Experimental Study on Bending Behavior of CLT-UHPC Composite Beam

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Abstract

Cross-laminated timber (CLT) and UHPC are both novel building materials. CLT panels are gaining popularity in the construction of floors, roofs, walls, and bridge decks due to the benefits of sustainability, light weight, comparable compressive strength to regular concrete, and superior dimensional stability in comparison to conventional wood. Despite these advantages, there are concerns about CLT's lower flexural stiffness and susceptibility to environmental effects. To address these concerns, it is proposed that the CLT core be encased in a thin layer of UHPC as an envelope material. Two eight-foot-long CLT-UHPC composite beams were cast using three- and five-layer CLT and tested to failure in a three-point loading configuration. The UHPC layer for both beams measured 1.50 in. (3.8 cm) at the bottom and 1.25 in. (3.2 cm) on the remaining three sides. In order to understand moisture transfer from UHPC to CLT and in CLT layers, a water proofing test was performed with different membranes between UHPC and CLT. Based on the results, a water proofing membrane were used as an interlayer between CLT and UHPC in the composite panel. Interface shear tests were conducted on CLT-UHPC composite specimens to quantify the interface behavior. The results of the experimental tests and numerical analysis demonstrate that the composite panels have enhanced structural performance and identify them as a viable alternative for modern building and bridge construction.

Keywords: CLT-UHPC Composite, Bending Resistance, Moisture Intrusion, Interface Shear

1 Introduction

The timber-concrete composite (TCC) structure is a unique construction technique where both materials can be effectively utilized as timber resists the tensile forces induced by gravity loads and concrete topping resists the compression load (Yeoh, Fragiacomo et al. 2011). The optimization of structural stiffness and strength is possible by using timber-concrete structure (Hu, Chui et al. 2001). Even though timber is widely available, being anisotropic, its use has been limited. Because of anisotropy, timbers oriented entirely in parallel direction have less strength in orthogonal direction. To overcome this problem, composite plate elements with different stiffness properties in different directions may be built with a crosswise perpendicular orientation of the strong fiber direction of timbers (Gsell, Feltrin et al. 2007), which is termed as cross-laminated timber (CLT). CLT elements are constructed with orthogonal layers that operate as reinforcement for the entire panel, adding dimensional stability and load carrying capacity in both directions. Several innovations have also emerged in concrete material as well. Ultra-High Performance Concrete (UHPC) is one of these modern concrete materials. UHPC has higher compressive strength, durability and long-term stability as compared to conventional concrete. The tensile strength of UHPC, both before and after cracking, is also significantly higher than normal concrete (Graybeal 2006). The development of UHPC introduced CLT-UHPC composites as a new member of TCC. However, introduction of innovative composite materials comes with its own challenges. This research focuses on analyzing potential concerns while using CLT-UHPC composites in construction. This includes determination of moisture transfer between materials, interfacial shear strength and flexural strength of CLT-UHPC composite sections.

2. Determination of Moisture Transfer

Moisture penetration at the interface is a potential concern for CLT-UHPC composites. Since the mechanical properties of timber are impacted by the percentage of moisture content, it is essential to understand the potential moisture intrusion due to addition of a UHPC layer. Similarly, loss of moisture content from UHPC can affect the strength of in-situ UHPC. Thus, experimental tests were performed to understand water migration. Nine specimens of 3 in.x3 in.x4 in. (7.6x 7.6 x 10.2cm) CLT core encased in 1 in. (2.5 cm) thick UHPC were tested. Two different commercially available water proofing products were used at the interface for three specimens while the remaining specimen didn't contain any water proofing layer. Additionally, a set of specimens comprising Styrofoam cores wrapped in packaging tape served as a reference specimen for moisture transfer measurements. Significant difference was observed in moisture transfer with the addition of water proofing membrane. For specimens with a water-resistant membrane, the percent increase in weight of the CLT core due to moisture was nearly $1/30^{th}$ of that for specimens with no water-resistant membranes.

3. Determination of Interfacial Shear Strength

While combining two different materials, it is critical to achieve composite behavior which is characterized by low interfacial slip, reduced deflection, and higher bending stiffness. To achieve this composite behavior, shear connectors are typically used at the material interface. The effectiveness of a CLT-UHPC composite element relies on the performance of interface connection and the type of shear connectors used. Common nail and ring shank nail were used as a shear connector for this research (due to their availability). Four sets of six specimens each, with CLT dimension 6 in.x5.5 in.x4 in. (15.2 x 14 x 10.2 cm), one connector at 6 in. spacing, and 1.25 in. (3.2 cm) thick UHPC layers on two opposite sides were fabricated. For quantifying the impact of the water proofing membrane in shear strength, two sets of specimens were constructed without the waterproofing membrane. Standard push-off tests were performed under displacement control. The force-slip relationship was used to obtain the average stiffness and slip modulus of the connection. The tests indicated ductile response of the connections. Benchmarked numerical models were developed to obtain additional insights into the interfacial shear behavior.

4. Bending Performance of Composite Panel

For analyzing bending performance, two eight-foot-long CLT-UHPC composite panels were cast using three- and five-layer CLT with water proofing layers and shear connectors at CLT-UHPC interface. The width of the encased CLT layers was 24 in. (61 cm) and depth was 4.5 in (11.4 cm) and 7.5 in. (19.0 cm) for 3-layer and 5-layer CLT blocks, respectively. UHPC layer for both panels were measured as 1.5 in (3.8 cm) at the bottom and 1.25 in (3.2 cm) on the remaining three sides. Additionally, a welded wire mesh was used in the top and bottom UHPC layers to increase strength and ductility. Nine small-scale UHPC slab specimens with dimensions of 22 in.x12 in.x2 in. (55.9 x 30.5 x 5.1 cm) and varied spacing of welded wire mesh were subjected to four point bending tests. Based on the experimental moment curvature relationship, stress-strain relation of UHPC was estimated through inverse analysis. Similarly, stress-strain behavior of welded wire mesh was obtained from tensile testing.

Three point bending tests were performed to predict the flexural behavior of the composite panels. The panels were loaded to one cycle of 5 kips (22.2 kN), one cycle of 10 kips (44.5 kN), 3 cycles of 16 kips (71.2 kN), 3 cycles of 21.3 kips (94.8 kN), and eventually to failure. Effective stiffness was computed for both specimens as an initial tangent modulus of force-deflection curve. Ductility index of the specimen was calculated by dividing the maximum displacement and displacement corresponding to yield point of steel. Experimental results indicated good ductility index. Finally, numerical analyses were performed in commercial finite element software and compared with experimental moment-curvature response.

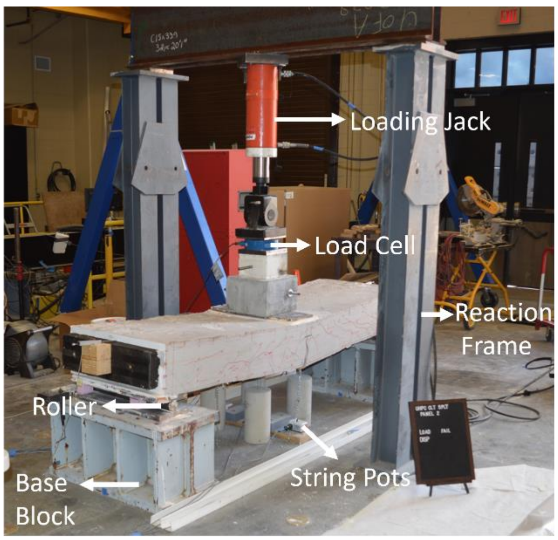

Figure 1 Bending Test of Composite Panel

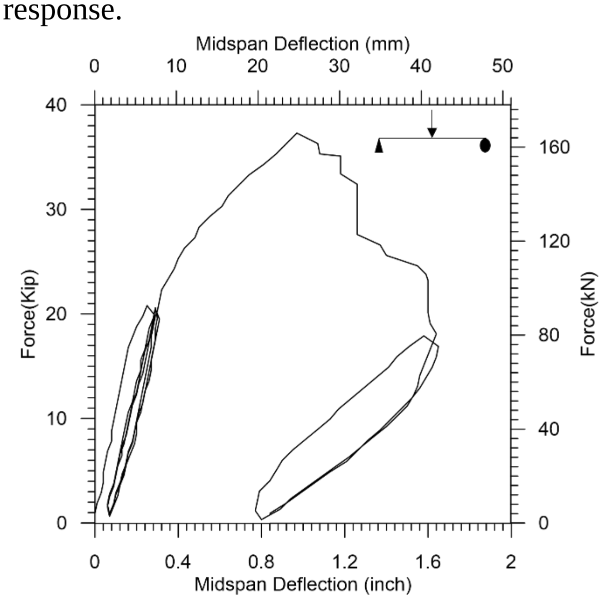

Figure 2 Force Vs Deflection for 3-Layer Composite Panel

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