Construction and Building Materials 56 (2014) 32–43

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Advances in moment transferring dvw reinforced timber connections – Numerical analyses and verification, Part 2

D. Brandon, A.J.M. Leijten *

Structural Design Unit, Faculty of Architecture, University of Technology Eindhoven, PO Box 513, 5600 MB Eindhoven, The Netherlands

HIGHLIGHTS

- Rotational stiffness of two closely spaced connections (a compound connection) is the same as a single connection.
- Application in column–beam and splice connections opens new design frontiers in structural timber design.
- This reinforced timber connection behaves isotropic, i.e. no angle to grain dependency.

ARTICLE INFO

Article history:
Received 3 October 2012
Received in revised form 21 October 2013
Accepted 8 January 2014
Available online 19 February 2014

Keywords:
Timber
Moment connection
Reinforcement
Steel tube
Dvw
Lignostone

ABSTRACT

This study focuses on the numerical simulation of the dvw reinforced timber connection with expanded tubes. In Part 1 it was shown that two connections, acting together in series, have the same rotational stiffness as one separate connection. Numerical analyses presented in this part (Part 2) confirm these findings. Additionally, several failure modes are studied, which can play an important role in the behaviour of the connection such as possible failures of the constituent materials and failure of the bond between the timber and its reinforcement. For evaluating the latter, special attention is given to the type of adhesive, the glue-line thickness and the peak shear stresses. The simulations are validated by experiments.

1. Introduction

It is generally known that timber connections are usually the weakest link in a timber structure. This study focuses on bending moment transferring connections as seen in column–beam connections that are reinforced to prevent premature timber failure. As discussed in Part 1 [1] densified veneer wood (dvw), trade name Lignostone^{R}, is used as reinforcement, because of its high embedment strength, high embedment stiffness, isotropic behaviour and high tensile strength. Gluing sheets of dvw to the timber at the location of the fasteners, prevents premature failure due to timber splitting and increases the connection stiffness and connection strength.

A dvw reinforced connection is previously studied in the form of a three-member connection [2], Figs. 1 and 2a. Flitch plate connections, shown in Figs. 1b–d and 2b, comprise of two three-member connections that are placed in series. The flitch plate functions as a connector that transfers the bending moment between the timber members. Generally the rotation of a flitch plate connection φ_{fp} (Fig. 2a) equals double the rotation of a three-member connection φ_3 (Fig. 2b) when subjected to a bending moment. Fig. 2c shows that the gap between two in-plane timber and dvw members can close which results an additional contact force. This phenomenon changes the force distribution in the flitch plate connection. Part 1 [1] showed, using an analytical approach and experimental verification, that the rotational stiffness of the flitch plate connection can be similar to the stiffness of the three-member connection under the condition that the timber members are closely spaced. Important aspects that are vital for the performance are studied by simulation in this part (Part 2). These aspects are the occurrence of plastic behaviour and different (local) failures of materials. One of these failures is delamination of the bond between dvw and timber. For this reason the stresses in the glue-line, the type of adhesive and thickness of the glue-line are evaluated numerically and experimentally. In addition, an estimate of the bond line capacity is made.

* Corresponding author. Tel.: +31 40 247 3928; fax: +31 40 245 0328.
E-mail address: a.j.m.leijten@tue.nl (A.J.M. Leijten).

http://dx.doi.org/10.1016/j.conbuildmat.2014.01.026
0950-0618/

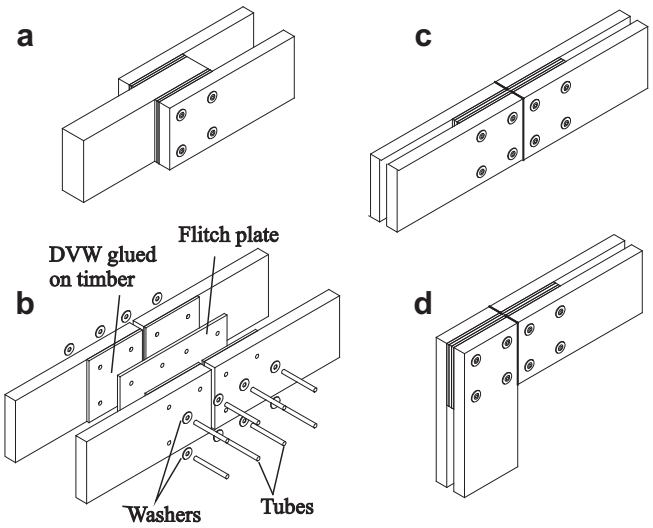

Fig. 1. Dvw reinforced connections.

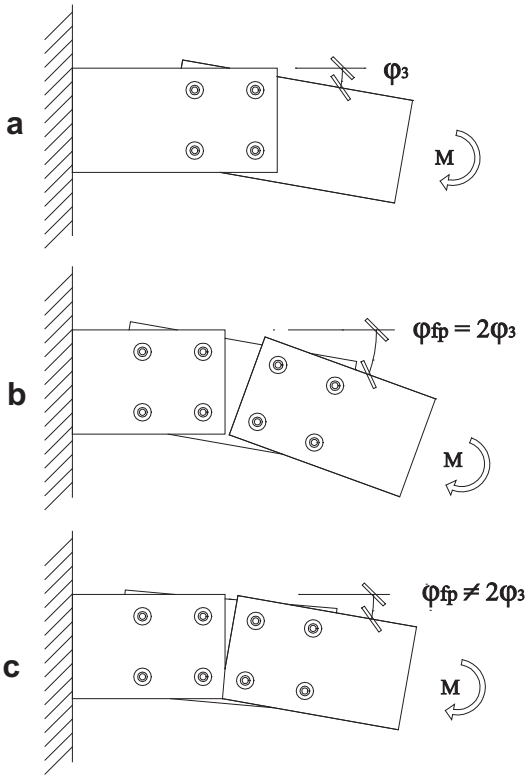

Fig. 2. The rotation of a single connection and a splice (double) connection.

2. Influencing parameters

Failure of the bond between the dvw and the timber can lead to premature failure of the connection and therefore must not be ignored. In Leijten [2] a simple analytical approach is presented to estimate the bending moment capacity of the bond line. It assumed that the bond strength exceeds the timber shear strength and that the shear stress distribution in the direction parallel to the grain is homogeneous, Fig. 3. Because of the low shear modulus perpendicular to grain of the timber adherent, the shear stresses in this direction are neglected as well as shear stresses imposed by a shear

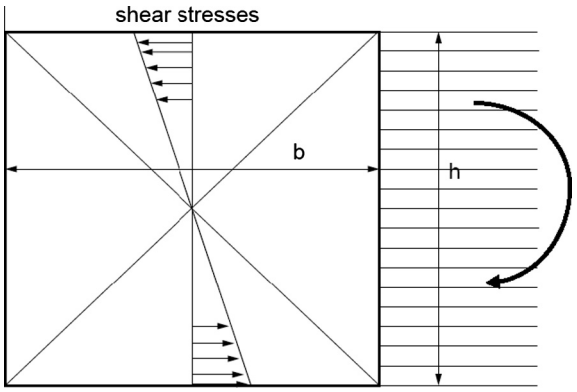

Fig. 3. Assumed shear stress distribution.

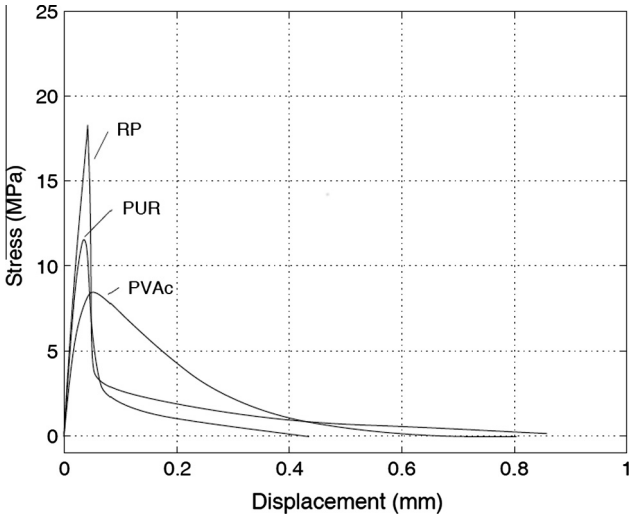

Fig. 4. Influence of adhesive type, Serrano [5].

load. This simplified approach based on linear elastic stress analyses results in a bending moment capacity given in Eq. (1),

$$M_{glueline} = 2\frac{2f_v}{h}\frac{2b}{h}\int_0^{h/2} x^3 dx = \frac{bh^2 f_v}{8} \quad (1)$$

where b, h are the width and depth dimensions of the dvw, respectively. f_v is the shear strength of the timber.

Due to the differences in strain of the adherents peak stresses occur in the bond line [3]. This is not taken into account in Leijten's approach. Although in experiments of [1,2] the connection never showed bond line failure, the reliability of Eq. (1) is debatable due to the simplifications.

Another way to estimate the moment capacity of the bond line is to use the Volkersen model [3]. This model takes into account non-homogeneous stress distributions, but ignores any material softening and does not account for the thickness of the adherent. The elastic shear deformation of the thin adhesive is taken into account, but the shear deformation of the significantly thicker timber adherent is neglected [4]. Therefore, the use of the Volkersen model for timber structures is questionable.

Studies by Serrano [5] show the influence of the adhesive type between timber adherents. A bond with a flexible adhesive such as Polyvinyl Acetate (PVAc) has higher fracture energy than a bond with a rigid adhesive like Resorcinol Phenol (RP) and Polyurethane (PU). This is shown by the differences of areas enclosed by the envelopes in Fig. 4. Particularly for long glue line lengths, high