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PERFORMANCE OF CROSS-LAMINATED TIMBER -CONCRETE COMPOSITE SYSTEMS WITH STEEL KERF PLATES

Shahnewaz, Md[1,3], Jackson, Robert[1], and Tannert, Thomas[2]
[1] Fast + Epp, Canada
[2] University of Northern British Columbia, Canada
[3] mshahnewaz@fastepp.com

Abstract: This paper investigated the performance of Timber-Concrete Composite (TCC) systems with steel kerf plates as shear connectors. The stiffness, strength, and failure modes of small-scale TCC specimens with steel kerf plates were evaluated in quasi-static monotonic tests. The specimens were comprised of 245mm thick, 7-ply CLT panels with 150 mm concrete topping connected with steel plates. The embedment depths of the steel plates in the CLT were varied from 35 mm to 90 mm to investigate the performance variation. Eighteen tests were conducted with six replicates from each type. The load-deformations and connector slips at CLT-concrete interfaces were measured at different locations. Results showed that load carrying capacity and stiffness of all test series were comparable and 35 mm steel plate embedment depth into CLT resulted sufficient composite action for the TCC slabs. The steel kerf plates showed excellent performance and are one of the most economical solution for shear flow connectors in TCC members.

1 INTRODUCTION

Timber-Concrete Composite (TCC) can be an attractive alternative solution to replace conventional timber or concrete floors. TCC systems are generally comprised of timber elements (beam or panel) connected to a concrete layer by means of a shear connector. Deflection and vibration often govern the design of TCC floor systems. Previous studies have shown that TCC can overcome some of the inefficiencies associated with traditional reinforced concrete or light wood frame floors regarding strength, section depth, stiffness, and vibration performance [1,2]. The availability of panel-type engineered wood products such as CLT offers designers greater versatility in terms of architectural expression and structural performance. The efficiency of TCCs depends largely on the cross-sectional properties of timber and concrete as well as the shear connections between them. Currently, connectors ranging from low to high stiffness' are available. Some examples are a) self-tapping screws, b) dowelled shear keys, c) proprietary HBV, d) steel kerf plates, e) transverse notch connection. It should be noted that typical reinforced concrete floors really don't harness the full section efficiently; 60% of the gross cracked concrete section does not contribute to the total load resistance [3].

In this paper experimental investigations on a Cross-Laminated Timber (CLT)-concrete composite system with steel kerf plates are presented. Steel plates, also referred to as "flat steel lock" are a very cost-effective TCC connector to transfer shear between timber and concrete. The objectives of the experimental programs were to investigate i) the contribution of shear between wood and concrete, ii) properties of various shear connectors, and iii) failure mechanisms and capacity of TCC system with steel kerf plates.

2 EXPERIMENTAL INVESTIGATIONS

A comprehensive test program as shown in Table 1 was designed to investigate the parameters for the successful implementation of a low-cost and efficient TCC system.

2.1 Materials

The TCC system was comprised of 7-ply, 245 mm CLT with 150 mm concrete topping. The CLT panels were made from SPF (Spruce Pine Fir) lumber, with 2100 Fb-1.8E MSR grade stock for strong axis laminations and SPF No.3/Stud grade stock for weak axis laminations (Table 1). All mass timber products for the testing were supplied by Structurlam. The minimum specified strength of concrete was 35 MPa. Concrete cylinder compression tests were conducted on 7th day and 34th day (the day of testing) and the average strengths were recorded as 34 MPa and 50 MPa, respectively. Type I ordinary Portland cement was used with the maximum aggregate size of 10 mm with superplasticizer as an additive to achieve a high flow, 80 mm slump associated with topping mixes. The concrete properties are shown in Table 2. As shown in Table 3, 6 mm thick and 75 mm deep steel kerf plates were used as TCC connectors. The steel plates were installed at 7 mm wide saw kerf with polyurethane adhesive.

Table 1: Properties of Mass Timber Products

Material	Grade	Species	Direction	Thickness	MOE	F_t	F_c	F_b	F_s, F_v	F_{cp}
				[mm]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]
CLT	245E	SPF	Strong	245	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: Concrete Properties

Material	f'_c	*Max Agg.*	*Weight*	*Admixture*	*Additive*	*Air Content*	w/c ratio	Slump
	[Mpa]	[mm]	[-]	[-]	[-]	[%]	[-]	[mm]
Ready-mix	35	10	Normal	Sika Air 260, Viscocrete 2100	Super-plasticizers	5	0.42	80±20

2.2 Specimen Description

A comprehensive test program as shown in Table 1 was designed to investigate the parameters for the successful implementation of a low-cost and efficient TCC system. A total of three test series were conducted, c.f. Table 3, at the University of Northern British Columbia Wood Innovation and Research Laboratory in Prince George.

The tests were conducted to investigate the shear capacity, stiffness and failure mechanisms of TCC systems with steel plates. 6 mm thick and 20 mm wide kerf plates were installed in the CLT in 35 mm deep and 7 mm wide saw kerf at 50 back bevel as shown in Figure 1 and Figure 2. Three varying embedment depths into - a) full first layer of CLT (35 mm), b) full second layer of CLT (70 mm), and c) partial third layer of CLT ((90 mm) were chosen to investigate the efficiency and failure pattern of steel plates embedment depth into the CLT. Table 3 and Figure 2 describes the three types of TCC systems.

Table 3: Description of Test Series

ID	Series Type	Connector	Connector depth	Embed in CLT	Embed in concrete	#of tests	*L* [mm]	b_c [mm]	b_t [mm]
S1-A	Series A	75×2100×6 mm steel plates	75	35	40	6	1000	300	300
S1-B	Series B		110	70	40	6	1000	300	300
S1-C	Series C		130	90	40	6	1000	300	300

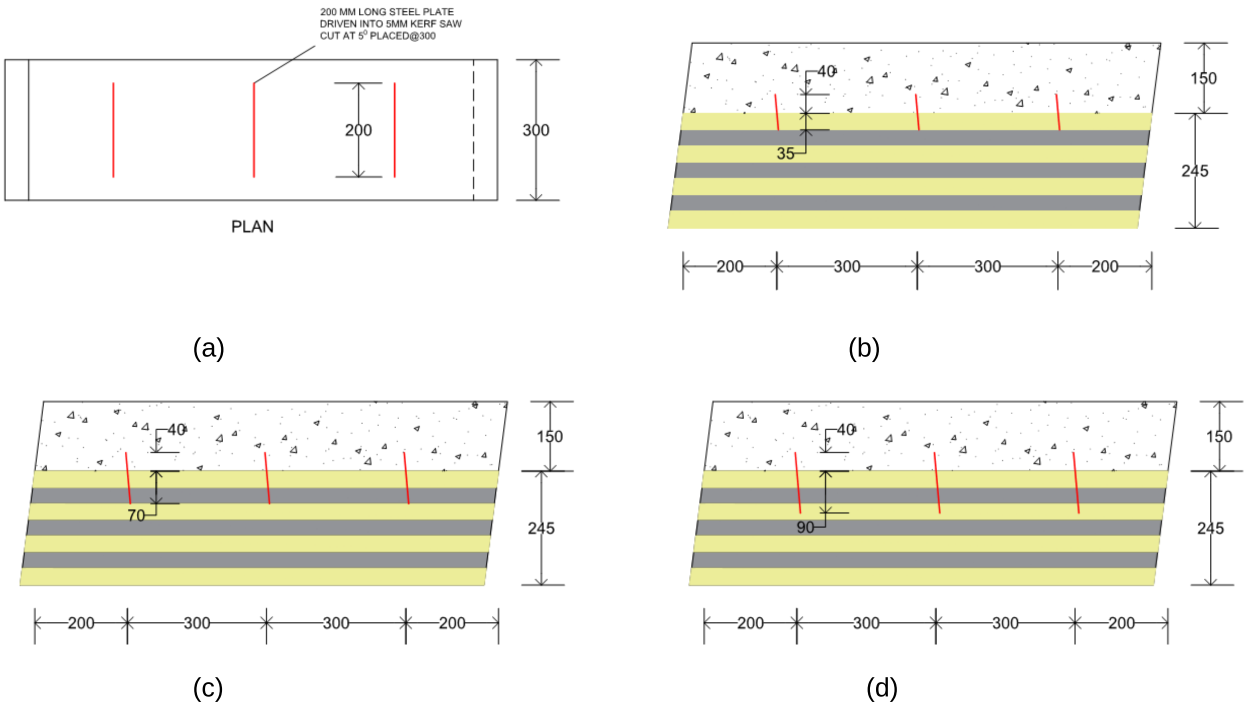

Figure 1: Schamatic of TCC series: (a) plan view, (b) S1-A with 35 mm steel embedment into CLT, (c) S1-B with 70 mm steel embedment into CLT, and (d) S1-C with 90 mm steel embedment into CLT

(a)

(b)

(c)

Figure 2: Photo of test series: (a) (b) S1-A, (c) S1-B, and (d) S1-C

2.3 Test Setup

The test set-up consisted of a compression load frame, shown in Figure 3. Test specimens were rotated by 12° similar to the procedure suggested in EN-408 [4], so that the resultant forces of loading and support are aligned. The angle was the consequence of the specimen height. 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 the maximum.

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

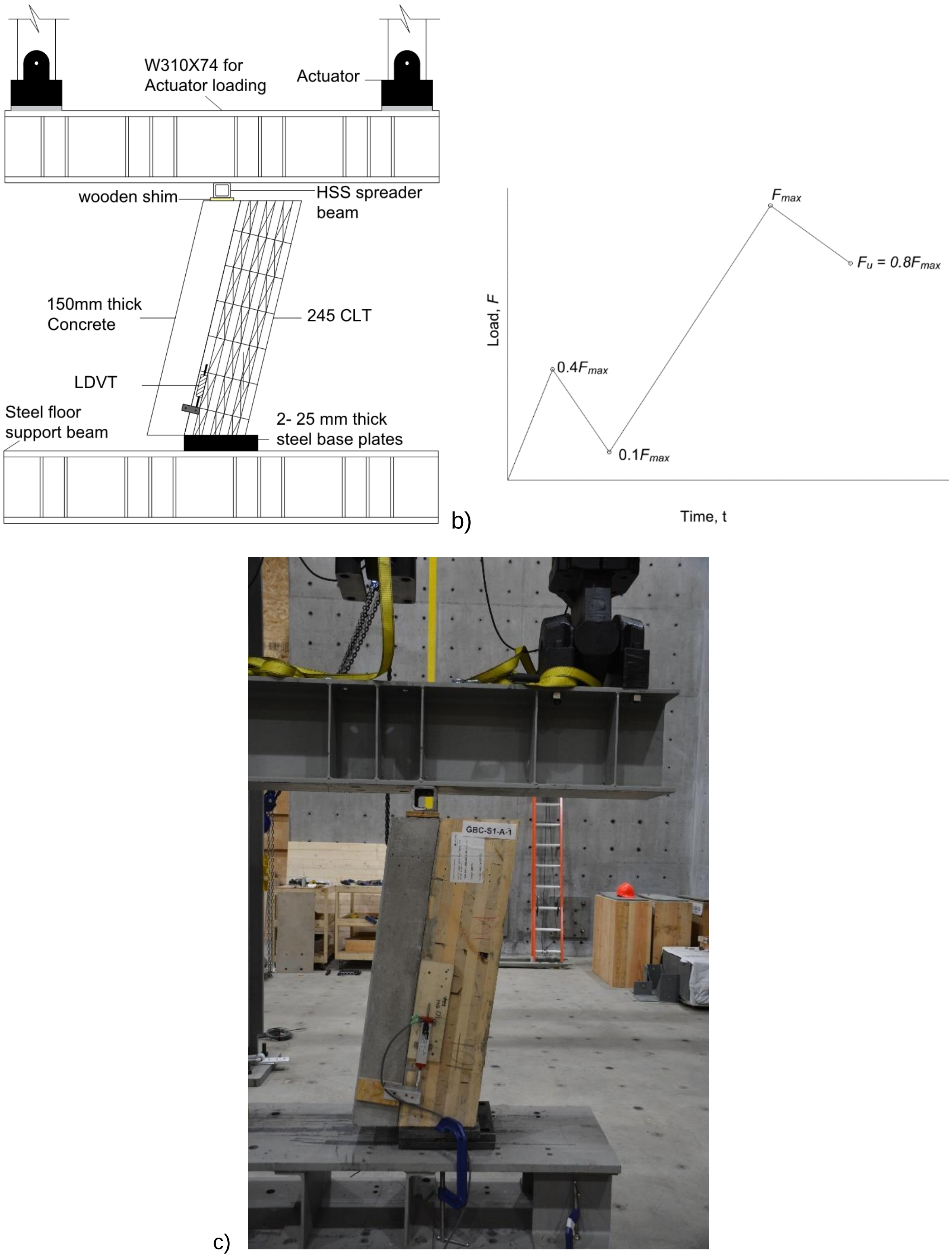

Figure 4: (a) Schematic of small-scale test setup, (b) loading protocol [EN 26891,] and (b) photo of a test setup

3 RESULTS AND DISCUSSION

3.1 Load-Deflection Curves

The load-deflection curves from the small-scale steel kerf plate connector tests, illustrated in Figure 5. The average from the load-deformations from each type of small-scale tests were plotted together in Figure 5d and were found almost linear with identical stiffness up to failure, which occurred between 325 kN and 375 kN and at roughly 3 mm for all specimens (Table 4). Load-carrying capacity, displacement at maximum load, and stiffness of all series were comparable. S1-A, S1-B, S1-C were tested for embedment depths of 35mm, 70mm, and 90 mm respectively. The small-scale test results validated the initial design assumptions that 35 mm CLT embedment is sufficient for the TCC slab bands.

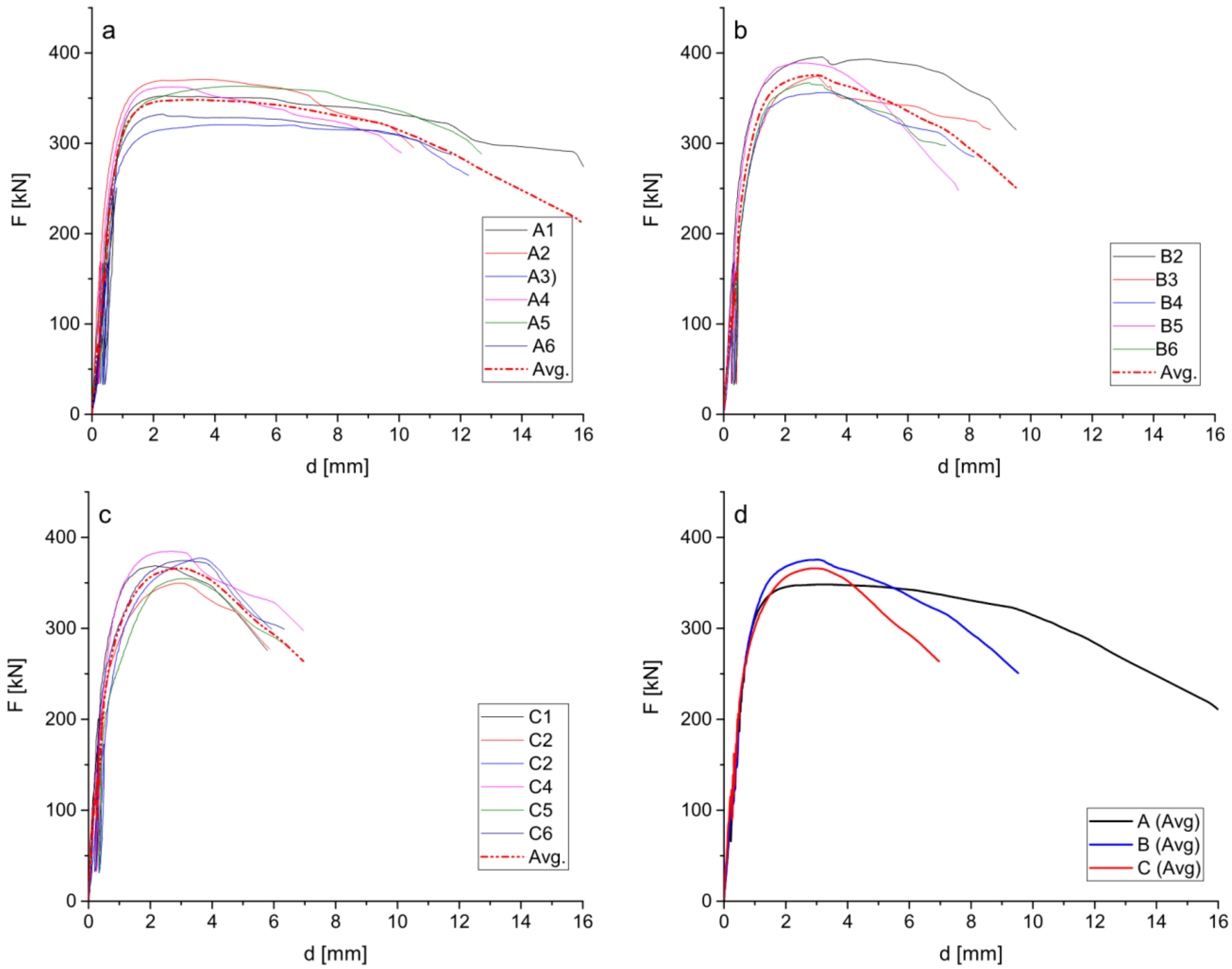

Figure 5: Small-scale test load-deflection curves: a) S1-A; b) S1-B; c) S1-C

Table 5: Results from TCC tests

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%

3.2 Failure Modes

Typical failure patterns of all three test series are shown in Figure 6. Both series A and C with 35 mm and 90 mm CLT embed were failed in concrete crushing at the location of steel plates where the concrete shear failure initiated. In series B, when the steel plates were ectended to the CLT cross layers i.e., 2nd layer into CLT, a rooling 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.

(a) (b) (c)

Figure 6: Typical failure pattern: a) Series A, b) Series B, and c) Series C

4 CONCLUSIONS

This research evaluated the performance and efficiency of TCC systems with steel kerf plates. There has been a relatively small amount of research on shear capacity of TCC panels as this seldom controls design. In addition to this being one of the main points of investigation, finding a low cost, simple to install shear connector was also of interest. The following key conclusions can be drawn from this testing program:

- Small-scale test results for the kerf plates validated the initial assumptions that 35 mm CLT embedment is sufficient for the TCC slab bands.
- 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.

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. Upon completion of this testing, the steel kerf plate TCC connector solution with 35 mm CLT embed was deployed with this innovative slab band solution.

5 ACKNOWLEDGEMENTS

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