled rate of 5 mm/min. Specimens were loaded to approx. 40% of the estimated capacity, then unloaded to approx. 10% of estimated capacity, and finally loaded to failure, defined as the point when load dropped to 80% of maximum.

The actuator load and the relative displacements between CLT and concrete were measured using two calibrated LVDTs (one in the front and one in the back), attached at mid-height of the specimens. The reported displacements are the averages between the two measurements.

The connector performance was analyzed at the maximum load F_{max}, displacement at maximum load d_{Fmax}, and two stiffness values k_1 and k_2. F_{max} and d_{Fmax} were determined directly from the load-displacement curves, k_1 was computed for the range between 10% and 30% of F_{max}; k_2 was computed for the range of 20 - 50% of F_{max}.

Figure 3. Test Setup

3.3 Full-scale floor tests

Two full-scale TCC floors, of 9.6 m long, with Type A steel kerf plate (35 mm steel embedment into CLT) and 150 mm concrete topping were tested under four-point bending, as shown in Figure 4. The floors were supported on glulam columns which were connected to the concrete strong floor by angle brackets with anchor bolts. Loads were applied to the floors at approximately one-third points using four actuators for a total of 1500 kN maximum capacity from the steel load frame as shown in Figure 4.

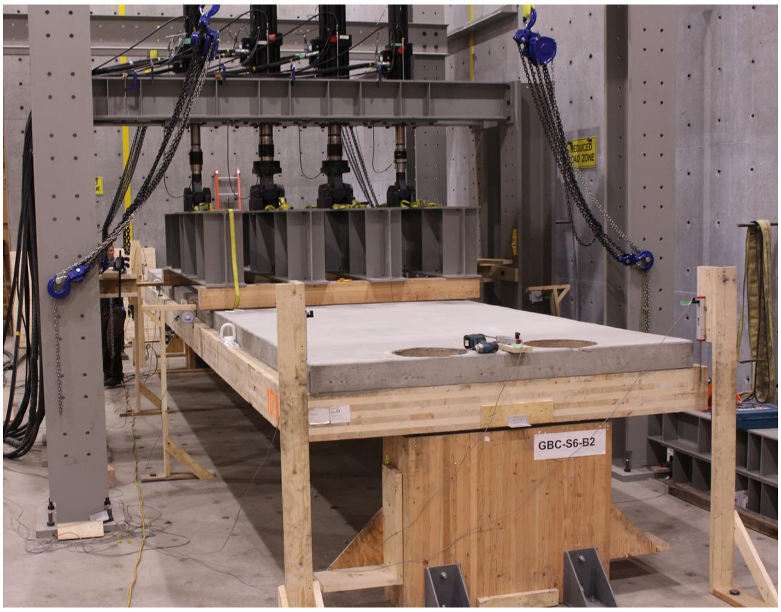

Figure 4. Rendering of "The Arbour" Building

3.4 Connector test results

The specimens in both series A and C with 35 mm and 90 mm CLT embedment failed in concrete crushing at the location of steel plates where the concrete shear failure initiated (Figure 5). In series B, when the steel plates were extended to the CLT cross layers i.e., 2nd layer into CLT, a rolling shear failure of the CLT cross layer was observed. Therefore, steel plated embed into the cross layer of CLT should be avoided in actual construction.

The load-displacement curves from the connector tests are illustrated in Figure 6. The average from the load-deformations from each type of small-scale were found to exhibit almost identical behaviour up to failure, which occurred between 325 kN and 375 kN and at roughly 3 mm for all specimens (Table 5). Load-carrying capacity, displacement at maximum load, and stiffness of all series were comparable

Figure 5. Typical failure

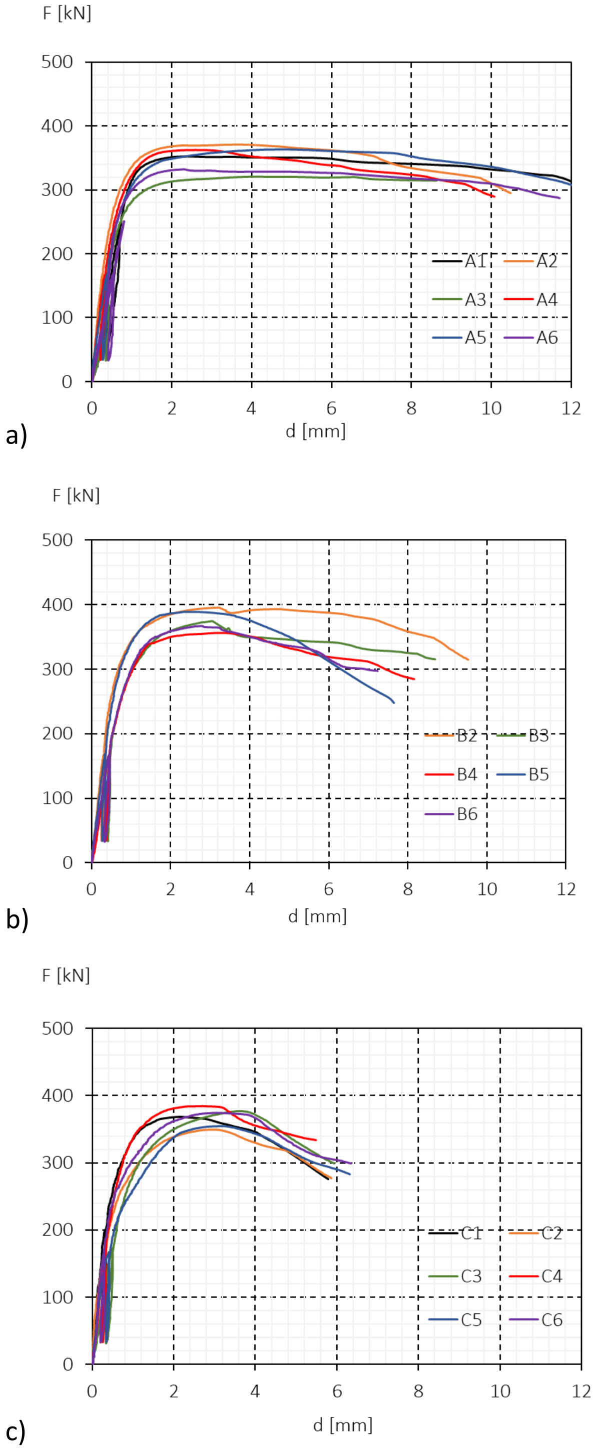

Figure 6. Load-deflection curves: a) Series A, b) series B, c) series C.

Table 5. Results from TCC Test Series

Series	F_{max} [kN]	d_{Fmax} [mm]	k_1 [kN/mm]	k_2 [kN/mm]
A-1	352	2.4	507	549
A-2	371	3.7	853	1054
A-3	321	4.1	495	1618
A-4	362	2.6	522	
A-5	363	4.9	476	801
A-6	332	2.3	291	481
Average	350	3.3	524	901
CoV	6%	31%	35%	51%
B-1*	failed prematurely at support			
B-2	395	3.2	585	1315
B-3	375	3.0	355	1144
B-4	356	3.3	475	998
B-5	389	2.3	500	965
B-6	367	2.8	358	766
Average	376	2.9	455	1037
CoV	4%	13%	22%	20%
C-1	369	2.2	704	1447
C-2	349	3.0	630	1112
C-3	377	3.6	406	600
C-4	384	2.7	557	1100
C-5	355	3.2	523	839
C-6	374	3.1	1025	1026
Average	368	3.0	641	1021
CoV	4%	17%	33%	28%

3.5 Full-scale TCC floor test results

The load-deflection curves of the full-scale TCC specimens are illustrated in Figure 7. The load-displacement behaviours of both floor panels were approximately the same until failure. The panels failed in bending at an average load of 1,040 kN. The initial failure in the TCC specimens happened in the connector with the final subsequent failure occurred at mid span due to bending.

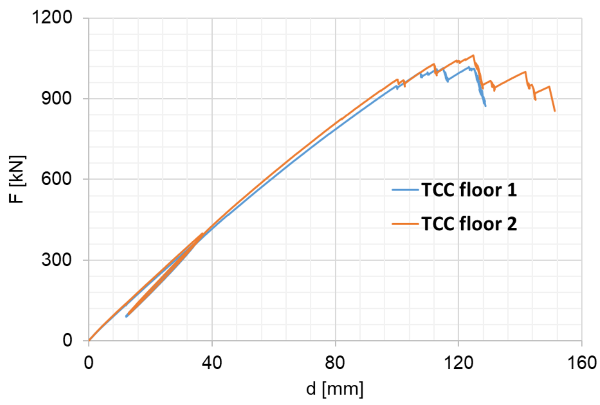

Figure 7. TCC full-scale load-deflection curves

4 Conclusions

A comprehensive test program was designed to systemically investigate the performance of steel kerf plates as shear connector for TCC systems. The following conclusions were drawn:

- Test results for the kerf plates validated the initial assumptions that 35 mm CLT embedment is sufficient.
- Increasing the kerf plate embedment depth from 35 mm to 90 mm does not increase the capacity and does change some of the failure mechanisms to rolling shear instead of concrete crushing.
- Using steel kerf plates as shear connector in full-scale TCC floors resulted high effective bending stiffness and very high composite efficiency, with gamma values close to 1.0.

Results and final findings from this test program have been implemented into the base building design for The Arbour, a 10-storey educational building for George Brown College, located in the East Bayfront district of Toronto, Canada.

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