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Advancing Timber for the Future Built Environment

STRUCTURAL BEHAVIOUR OF TIMBER-CONCRETE COMPOSITES INCORPORATING RIBBED CONCRETE LAYER

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ABSTRACT: This study investigates the applicability of lightweight timber-concrete composites employing an innovative ribbed concrete layer. Push-out tests were conducted, and the structural performance was assessed by examining the applied load and the relative slips between timber and concrete in accordance with BSEN26891. Specimens were fabricated from cross-laminated timber in conjunction with ribbed concrete or solid concrete layer with screw penetration inclined at 90°,45° or 30° in cross-inclined configuration. The findings reveal that timber-ribbed concrete composites have similar structural behavior to those with solid concrete layer but with a minor reduction in ultimate slip modulus and a slight increase in the slip between timber and concrete. Cross-inclined screws resulted in improved load-slip performance and reduced concrete cracking of ribbed concrete specimens. The results highlight the potential of ribbed concrete layer as an alternative approach to improve the efficiency and sustainability of timber-concrete composite structures.

KEYWORDS: Timber Concrete Composite, Push-Out Test, Ribbed Concrete Layer, Cross-Laminated Timber, Screw Connection

1 – INTRODUCTION

Timber-concrete composite (TCC) structures have gained significant application in building construction, providing a more sustainable and optimised approach to utilising the mechanical strengths of timber and concrete materials [1]. Timber has lightweight features and provides high tensile strength, whereas concrete resists compressive forces during composite action [2]. The enhanced load and fire resistance characteristics of TCC have led to the widespread adoption as flooring systems in buildings and renovating old timber structures. However, the mechanical strengths of timber and concrete materials and effective load transfer between connectors are critical to the structural performance of TCC structures. Shear connectors such as dowels improve ductility and partial composite action between timber and concrete, making TCC resilient under cyclic or earthquake load applications [3].

Concrete layer in TCC floors significantly impacts structural self-weight, flexural capacity and vibration characteristics of composite members [4]. Concrete accounts for up to a third of TCC cross-section and contributes more than three times the overall structural self-weight using normal concrete, considerably increasing the span-weight ratio, and affecting the long-term deflection behaviour in long-span applications [5]. Previous studies have extensively examined TCC systems with solid concrete and timber sections, focusing on stiffness of various shear connectors between timber and concrete such as screws, notches or adhesives [6], [7], [8], amongst others Recently, there have been efforts by to reduce concrete self-weight through the utilisation of lightweight aggregate concrete and high-performance concrete contributing to significant weight reduction in TCC [9], [10].

However, incorporation of innovative concrete or timber geometries such as hollow or voided sections in TCC has become an emerging solution to reduce self-weight and optimise structural performance of TCC structures [11]. Timber-hollow concrete structures significantly improves sustainability by optimising material utilisation in the tensile region below neutral axis in concrete layer. Voids in concrete layer also provides secondary openings for building services and improves thermal insulation. Hollow

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concrete has been used extensively in reinforced concrete buildings and composite steel structures due to its enhanced structural properties [12][13]. However, application in TCC is limited. Ou et al. [14], [15] investigated hollow timber concrete composites floor using corrugated glass fibre reinforced polymer as interlayer, achieving 42-51% reduction in concrete volume while demonstrating high efficiency in ultimate moment and stiffness. Furthermore, Tannert et al. [16] examined the long-term performance of TCC beams with longitudinal or transverse voids in concrete slab, and attained 45% weight reduction and efficient composite action with minimal degradation of adhesive connection despite reduction in bonded area between timber and concrete.

Innovative timber-ribbed concrete composite has potential as a more optimised approach to sustainable TCC structures. However, ribbed concrete layer significantly affects the mechanical behaviour of composites due to reduced material stiffness and frictional contact area between concrete and timber. Moreover, the fabrication of voids concrete geometry usually requires permanent formwork as interlayer which increases self-weight and reduces TCC stiffness [17] Therefore, understanding the structural performance of timber concrete composite incorporating innovative ribbed concrete is essential to exploit the structural benefits for practical implementation. This research is aimed at investigating the impact of innovative ribbed concrete layer on the structural behaviour of TCC, in comparison with solid concrete layer with screw connectors at various penetration angles through a series of push-out tests to evaluate the relative slip, slip modulus, maximum force and failure modes. The findings provide insight on the structural performance of ribbed concrete, advancing lightweight TCC structures for long-span applications and promote sustainability by minimising concrete volume and related embodied carbon while optimising composite performance.

2 – EXPERIMENTAL PROGRAM

2.1 MATERIAL PROPERTIES

Normal-weight concrete was used in this research and designed to achieve a target compressive strength of 35MPa at 28 days following Building Research Establishment (BRE) guidance. The maximum fine and coarse aggregates size was 5mm and 20mm respectively. Ordinary Portland Cement (OPC) of grade 52.5N was used as binder. A water-cement ratio (w/c) of 0.55 and a mix ratio of 1:2:3 (cement: sand: coarse) by weight was used in preparing the concrete mix. Slump values were measured immediately after mixing as per BSEN12350[18]. Additionally, 100×100×100mm concrete cubes were manufactured and tested for compressive strength at 28 days following BSEN 12390 [19].

Partially threaded self-tapping screws with a nominal diameter of 6mm and an overall length of 100mm were used as shear connectors. The screws are made from hardened carbon screws with corrosion-resistant coating. The washer head design enhances pull-out resistance in concrete, while the self-drilling tip eliminates predrilling [17].

Three-layer cross-laminated timber of overall thickness of 90mm made from *Sitka Spruce* wood in longitudinal and transverse layers was utilised. The average density and moisture content of CLT was 459.87kg/m^{3,} and of 10.22% respectively, determined in accordance with BSEN408:2010 [20]. The physical and mechanical properties of materials used are summarised in Table 1.

Table 1: *Physical and Mechanical Properties of Materials*

Material	Property	Value	Units
Concrete	Compressive Strength	37.32	MPa
	Density	2354.67	kg/m^3
	Slump	52.5	mm
Screws	Outer Diameter	6	mm
	Length	100	mm
	Yield Strength	1000	N/mm^2
	Yield Moment	9493.71	Nmm
CLT	Density	459.87	kg/m^3
	Moisture Content	10.22	%

2.2 SPECIMEN CONFIGURATION AND FABRICATION

A total of 24 TCC specimens were fabricated as provided in Table 2. The specimens comprised of 90×300×450mm central cross-laminated timber (CLT) panels, conjoined with 60×300×450 mm solid or ribbed concrete layer on either side with screws as shown in Figure 1. CLT panels were predrilled and 6mm diameter partly threaded self-drilling screws were inserted at a penetration depth of 60mm at 30°, 45° or 90° angle relative to the timber surface. Screws were inserted with a longitudinal and transverse spacing of 100mm and 150mm respectively in accordance with Eurocode 5 [21]. The ribbed concrete layer was fabricated using 30mm thick Expanded

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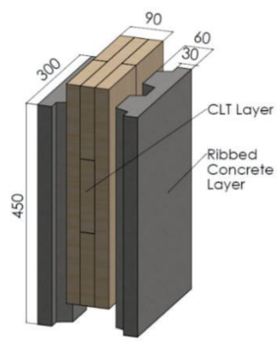
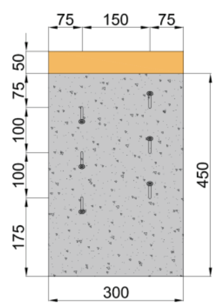
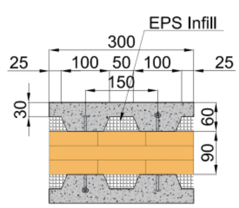
Polystyrene Styrofoam (EPS) panels attached to CLT using glue as shown in Figure 1c. EPS panels are considered non-structural elements. The ribbed concrete section was designed to achieve approximately 20% reduction in concrete volume. Fabricated CLT specimens were placed into formwork and concrete was poured to fill the formwork as shown in Figure 2. Each specimen was subsequently labelled to ensure specimen identification and efficient data collection, for instance, TCC-NC-S90, where TCC represents timber-concrete composites, NC signifies normal concrete, S is solid concrete section, and 90 is screw penetration angle at 90°. A similar designation was used for ribbed concrete section with R replacing S. Both solid and ribbed concrete composite fabricated specimens were left to cure for a minimum of 28 days under standard laboratory conditions.



(a) 3D model of Innovative Timber-Ribbed Concrete Composite Specimen



(b) Screw Configuration and Dimensions



(C) Ribbed Concrete Layer Section

Figure 1 *Specimen configuration(mm)*

Table 2: *Specimen Configuration*

Specimen Configuration	Screw Angle/ Configuration	Insertion Depth [mm]	No. of Samples
TCC-NC-S90	90°		4
TCC-NC-S45	45°	60	4
TCC-NC-S30	30°		4
TCC-NC-R90	90°		4
TCC-NC-R45	45°	60	4
TCC-NC-R30	30°		4

(a) (b)

Figure 2: *(a)CLT Specimen with attached EPS panels and screws in formworkand and (b) CLT-concrete composites*

2.3 TEST SETUP AND LOADING PROTOCOL

TCC specimen was positioned and supported at their base as shown in Figure 3. A steel plate was placed on top of the CLT specimen to distribute the applied load uniformly. A vertical force was applied using a Zwick Zoel Actuator with a 300kN maximum load capacity at a loading rate of 0.7mm/min. Four linear variable displacement transducers (LVDT) with 25mm capacity were attached on both sides of the CLT section to measure the vertical displacement. The force was applied in accordance with the loading profile in BSEN26891[22]. Estimated failure load F_{est} was determined by testing one specimen in each series. The specimens were loaded to $0.4F_{est}$, then unloaded to $0.1F_{est}$, and thereafter loaded gradually until failure. The load-slip graph was plotted by taking the applied load recorded directly from the load cell and the displacement was averaged from measurements of four LVDTs. The main parameters determined include relative slips, ultimate force and slip modulus.

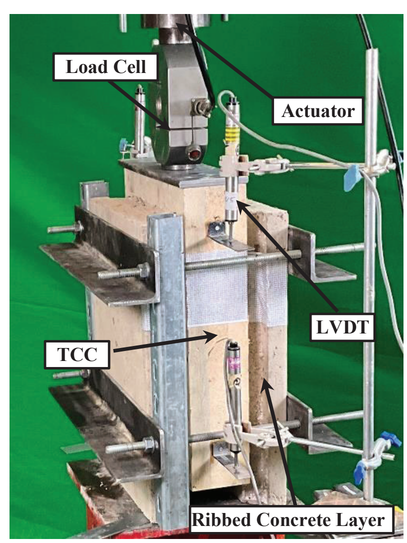


Figure 3 *Experimental setup of TCC specimen*

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3 – RESULTS & DISCUSSION

This section presents the results and discussion of experimental investigation of timber concrete composites using ribbed concrete layer and the influence of screws at various penetration angles on structural performance in comparison with solid concrete specimens as shown in the load-slip graphs in Figure 4. Both ribbed and solid concrete specimens experienced elastic behaviour for relatively small slips which was accompanied by concrete cracking sound with loss of stiffness followed by a rebound until maximum applied load was attained. The main mechanical parameters were evaluated using the load-slip graph. These include the ultimate force (F_{max}), slip at maximum force (v_{max}), initial slip modulus ($k_{i0.4}$), serviceability slip modulus(k_{ser}), ultimate slip modulus(k_{ult}) and slip modulus at collapse load ($k_{0.8}$) using numerical equations in BSEN 26891[22] and provided in Table 3. The findings highlight the structural performance of ribbed concrete layer and influence of screw penetration angle.

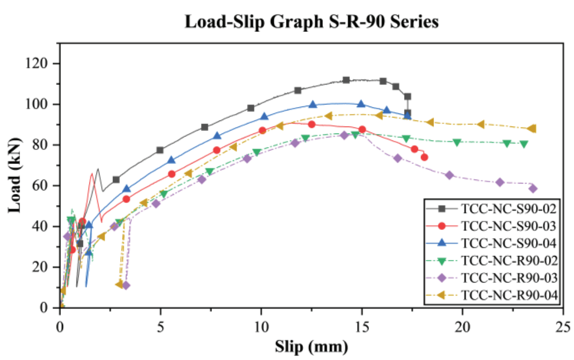

Figure 4a: Load-slip graph for 90° Solid and Ribbed TCC specimens

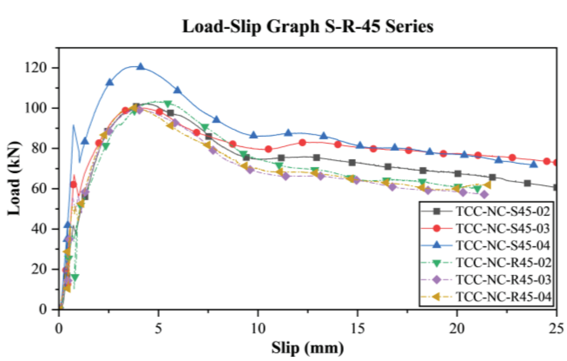

Figure 4b: Load-slip graph for 45° Solid and Ribbed TCC specimens

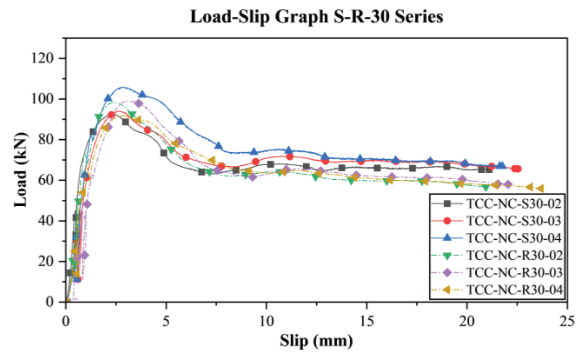

Figure 4c: Load-slip graph for 30° Solid and Ribbed TCC specimens

3.1 EFFECT OF SCREW PENETRATION ANGLE

The force transfer between the timber and concrete was affected by the screw penetration angle. The maximum load resisted by solid concrete section with 90° screws was 101.05kN, which increased by 5% in 30° specimens and further increased by 9% in 45° specimens. A similar trend was observed in ribbed concrete section with significantly reduced force with 90° specimens achieving 88.56kN, which also increased by 9% in 30° specimens and 14% in 45° specimens. These results suggest that 45° inclination provides superior load resistance and force distribution between timber and concrete layers in solid and ribbed concrete specimens as observed by other authors [6].

The interlayer slip values were similarly reduced with decreasing screw penetration angle relative to timber surface. For solid concrete specimens, with 90°screw, the slip was 13.52mm, while with 45° screw, it reduced to 4.08mm and further reduced with 30° screw to 2.63 resulting in 70% and 81% reduction respectively. Similarly, ribbed concrete specimens experienced slightly higher slip values, with 90° screw specimens attaining 14.63mm while 45° and 30° specimens experienced reduced slip values of 71% and 82%, respectively. These results indicate that inclined screws improve connection stability by limiting the relative displacement between timber and concrete layers with 30° specimens achieving smaller interlayer slip values.

The serviceability slip modulus which represents the stiffness of TCC connection in response the load and relative displacement increased with inclined screws. For solid concrete specimens with screws at 30° and 45°, the slip modulus increased by 115% and 166% respectively, compared to 90° specimens which attained 42.21kN/mm. In ribbed concrete specimens, 30° specimens obtained the highest slip modulus of 94.87kN/mm, whereas 45° and 90°

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specimens attained 9% and 3% reduction respectively. However, as the screw penetration angle decreased relative to CLT surface, the ultimate slip modulus also increased consistently for solid and ribbed concrete specimens. 30° solid and ribbed concrete specimens achieved the highest ultimate slip modulus of 81.67kN/mm and 71.21kN/mm respectively, representing 354-424% more than 90° specimens and 223-219% in 45° specimens. Conversely, 90° specimens showed the lowest slip modulus of 17.99kN/mm in solid concrete and 13.58kN/mm in ribbed concrete specimens. The sharp increase in ultimate slip modulus for inclined screws demonstrates the effectiveness of angled screws in transferring load between timber and concrete with the highest values recorded for 30° screws.

Overall results indicate that screw penetration angle has a significant impact on slip, slip modulus and overall load-carrying capacity of timber-ribbed concrete composite with cross-inclined screws providing improved load transfer and reduced slip, enhancing the overall structural performance of the composite.

3.2 INFLUENCE OF RIBBED CONCRETE LAYER ON STRUCTURAL PERFORMANCE

The type of concrete layer influenced the overall stiffness of the TCC during push-out test. Concrete layer resisted shear forces from screws and compressive forces from support during loading. In addition, ribbed concrete layer affected force distribution across the composite and impacted frictional resistance between timber and concrete during contact.

The maximum load of normal concrete sections was comparatively higher than ribbed concrete sections. 90° solid concrete specimens attained an average of 101.05kN, which was 12% higher than 90° ribbed concrete section. Similarly, 45° solid concrete specimens recorded 9% increase in load than similar ribbed concrete specimens. Furthermore, 30° solid concrete specimens achieved 9% higher load than identical ribbed concrete specimens. However, the percentage coefficient of variation (CoV) of ribbed concrete specimens were lower, ranging between 2-6% than solid concrete specimens with 7-11%, signifying improved consistency with ribbed concrete TCC specimens despite relatively lower load-carrying capacity.

Slip values were consistently higher in ribbed concrete specimens than solid concrete sections. Solid concrete specimens with 90° screws experienced 13.52mm slip whereas ribbed concrete specimens attained increased slip of 14.63mm representing 8% higher. Similarly, 45° ribbed concrete specimens experienced 4% increase compared to solid concrete section. In the same way 30° specimens also achieved 3% increase compared to solid concrete section. This slight increase in slip values for ribbed concrete specimens highlight the effect of reduced frictional contact area between timber and concrete.

The slip modulus of TCC specimens was influenced by the concrete layer. At 90° screw angle, ribbed concrete layer specimens achieved serviceability slip modulus of 91.92kN/mm which was 108% higher than 42.21kN/mm recorded for solid concrete specimens. For 30° and 45° specimens, the serviceability slip modulus of ribbed concrete was 94.87kN/mm and 86.03kN/mm respectively, representing 4% decrease and 23% increase compared to solid concrete which recorded 90.87kN/mm for 30° and 112.33kN/mm for 45° specimens. Ultimate slip modulus was consistently lower in ribbed concrete than solid concrete section for all screw angles. Ultimate slip modulus for 90° ribbed concrete was 25% lower than solid concrete specimen counterparts. Similarly, 30° and 45° ribbed concrete specimens also recorded 13% and 25% lower than matching solid concrete specimens. This highlights the effect of ribbed concrete geometry on overall stiffness of TCC indicating slightly lower slip and slip modulus due to reduced stiffness of concrete section and frictional contact area between timber and concrete.

Comparison of each screw penetration angles revealed that solid concrete section provided higher slip modulus with the highest improvement observed at 45° and 30° specimens as summarised in Table 3. The findings highlight increase in slip and reduction of slip modulus in ribbed concrete specimens while attaining 20% reduction in concrete self-weight compared to full concrete sections making it a good option in scenarios where lightweight construction is prioritised.

3.3 FAILURE MODE AND MECHANISM

Figure 5 shows the failure modes of both solid or ribbed concrete TCC specimens. The interaction between timber-screws-concrete during push-out test resulted in various failure modes such as screw yielding, concrete cracking and timber embedment failure. The degree of concrete cracking was similar in solid concrete and ribbed concrete specimens with reduced level of cracking with decreasing screw angle relative to timber surface. 90° specimens exhibited noticeable cracking due to high shear stresses transmitted by vertical screws at the timber-concrete interface. The ribbed concrete cracking was notable

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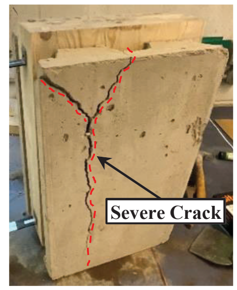
splitting through the web and flanges like solid concrete which also experienced concrete cracking through the section as shown in Figure 5a and Figure 5b. Minor cracks were observed in 45° ribbed concrete specimens across the flange and web of concrete due to punching of compression screws as shown in Figure 5c. However, there were no noticeable cracks in 30° solid or ribbed concrete specimens as shown in Figure 5d. This was due to the distribution of axial loads in angled screws delaying concrete cracking with steeper penetration angle.

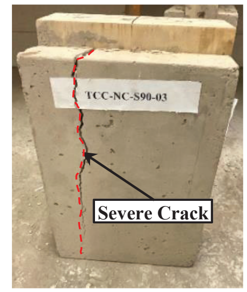
Screw yielding and formation of plastic hinges were observed in all specimens with a reduced degree of yielding in lower penetration angle screws relative to timber surface. 90° screw ribbed concrete specimens experienced double plastic hinges like solid concrete layer specimens with a relatively lower degree of yielding due to the low ultimate force transferred to screws. 45° specimens also demonstrated two plastic hinges in timber and concrete. However, the reduced shear forces in ribbed concrete limited the extent of yielding. 30° specimens proved most beneficial with very small yielding occurring in screws for both solid concrete and ribbed concrete sections.

Timber embedment failure in ribbed concrete specimens was lower than in solid concrete specimens. 90° screw specimens experienced high shear stresses around screw resulting in increased embedment depth. However, embedment in ribbed concrete specimens was less pronounced than in solid concrete specimens, presumably due to a relatively low ultimate load. The reduced deformation of timber fibres around screws for 90° ribbed concrete specimens enhanced connection stability compared to solid concrete specimens. 30° and 45° specimens evenly distributed applied loads across compression and tensile screws significantly reducing embedment depth in timber. The failure modes of TCC specimen are shown in Figure 5.

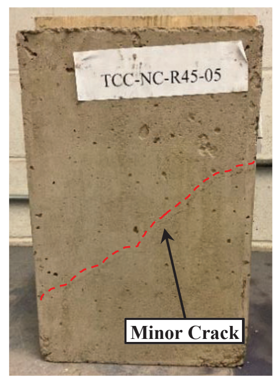
In conclusion, concrete cracking in ribbed concrete specimens was observed in web and flanges which was notable in vertical screw specimens. The extent of embedment failure and screw plastic hinge formation increased with decreased penetration angle to timber surface. Moreover, 30° ribbed concrete specimens provided the most favourable embedment timber failure and screw yielding. This indicates a robust connection between timber fibres with inclined screws, resulting in efficient force transmission. These results underscore the importance of optimising screw angle and utilising ribbed concrete layer for enhanced structural performance of TCC systems.



(a) Severe cracking in 90° Ribbed NC Specimen through web and flanges

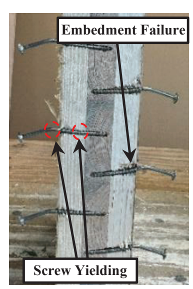


(b) Severe cracking in 90° Solid NC Specimen

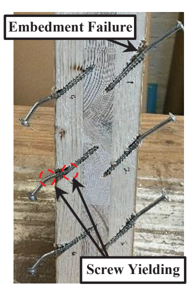


(c) Minor cracking in 45° Ribbed NC Specimen through cross-section

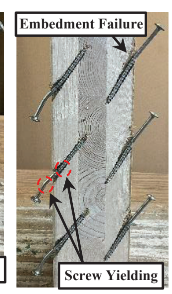
(d) No visible cracking in 30° Ribbed NC Specimen



(e) Typical screw yielding and timber embedment of 90° TCC specimen



(f) Typical screw yielding and timber embedment of 45° TCC specimen



(g) Typical Screw Yielding and timber embedment of 30° TCC specimen

Figure 5: *Failure Mode of TCC specimens*

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Table 3: *Experimental results from push out test*

Specimen ID	F_{est} / F_{max} [kN]	v_{max} [mm]	$k_{i\ 0.4}$ [kN/mm]	k_{ser} [kN/mm]	k_{ult} [kN/mm]	$k_{0.8}$ [kN/mm]	Failure Mode
*TCC-NC-S90-01	103.65	11.69					
TCC-NC-S90-02	111.98	15.00	39.44	36.42	18.75	11.15	
TCC-NC-S90-03	90.79	11.48	62.48	65.92	17.94	12.09	CC(Severe) + SY + EF
TCC-NC-S90-04	100.37	14.07	27.56	24.27	17.29	11.87	
Mean	101.05	13.52	43.16	42.21	17.99	11.70	
CoV(%)	10.50	13.48	41.14	50.74	4.06	4.24	
*TCC-NC-R90-05	111.34	13.94					
TCC-NC-R90-06	85.58	14.22	80.48	116.48	14.73	10.96	
TCC-NC-R90-07	85.05	14.66	89.32	98.56	13.36	10.47	CC(Severe) + SY + EF
TCC-NC-R90-08	95.04	15.01	58.78	60.73	12.65	10.41	
Mean	88.56	14.63	76.19	91.92	13.58	10.61	
CoV(%)	6.35	2.72	20.63	30.97	7.78	2.83	
*TCC-NC-S45-01	72.02	3.75					
*TCC-NC-S45-02	102.38	4.44					
TCC-NC-S45-03	100.03	4.27	73.96	98.36	56.48	43.68	CC(Minor) + SY + EF
TCC-NC-S45-04	120.68	3.89	96.49	126.30	59.83	46.80	
Mean	110.35	4.08	85.22	112.33	58.16	45.24	
CoV(%)	13.23	6.59	18.70	17.59	4.08	4.88	
*TCC-NC-R45-05	101.40	4.22					
TCC-NC-R45-06	103.52	4.83	55.71	68.47	38.86	33.60	
TCC-NC-R45-07	99.26	4.14	72.73	96.48	45.16	40.02	CC(Minor) + SY + EF
TCC-NC-R45-08	100.18	3.76	74.83	93.13	46.08	41.21	
Mean	100.99	4.24	67.76	86.03	43.36	38.28	
CoV(%)	2.22	12.86	15.47	17.78	9.07	10.70	
*TCC-NC-S30-01	109.29	2.96					
TCC-NC-S30-02	92.78	2.35	96.95	121.12	108.25	92.06	
TCC-NC-S30-03	93.99	2.69	57.30	69.76	67.91	64.15	SY + EF
TCC-NC-S30-04	105.83	2.85	64.57	81.74	68.85	58.64	
Mean	97.53	2.63	72.94	90.87	81.67	71.62	
CoV(%)	7.39	9.73	28.94	29.57	28.19	25.02	
*TCC-NC-R30-05	107.78	2.74					
TCC-NC-R30-06	98.31	2.36	80.87	107.98	87.26	66.67	
TCC-NC-R30-07	99.09	3.01	52.68	82.38	52.26	46.66	SY + EF
TCC-NC-R30-08	91.74	2.75	70.07	94.27	74.11	59.82	
Mean	96.38	2.70	67.87	94.87	71.21	57.72	
CoV(%)	4.19	12.12	20.96	13.50	24.83	17.62	

CC-Concrete Cracking, SY- Screw Yielding, EF- Timber Embedment Failure, * Represents estimated failure load specimens.

4 – CONCLUSION

The result indicates that TCC with ribbed concrete layers is an efficient and optimised alternative to conventional solid TCC systems due to its low self-weight and concrete material utilisation. The main findings are summarised as follows:

a. A slight increase in slip was observed in ribbed concrete TCC specimens, nonetheless the overall structural behaviour is comparable to that of solid concrete layer TCC specimens.

b. The ultimate slip modulus of ribbed TCC specimens reduced marginally relative to normal concrete specimens despite reduced concrete stiffness and frictional contact area between CLT and ribbed concrete layer.

c. Ribbed TCC specimens with cross-inclined screws exhibited superior slip resistance and ultimate stiffness modulus comparable to solid concrete specimens with 30° screws providing the efficient structural performance.

d. Concrete failure of solid or ribbed TCC specimens was similar exhibiting a reduction in cracks with reduced screw penetration angle relative to timber surface. Likewise, the local crushing of timber fibres around screws and plastic deformation of screws as decreased with reduced screw angle. Furthermore, 30° ribbed concrete specimens exhibited minimal failure behaviour.

This research underlines the potential of timber-ribbed concrete layer to achieve lightweight and high-performance structural material contributing to advancing sustainable construction practices. Subsequent research could focus on the bending and dynamic behaviour of timber-ribbed concrete composite floors for long-span applications.

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5 – REFERENCES

[1] Y. David, F. Massimo, D. F. Mary, and H. B. Koh, “State of the Art on Timber-Concrete Composite Structures: Literature Review,” Journal of Structural Engineering, vol. 137, no. 10, pp. 1085–1095, Oct. 2011, doi: 10.1061/(ASCE)ST.1943-541X.0000353.

[2] A. Siddika, M. A. Al Mamun, F. Aslani, Y. Zhuge, R. Alyousef, and A. Hajimohammadi, “Cross-laminated timber–concrete composite structural floor system: A state-of-the-art review,” Eng Fail Anal, vol. 130, p. 105766, Dec. 2021, doi: 10.1016/J.ENGFAILANAL.2021.105766.

[3] J. Cao, H. Xiong, and J. Chen, “Mechanical performance of timber-concrete bolted connections under cyclic loading,” Structures, vol. 34, pp. 3464–3477, Dec. 2021, doi: 10.1016/J.ISTRUC.2021.09.086.

[4] T. T. Nguyen, L. Sorelli, and P. Blanchet, “Composite slab floors made of cross laminated timber and ultra high-performance concrete: Early-age deflection, stripping time, and its implication on the structural performances,” Eng Struct, vol. 295, p. 116810, Nov. 2023, doi: 10.1016/J.ENGSTRUCT.2023.116810.

[5] B. Shi, W. Liu, H. Yang, and X. Ling, “Long-term performance of timber-concrete composite systems with notch-screw connections,” Eng Struct, vol. 213, p. 110585, Jun. 2020, doi: 10.1016/J.ENGSTRUCT.2020.110585.

[6] S. Di Nino, A. Gregori, and M. Fragiacomo, “Experimental and numerical investigations on timber-concrete connections with inclined screws,” Eng Struct, vol. 209, p. 109993, Apr. 2020, doi: 10.1016/J.ENGSTRUCT.2019.109993.

[7] A. M. P. G. Dias, U. Kuhlmann, K. Kudla, S. Mönch, and A. M. A. Dias, “Performance of dowel-type fasteners and notches for hybrid timber structures,” Eng Struct, vol. 171, pp. 40–46, Sep. 2018, doi: 10.1016/J.ENGSTRUCT.2018.05.057.

[8] K. Buka-Vaivade and D. Serdjuks, “Behavior of timber-concrete composite with defects in adhesive connection,” Procedia Structural Integrity, vol. 37, no. C, pp. 563–569, Jan. 2022, doi: 10.1016/J.PROSTR.2022.01.123.

[9] E. Appavuravther, B. Vandoren, and J. Henriques, “Behaviour of screw connections in timber-concrete composites using low strength lightweight concrete,”

 https://doi.org/10.52202/080513-0462

Constr Build Mater, vol. 286, p. 122973, Jun. 2021, doi: 10.1016/J.CONBUILDMAT.2021.122973.

[10] S. Lamothe, L. Sorelli, P. Blanchet, and P. Galimard, "Lightweight and slender timber-concrete composite floors made of CLT-HPC and CLT-UHPC with ductile notch connectors," Eng Struct, vol. 243, p. 112409, Sep. 2021, doi: 10.1016/J.ENGSTRUCT.2021.112409.

[11] J. Estévez-Cimadevila, E. Martín-Gutiérrez, F. Suárez-Riestra, D. Otero-Chans, and J. A. Vázquez-Rodríguez, "Timber-concrete composite structural flooring system," Journal of Building Engineering, vol. 49, p. 104078, May 2022, doi: 10.1016/J.JOBE.2022.104078.

[12] X. Xu, J. Yu, S. Wang, and J. Wang, "Research and application of active hollow core slabs in building systems for utilizing low energy sources," Appl Energy, vol. 116, pp. 424–435, Mar. 2014, doi: 10.1016/J.APENERGY.2013.09.064.

[13] S. Thondel and J. Studnicka, "Behaviour of Steel-Concrete Composite Beam with High Ribbed Deck," Procedia Eng, vol. 40, pp. 457–462, Jan. 2012, doi: 10.1016/J.PROENG.2012.07.125.

[14] Y. Ou, J. M. Gattas, D. Fernando, and J. L. Torero, "Experimental investigation of a timber-concrete floor panel system with a hybrid glass fibre reinforced polymer-timber corrugated core," Eng Struct, vol. 203, p. 109832, Jan. 2020, doi: 10.1016/J.ENGSTRUCT.2019.109832.

[15] Y. Ou, D. Fernando, and J. M. Gattas, "Novel hybrid FRP-timber-concrete floor panel system," in APFIS2017-6th Asia-Pacific Conference on FRP in Structures, Singapore, 2017, pp. 1–7.

[16] T. Tannert, B. Endacott, M. Brunner, and T. Vallée, "Long-term performance of adhesively bonded timber-concrete composites," Int J Adhes Adhes, vol. 72, pp. 51–61, Jan. 2017, doi: 10.1016/J.IJADHADH.2016.10.005.

[17] M. A. H. Mirdad and Y. H. Chui, "Load-slip performance of Mass Timber Panel-Concrete (MTPC) composite connection with Self-tapping screws and insulation layer," Constr Build Mater, vol. 213, pp. 696–708, Jul. 2019, doi: 10.1016/J.CONBUILDMAT.2019.04.117.

[18] British Standard Institution, "BS EN 12350-2:2019. Testing fresh concrete. Slump test," London, UK, 2019.

[19] British Standard Institution, "BSEN 12390-3:2019 - Testing hardened concrete-Part 3: Compressive strength of test specimens," London, UK, 2019.

[20] British Standard Institution, "BSEN408:2010+A1:2012- Timber Structures - Structural timber and glued laminated timber-Determination of some physical and mechanical properties," London, UK, 2011.

[21] J. Ehlbeck and H. J. Larsen, "Eurocode 5-Design of timber structures: Joints," in International Workshop on Wood Connectors, Forest Products Society, 1993, pp. 9–23.

[22] British Standard Institute, "BS EN 26891:1991-Timber structures. Joints made with mechanical fasteners. General principles for the determination of strength and deformation characteristics," London, UK, 1991.