HOKKAIDO UNIVERSITY

Title	INVESTIGATION ON TCC SYSTEMS USING SELF-COMPACTING CONCRETE
Author(s)	MOSHIRI, FARZAD; SHRESTHA, RIJUN; CREWS, KEITH
Citation	Proceedings of the Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-13), September 11-13, 2013, Sapporo, Japan, A-6-1., A-6-1
Issue Date	2013-09-11
Doc URL	http://hdl.handle.net/2115/54227
Type	proceedings
Note	The Thirteenth East Asia-Pacific Conference on Structural Engineering and Construction (EASEC-13), September 11-13, 2013, Sapporo, Japan.
File Information	easec13-A-6-1.pdf

Instructions for use

Hokkaido University Collection of Scholarly and Academic Papers : HUSCAP

INVESTIGATION ON TCC SYSTEMS USING SELF-COMPACTING CONCRETE

Farzad Moshiri[1*], Rijun Shrestha[2]and Keith Crews[3]

[1]*PhD candidate, University of Technology, Sydney, Australia (corresponding author)*
[2]*Lecturer, University of Technology, Sydney, Australia*
[3]*Professor of Structural Engineering, University of Technology, Sydney, Australia*

ABSTRACT

Interest in timber-concrete composite (TCC) floors has increased over the last 20-30 years. Since the 1990‘s, TCC solution is seen as a viable and effective alternative to conventional reinforced concrete and/or traditional timber floors in multi-storey buildings. TCC technology relies on timber and concrete members acting compositely together. Thus, the strength, stiffness, location and number of connectors play a crucial role for the composite action and determine the structural and serviceability performance of TCC solutions.

To date, conventional concrete (CC) has been used in most investigations on TCCs. Also, there are only few researches about the effect of concrete properties on the structural behaviour of TCCs. Self-compacting concrete (SCC) is highly workable and can be compacted without use of conventional vibration methods. As such, there is a potential for application of SCC in difficult to access areas or areas where complex formwork make it difficult to use conventional vibration methods.

University of Technology Sydney has investigated TCC solutions since 2007. The investigation presented in this paper focuses on utilising mechanical fasteners for their ductility and stiffness to compositely attach a SCC slab to a timber beam and to investigate the effect of use of SCC on the behaviour of such connections. The experimental aspect of the research consists of push-out tests and aims to characterise slip modulus and load capacity. The responses of the specimens are also compared to that of TCC systems with conventional concrete. The failure modes of the connections are also studied.

Keywords: timber concrete composite (TCC), Self Compacting Concrete (SCC), shears connection, push-out test, SFS screws

1. INTRODUCTION AND BACKGROUND

Timber-concrete composite (TCC) floor has gained wider recognition in the construction industry as an effective and viable alternative to conventional reinforced concrete and/or traditional timber

[*]Presenter and Corresponding author: Email: Farzad.Moshiri@uts.edu.au

floors in multi-storey buildings over the last 20-30 years, but they are especially competitive in cases where a timber floor already exists and the concrete is cast and connected on top to rehabilitate the flooring system (Jorge, Lopes et al. 2011).The system involves a timber base supporting a concrete slab, and composite action is achieved between the two layers through various types of shear connection that transfer shear forces and impedes slip between the members. Strength, stiffness, location and number of connectors play a crucial role for the composite action and determine the structural and serviceability performance of TCC solutions(Moshiri, Crews et al. 2012 (a); Moshiri, Garven et al. 2012(b)).

There are only few researches about the effect of concrete properties on the structural behaviour of TCCs. With the advance in high performance concrete, concrete mixes can be designed to new requirements of strength and serviceability such as Self Compacting Concrete (SCC), Light-Weight Concrete (LWC) and Fibre Reinforced Concrete (FRC) (Kieslich & Holschemacher 2010).

SCC has been using increasingly for more than two decades in pre-cast concrete technology whereas its application provides an interesting development in TCC technology to increase the workability of concrete without the need of an external vibration which is favourable to flow over congested area properly and in places (Ramezanianpour, Samadian et al. 2012).Utilising SCC in TCCs is of interest for two reasons, the first is because the concrete needs to be workable and compactable in order to fill the formwork properly, and it needs to be pumpable as some locations, particularly in retrofits may not be able to be reached by crane (Kieslich & Holschemacher 2010).

The components of SCC and conventional concrete are identical including cement, water, aggregates, admixtures, and mineral additions but the composition of the mixture, fresh and hardened properties are different. SCC includes larger amount of mineral fillers (i.e. finely crushed limestone or fly ash) and water-reducing admixtures. Moreover the maximum size of coarse aggregate is less than that used in conventional concrete.

2. TEST PREPARATION AND CONNECTION DESCRIPTION

University of Technology, Sydney has been involving in investigation on TCC solutions since 2007. The investigation presented in this paper studies the mechanical properties of TCC joint with inclined crossed screws using SCC and CC slabs.

The experimental aspect of the research consists of push-out tests and aims to characterise load-slip response, slip modulus and load capacity of dual SFS intec screws specimens casted with SCC. The responses of the specimens are also compared to that of TCC systems with conventional concrete and the failure modes of the connections were also investigated.

The behaviour of the composite system as well as each individual component is of interest. The tests included the use of varying concrete mix designs, in order to observe how the mix design influences the response of the connection. A total of eight samples were prepared each for two different mixes, conventional concrete (2400 kg/m^3, 35), SCC (2500 kg/m^3, 35 MPa). The samples were prepared with dimensions as displayed in Figure 1.

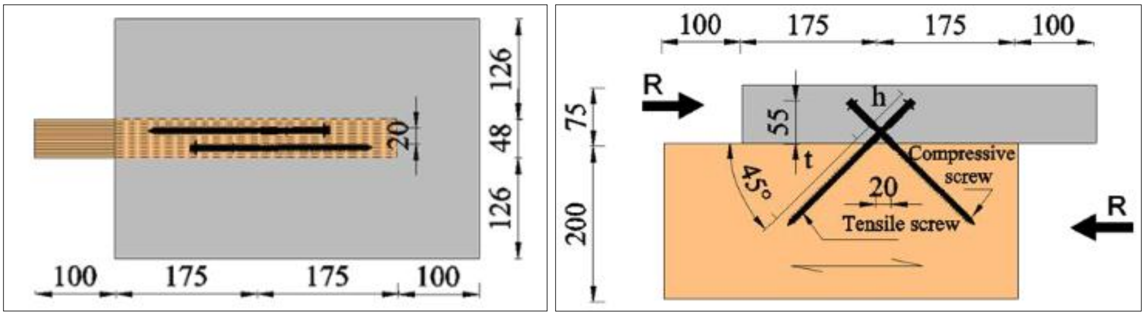

Figure 1: The cross section of TCC specimen (left) and the plan view of TCC specimen (right).

2.1. CONCRETE PROPERTIES

The adequacy of the mix was determined using different specific test methods including slump-flow, G ring, V funnel and L box which measure the amount of flowability, passing ability and filling ability of the SCC mix. The specifications of the concrete can be seen in Table 1.Water reducer, superplasticiser and viscosity modifying admixture were used to adjust the mix design. After 7 days the formwork was removed and the concrete was cured for another 21 days under normal lab conditions.

Table 1: concrete mix designs.

Mix	Gravel 20mm (kg)	Gravel 10mm (kg)	Coarse Sand (kg)	Fine Sand (kg)	Cementitious content (kg)	Water (kg)
CC-2400	755	406.5	355.6	355.7	350.4	130.1
SCC-2400	-	860.2	466.4	466.4	400	208

3. TIMBER (LVL)

Timber specifications and design properties are given in Table 2.

Table 2: Mechanical property of timber((CHHWA) 2011).

Mechanical property	Value (MPa)
Veneer Species	Radiata Pine or Douglas Fir
Density	560 - 650 kg/m3
Modulus of Elasticity (E)	13,200 MPa
Modulus of Rigidity (G)	660 MPa
Characteristic Stress in bending (fb)	44.6 Mpa
Characteristic Stress in tension parallel to grain (ft)	23.8 Mpa
Characteristic Stress in compression parallel to grain (fc)	41 MPa
Characteristic Stress in compression perpendicular to grain (fp)	12 MPa
Characteristic Stress in longitudinal shear (fs)	4.6 MPa

The laminated veneer lumber (LVL) from the hySPAN range produced by Carter Holt Harvey Wood is employed as timber joist in TCC specimens.

3.1. SHEAR CONNECTION

The shear connections used in the specimens comprised of dual VB-48-7.5 x 165 SFS intec screws embedded into the timber at ±45 degree angles as shown in Figure 2. The screws were placed at the midpoint of the timber-concrete interface and a guide was used to ensure the screws were inserted at the required angle and depth. The SFS screw connectors were developed by (Meierhofer 1992) and were specifically designed to be used in TCC structures, either in the construction of new flooring systems or the rehabilitation of existing timber floors. Each SFS screw had a 6 mm diameter and 85 mm long top section which acts as an anchor in the concrete, and a 7.5mm diameter 165mm long threaded section which is embedded into the timber component, as depicted in Figure 2. In investigations carried out by (Blass, Ehlbeck et al. 1995), (Van der Linden 1999), (Frangi & Fontana 2003), (Steinberg, Selle et al. 2003), (Grantham, Enjily et al. 2004), (Lukaszewska 2009), (Jorge, Schänzlin et al. 2010) and (Jorge et al. 2011), (Moshiri et al. 2012 (a))and (Moshiri et al. 2012(b)), SFS screws have been employed to connect timber to concrete components in TCC.

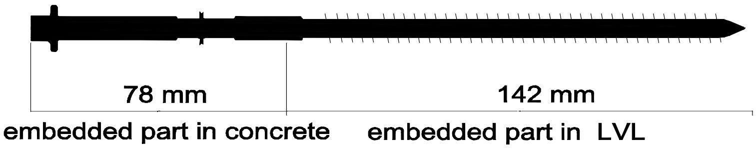

Figure 2: SFS screw.

4. TEST SET-UP, TEST PROCEDURE AND DATA RECORDING

The push out tests were conducted after 28 days of curing to measure the effectiveness of the shear connection in terms of its strength and stiffness. During the tests, the TCC specimens were held upright in a steel frame as test rig. The specimens were placed so that the free end of the timber was at the top where the load was to be applied as shown in Figure 3.

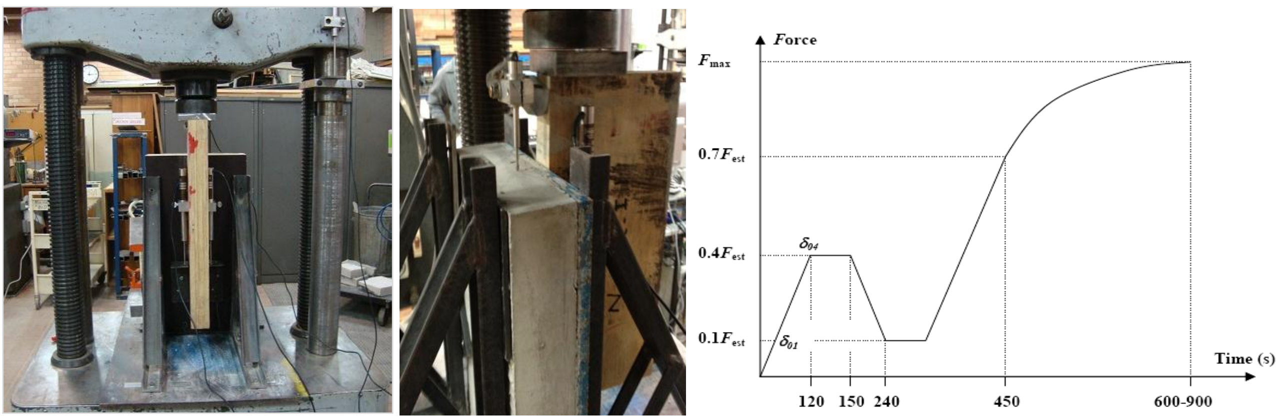

Figure 3: Set-up of a specimen in the test rig and loading regime in comply with (CEN 1991).

The inclusion of a steel block which was placed on top of the timber ensured that uniform load distribution was being achieved. A load cell and three Linear Variable Differential Transformers (LVDTs) were applied to measure data. The testing procedure was speed controlled in accordance with the provisions of **(CEN 1991)** which sets a required loading sequence as depicted in Figure 3. The samples are loaded to 40% of anticipated failure load, F_{est} over a period of two minutes. The load is then maintained at this level for 30 seconds, before being reduced to 10% of F_{est} over a period of 90 seconds and is held at this level for a further 30 seconds. Following this, the sample is loaded at a continuous rate until failure and the failure modes have been investigated.

Slip modulus and stiffness of the connection were obtained from load-slip response of connections which were plotted by measuring the applied load and the slip at the interface between the timber and the concrete.

5. RESULTS AND DISCUSSION

During the tests, applied load and corresponding deflection and slip at the three locations where the LVDTs were placed were recorded. The load-slip responses of the test series are shown in Figure 4.

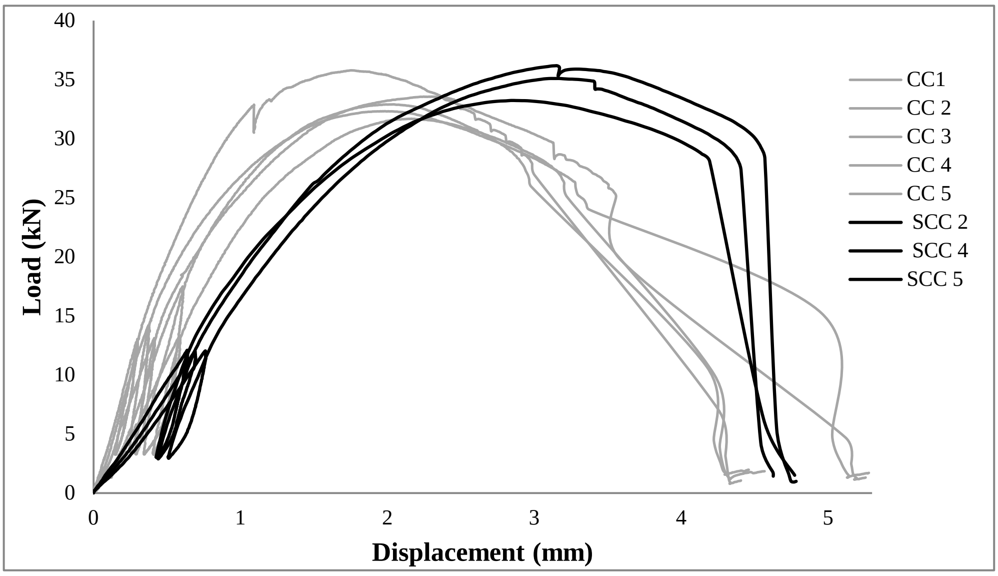

Figure 4: Load-Slip responses for Specimens.

5.1. STRENGTH ANALYSIS

Maximum load capacities of TCC joint of two different test series are shown in Table 3. Comparing CC and SCC series, application of SCC decreases the strength about 4% as shown in Table 3 .

Table 3: Strength of different test series.

Test series	specimens	Range(kN)	Mean Strength(kN)	Strength Qk (kN)	σ	CoV (%)
CC	5	31.69-35.78	33.25	31.6	1.58	4.75%
SCC	3	33.23-36.17	34.6	32.95	1.3	3.76%

5.2. STIFFNESS ANALYSIS

Three different slip moduli corresponding to serviceability, ultimate and 0.8 F_{max} of TCC joint are illustrated in Table 4. Application of SCC instead of conventional concrete series reduced different slip moduli including $K_{s,0.4}$,$K_{s,0.6}$ and $K_{s,0.8}$ about 20%,40% and 30%, respectively.

Table 4: Slip moduli of different test series.

Test series	specimens	slip modulus	Range(kN/mm)	Mean(kN/mm)	σ	cov(%)
CC	5	Ks,0.4	16.75-54.05	28.8	14.66	51%
		Ks,0.6	18.07-43.49	26.63	10.15	38%
		Ks,0.8	16.9-35.4	23.37	7.24	31%
SCC	3	Ks,0.4	21.53-24.42	22.69	1.52	6.70%
		Ks,0.6	17.55-19.68	18.95	1.21	6.40%
		Ks,0.8	16.4-17.55	17.08	0.6	3.50%

5.3. Failure mode analysis

Failure mechanism of specimen including the failure of screws as well as angle of screws at the plane of connection and state of concrete and timber around connection were of interest. Following the failure of the specimens, they were removed from the frame and were splitted to determine the failure mode. The General and localised failure modes of different test series are illustrated in Figure 5. The tensile failure of screw working in tension is observed as dominant failure mechanism of both SCC and CC series as indicated in Figure 5 andFigure 6.

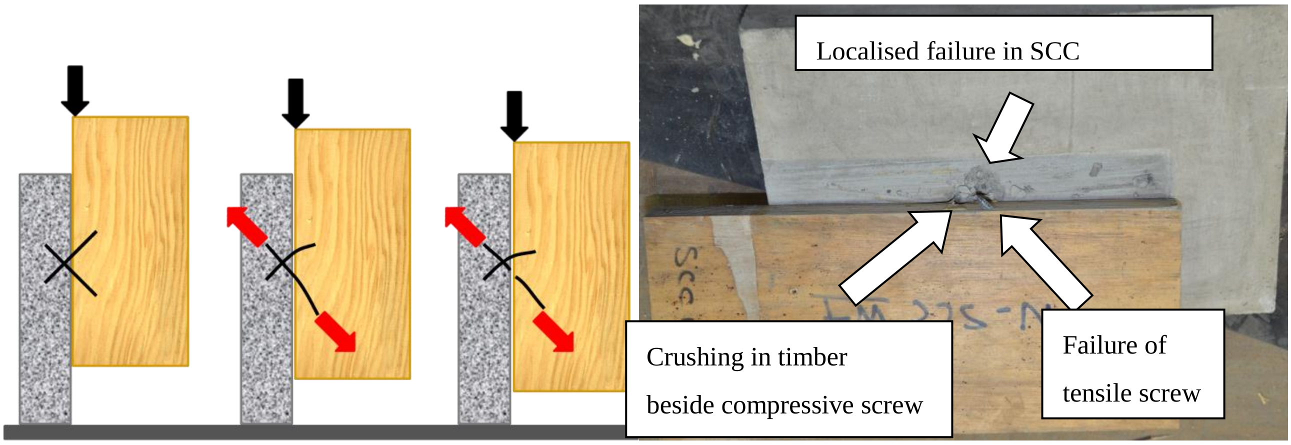

Figure 5: failure of test series.

As shown in Figure 4 the behaviour of the SCC and CC series were fairly consistent. The load increased quite steadily, slowing slightly before peaking. Most of the specimens for SCC series reached a maximum load of around 35kN. After the peak load (F_{max}) was reached, load gradually reduced to around 80-90% of F_{max} before a sudden failure occurred. Close inspection of failed specimens as shown in Figure 6 indicated that the connections failed due to a tensile failure in the screw, with shear being a contributor and localised damage in surrounding concrete. Necking was evident in the tension screw in all cases, further highlighting a tensile failure after undergoing plastic deformation. Furthermore, the screws failed at their narrowest point, located 10-20 mm above the thread and embedded in the concrete. A total deflection of 2 - 3.5 mm was recorded across the specimens.

Figure 6: Opened specimen of SCC series, tensile screw (on left) and compressive screw (on right).

6. CONCLUSIONS

The application of SCC indicates an innovative development of TCC technology to obtain a workable and compactable concrete. Investigation on application of SCC and its influence on mechanical properties of TCC joint have been presented in this paper. This work increased the understanding of key parameters of strength, stiffness and failure mechanism of TCC joints using LVL and SCC. The general load-slip responses and failure mode of SCC series indicates a similar trend as with conventional concrete. However, application of SCC reduces serviceability slip modulus about 20% but no significant reduction in strength of the connections could be observed. The lower stiffness of TCC joints with SCC might limit its application but SCC is promising for TCC construction where the pumping and compaction of conventional concrete is a significant challenge, such as renovation of existing timber floors in multi stories building.

7. ACKNOWLEDGEMENT

The authors gratefully acknowledge the financial support of Structural Timber Innovation Company (STIC).

REFERENCES

(CHHWA) C. H. H. W. A. 2011, Span Guide for Residential Framing, in C.H.H.W.A. (CHHWA) (ed.)CHHWA, Australia.

Blass H. J., Ehlbeck J. et al. 1995, 'Trag- und Verformungsverhalten von Holz-Beton-Verbundkonstruktionen'.

CEN 1991, Timber structures - joints made with mechanical fasteners - general principles for the determination of strength and deformation characteristics, EN26891, European Committee for Standardization, Brussels, Belgium.

Frangi A. & Fontana M. 2003, 'Elasto-Plastic Model for Timber-Concrete Composite Beams with Ductile Connection', Structural Engineering International, vol. 13, pp. 47-57.

Grantham R., Enjily V. et al. 2004, 'Potential upgrade of timber frame buildings in the UK using timber-concrete composites', paper presented to the *World Conference on Timber Engineering WCTE* Lathi,Finland.

Jorge L. F. C., Lopes S. M. R. et al. 2011, 'Interlayer Influence on Timber-LWAC Composite Structures with Screw Connections', Journal of Structural Engineering, vol. 137, no. 5, pp. 618-24.

Jorge L. F. C., Schänzlin J. et al. 2010, 'Time-dependent behaviour of timber lightweight concrete composite floors', Engineering Structures, vol. 32, no. 12, pp. 3966-73.

Kieslich & Holschemacher 2010, 'Composite constructions of timber and high-performance concrete', Advanced material research, vol. 133 - 134, pp. 1171-6.

Lukaszewska E. 2009, 'Development of Prefabricated Timber-Concrete Composite Floors', Universitetstryckeriet, Luleå, Lulea.

Meierhofer U. 1992, 'a new efficient system for timber/concrete composite structural elements. Test, research and development', *the IUFRO S5.02 Timber Engineering Conference*

Moshiri F., Crews K. et al. 2012 (a), 'The effect of interlayer on the structural behaviour of timber concrete composite joints using light-weight and conventional concrete', paper presented to the *Diversity in Composites*, Leura, New South Wales, Australia.

Moshiri F., Garven C. et al. 2012(b), 'An investigation on tcc systems using light-weight concrete', paper presented to the *world conference on timber engineering(WCTE)*, New Zealand.

Ramezanianpour A., Samadian M. et al. 2012, 'Engineering properties and durability of self-consolidating concretes (SCC) containing volcanic pumice ash', Asian journal of civil engineering (building and housing), vol. 13, no. 4, pp. 521-30.

Steinberg E., Selle R. et al. 2003, 'Connectors for Timber–Lightweight Concrete Composite ', Journal of Structural Engineering, vol. 129, no. 11, pp. 1538-45.

Van der Linden M. L. R. 1999, 'Timber-Concrete Composite Floor Systems', Delft University Press.