Construction and Building Materials 53 (2014) 381–391

Contents lists available at ScienceDirect

Construction and Building Materials

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

Analysis of the behaviour of a bonded joint between laminated wood and ultra high performance fibre reinforced concrete using push-out test

Georges Youssef [a,*], Louisa Loulou [b], Sylvain Chataigner [a,c], Sabine Caré [b], André Flety [a], Robert Le Roy [b], Michel Bornert [b], Christophe Aubagnac [a]

[a] Département Laboratoire d'Autun – CETE Lyon/Bd de l'Industrie, BP 141, 71405 Autun, France
[b] Université Paris-Est, Laboratoire Navier (UMR 8205), CNRS, ENPC, IFSTTAR/6-8 Av. Blaise Pascal, 77455 Marne La Vallée, France
[c] LUNAM Université – IFSTTAR de Nantes – SOA/Route de Bouaye, 44341 Bouguenais, France

HIGHLIGHTS

- A test protocol using the push-out test was developed.
- The polyurethane did not provide sufficient capacity for the bonded assembly.
- The bonded assembly's ultimate capacity did not correlate with used adhesive's stiffness.
- We obtained adhesion properties drop of about 30% due to ageing.
- A method for measuring strains by digital image correlation was also tested.

ARTICLE INFO

Article history:
Received 25 January 2013
Received in revised form 17 October 2013
Accepted 31 October 2013
Available online 25 December 2013

Keywords:
Timber–concrete joints
Bonding structural
Shear strength
Stiffness
Push-out test
Digital image correlation
Hygro-thermal deformations

ABSTRACT

Bonded composite constructions using timber and ultra-high performance fibre reinforced concrete (UHPFRC) are investigated as highly innovative structural elements technically and economically efficient, and having better environmental performances. Such technique could indeed offer new structures typologies for bridges for instance associating timber for main beams with UHPFRC slabs. In timber–concrete-composite structures, connection is traditionally achieved with mechanical means. The research presented herein describes the timber–concrete assembly by adhesive bonding and specially the behaviour of bonded joint between Laminated Wood (LW) and UHPFRC. This type of assembly has to be investigated concerning mainly the durability of the bonded assembly and its ability to transmit the forces concentrated on edges. The present study describes the development of a test called "Push-Out" used to characterize the behaviour of the timber–concrete bonded after or prior to environmental ageing. Following the development of the used test protocol, investigations are realized on four different commercial resins to study the influence of the adhesive stiffness on the force transfer focusing in particular on the failure mode, on the ultimate capacities and some local deformations. The mechanical behaviour of the bonded joint is investigated in particular from a theoretical point of view and from the determination of deformation field obtained by Digital Image Correlation (DIC).

1. Influence of the stiffness of the resin

1.1. Context of the research

Timber–concrete composite structures have been used in many countries. These structures are becoming important because they bring many advantages when compared with traditional timber structures. Structurally, wood is a lightweight material, it is renewable and, when properly treated, it is durable. Concrete increases the stiffness of the structure and protects the wood from environmental effects [1]. There have been few investigations [2–6] on the use of adhesives for the connection of timber beams with standard concrete slabs. Within all these cases, the transfer of shear forces through the bond was limited by the low tensile strength of the concrete material. In this context, the use of steel fibre reinforced high-, or ultra-high-performance fibre reinforced concretes seem promising, because it exhibits high tensile strength of the concrete material [7]. A further advantage that results from the steel fibre reinforcement is that the concrete slabs can be very thin because there is no need for conventional steel-bar reinforcement. Thereby, the weight of the composite construction can be reduced further.

* Corresponding author. Tel.: +33 3 85 86 67 41; fax: +33 3 85 86 67 79.
E-mail address: georges.youssef@hotmail.com (G. Youssef).

0950-0618/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.conbuildmat.2013.10.074

IFSTTAR Institute (Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux) has worked from many years on the development of composite timber–concrete structures to obtain new typologies of structures, technically and economically efficient, and having a better environmental performance [8]. Up to date, the connection between the timber and the concrete has been achieved with mechanical means such as screws, bolts or with a concrete indentation into the wood [9–13]. Since a few years, the technique of structural adhesive bonding has been used and developed and is the subject of a patent. This technique, unlike the conventional assembly techniques (local or discontinuous connectors), can ensure an almost-perfect connection between the two materials [14,15], and thus optimize the quantity of material to be used in structures as each part may contribute to the structure according to its own mechanical performance.

Although the assembly by structural bonding has been used for several years for other civil engineering applications (for example, in the case of adhesively bonded composite reinforcement or composite steel–concrete structures [16–22]), its possible use for this type of application has to be investigated in particular to verify its ability to transmit the forces concentrated on edges or to resist to environmental loading. First studies conducted at Navier Laboratory have investigated on large scale the process for composite wood–concrete beams. Static and fatigue validations of the process have been realized [14], and there is now an interest in the environmental durability of such structures [23].

In order to conduct a more consistent number of investigations with a more limited quantity of material, it was decided to investigate the use of the "Push-Out" test that consists in loading the two symmetrical joints in shear using a compression tool in order to study in particular the influence of the properties of the resin on the shear capacity of the bonded joint. In the following section (Section 1.2), as a preliminary work, a numerical study is undertaken to confirm the importance of the choice of the resin on the mechanical behaviour of a bonded composite construction. The experimental program will then be described (Section 1.3).

1.2. Properties of bonded composite construction, preliminary work

In composite structures, strength and deformation characteristics of interface connections are very important in order to evaluate the mechanical behaviour of the structure. The degree of composite action depends on the type of connector, timber and concrete properties.

The major influence on the effectiveness of timber–concrete composite structures can be assigned to the stiffness of the connection between timber and concrete. Flexible connections like dowel-type fasteners, which were mostly used up to now, lead to decreasing bending stiffness of the members. Using the adhesive bonding technology is a way to realize a rigid compound. Especially if fibre-reinforced concretes are applied, this technology is reasonable because of the high tensile strength of the concrete material. Until now, few investigations were made on this type of application.

Many studies got interested in the influence of the stiffness of the connector on the stiffness of the obtained composite structure studying different existing connector systems. These studies allowed [14,24,25] to realize a pseudo-classification of the used connectors: Local connectors (tips, screws, studs, long bolts, etc.) that provide a limited stiffness to the structure, half-continuous connectors (set of long bolts, expanded metal, etc.) whose properties of stiffness are highly dependent of the distribution and geometry of the elements, and structural adhesive bonding, that allow to ensure an optimal mixed functioning of the structure (Fig. 1). It is important to note that structural adhesive bonding reduces stress concentration phenomena compared with more conventional methods of assembly and that the stiffness of the connection depends in that case on the stiffness of the used adhesive and the thickness of the adhesive layer.

The connecting system exhibits a non-linear shear force-relative slip relationship even for low load values [26,27]. Indeed, the use of an adhesive allows distributing the shear forces uniformly over the entire surface and thus limits the local force concentrations which are unavoidable when mechanical connections are used. The adhesive connection is also quite slip-free, which helps to reduce the deflections.

In order to assess the influence of the stiffness of the adhesive on the elastic behaviour of a composite beam, numerical modelling using finite elements FE was carried out [28]. A 10 m long, and 240 mm wide timber–concrete beam has been modelled and subjected to 4 points bending. Distance between the loading points is 2.2 m and the value of each applied load is 500 kN (Fig. 2b). A rectangular section is included to simplify the analysis and realize a 2D calculation supposing plane strain conditions. The concrete element has a thickness of 170 mm, the element in wood has a thickness of 600 mm and the adhesive layer has a thickness of 2 mm (Fig. 2a). The three materials are supposed to be isotropic and elastic, and perfect adhesion between the three materials is considered. The study focused on the evolution of the mid-span displacement as a function of the elastic modulus of the adhesive (Fig. 3).

The numerical modelling shows that mid-span displacement of the composite structure is very little affected by the elastic modulus of the used adhesive when its stiffness varies between 200 and 10 000 MPa (Fig. 3). Most so-called structural adhesives have an elastic modulus greater than 200 MPa and are thus within this range of stiffness. This result is consistent with Fig. 1.

It exists therefore an important range for the designer on the choice of the adhesive. It must be emphasized that the stiffness of the used adhesive will also impact on the behaviour of the structure in response to hygro-thermal stress. This is in particular the subject of this work.

1.3. Aim of the research

If in the short term, structural adhesive bonding seems adequate [14,15], it is momentous to get interested in the ageing of such an assembly solution. More particularly, the influence of the stiffness of the used connection in the case of thermo-hygroscopic loading (ageing conditions) may be an important topic to investigate. Initial investigations on constrained shrinkage phenomenon

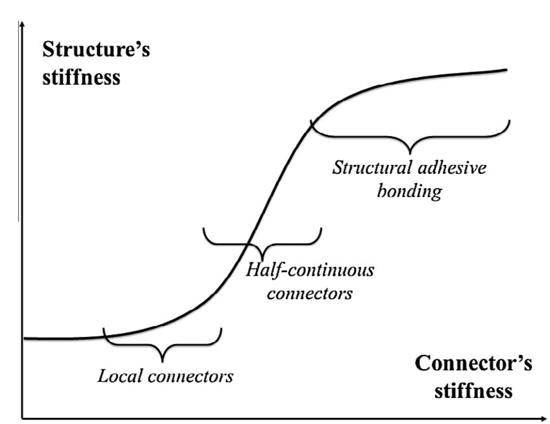

Fig. 1. Stiffness of a composite structure against the stiffness of the used connector.