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Sustainable steel-timber joints for framed structures

Mark A. Bradford,* Amirhossein Hassanieh, Hamid R. Valipour, Stephen J. Foster

Centre for Infrastructure Engineering & Safety, School of Civil & Environmental Engineering, UNSW Australia, UNSW Sydney, 2052, Australia

Abstract

The mechanical characteristics of steel-timber composite (STC) connections play an essential role in the safe and economical design of hybrid STC structures and floor systems. Accordingly, this study investigates the load-slip behaviour of lap Laminated Veneer Lumber (LVL) timber-steel plate composite joints. Push-out tests on four different types of STC lap joints connected by coach screws (with and without a reinforcing nail plate), high-strength bolts and a combination of glued and screwed joints are reported, and the load-slip behaviour and failure modes of the connections are characterised. The use of a nail plate is found to be effective in reinforcing the timber and in increasing the stiffness of STC lap joints with coach screws, but they do not produce a significant improvement in their strength. A non-linear regression is carried out and an empirical load-slip formulation for STC lap joints with coach screws and high strength bolted connectors is proposed in analytical form.

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Keywords: Hybrid structure; load-slip; shear-connectors; steel-timber composite (STC); timber.

1. Introduction

The application of timber and engineered wood products such as Laminated Veneer Lumber (LVL), Glued laminated timber (Glulam) and Cross Laminated Timber (CLT/X-lam) have increased dramatically in the construction industry, owing to their lower carbon footprint, relatively high strength and stiffness, lower self-weight and the faster installation of prefabricated structural components made of engineered timber [1]. There are also significant advantages in using timber in conjunction with contemporary construction materials (concrete and steel), and over the past two decades considerable research has been devoted to their numerical analysis and experimental study, as well

* Corresponding author. Tel.: +61-2-938505014; fax: +61-2-9385-9747.
E-mail address: m.bradford@unsw.edu.au

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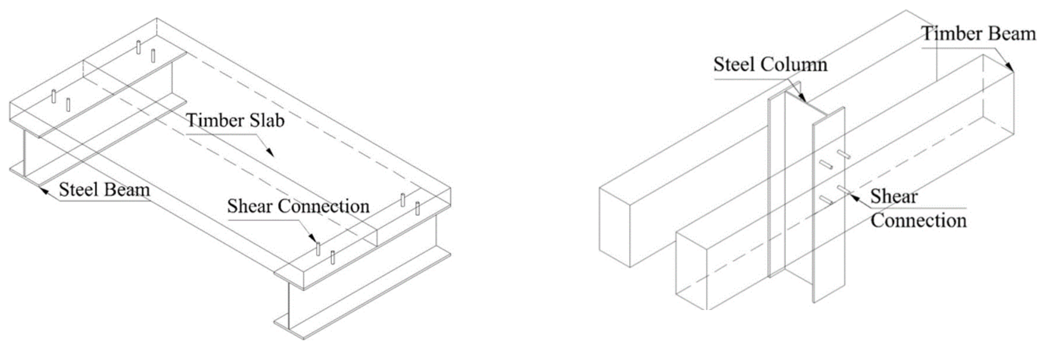
as development of simplified design methods and provisions for timber-timber and timber-concrete composite structures [2-4]. Steel-timber frame structures can be deconstructed at the end of the structural life of the frame, with the elements being recyclable structurally. In addition, timber is recognized as a carbon sink, thereby decreasing the carbon footprint of such structures. However, little attention has been paid to the application of hybrid steel-timber composite systems, and existing design provisions and data on steel-timber composite structures are lacking and they are limited mainly to the use of steel plates and/or sheets for strengthening timber elements or for composite flitch beams [5,6].

Developing and characterising the behaviour of practicable simple connections that are able to transfer the forces from the timber to the steel and vice versa both reliably and efficiently is still the most significant challenge for the development of hybrid steel-timber structures, and it requires systematic and thorough investigation. Accordingly, this paper investigates the short-term mechanical behaviour of STC joints in which a cross-banded LVL panel is connected to the flange of a steel girder using coach screws, bolts and/or glue (Fig. 1a). The load-slip response and failure modes of the STC joints are obtained from push-out tests and empirical load-slip formulae for STC lap joints with coach screws and high-strength bolts are proposed and calibrated against the experimental data. These load-slip models can be used for the non-linear analysis of steel-timber composite beams as well as hybrid steel-timber frames in which parallel continuous LVL beams are connected to the steel column flanges by using screws or bolts (Fig. 1b). It is noteworthy that while the fire performance of timber floors is deemed a major concern that requires thorough investigation, however, such a study of a STC system is beyond the scope of this paper.



(a) floor with steel beams and cross-banded LVL slabs (b) semi-rigid frame with parallel continuous LVL girders

Fig. 1. Hybrid steel-timber frame elements.

2. Experimental program

2.1. Material properties

The push-out specimens were categorised into six different groups (Fig. 2) with respect to the type of connection and the application of a nail plate as reinforcement of the connection zone. In total, seventeen different types (each type comprising three identical samples) of STC joints whose geometry, detail and setup are shown in Fig. 2 and in Table 1 were tested. The primary variables within the different push-out specimens were the loading direction with respect to the orientation of the LVL grain (parallel or perpendicular to the grain), the type of the mechanical connectors, the diameter of the coach screws and the use of glue in conjunction with screws. Furthermore, the influence of using nail plates to reinforce the timber around the location of coach screws that are both parallel and perpendicular to the grain direction are considered.

In this study, hySPAN cross-banded LVL panels were used to fabricate the push-out specimens, being manufactured from Radiata Pinewood structural laminated veneer lumber and tested in accordance with AS/NZS 4357:2005 [7]. Phenolic adhesive, producing a type (A) bond as per AS/NZS 2098 [8] had been used for manufacturing the LVLs. The average density and moisture content of the LVL panels were 600 kg/m^3 and 9% respectively. The mechanical properties of the LVL panels are given in Table 2.