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Ductile adhesively-bonded timber joints – Part 2: Strain rate effect

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HIGHLIGHTS

- Strain rate-dependent numerical modeling of timber adhesive joints was performed.
- The strain rate varied within the adhesive layer at a constant external rate.
- Increasing the external rate shifted the load-displacement curve upwards.
- An increasing strain rate changed the joint behavior from ductile to brittle.

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ABSTRACT

The mechanical behavior of adhesively-bonded timber joints, composed of a ductile acrylic or a brittle epoxy adhesive, was numerically modeled. The models took the strain rate sensitivity of the ductile adhesive into account. They were validated by experimental results presented in Part 1 of this paper. The effect of a varying joint displacement rate on the responses of the ductile joints was subsequently numerically studied. At the same joint displacement rate, the true strain rates in the acrylic adhesive layer varied significantly throughout the loading process and along the adhesive layer. Increasing the joint displacement rate shifted the load-displacement curve upwards, i.e. the yield load and displacement increased, the ultimate load and displacement however decreased, while the joint stiffness was not affected. A logarithmic relationship between these loads and displacements and the displacement rate was observed. The energy- and displacement-based ductility indexes of the acrylic joints decreased with increasing displacement rate, changing the joint behavior from ductile to brittle at higher rates.

1. Introduction

In Part 1 of this research [1], experiments on large-scale bonded timber lap joints, as shown in Fig. 1, have been conducted, including two different commercial adhesives: a ductile acrylic adhesive, SikaFast5221NT, and a brittle epoxy adhesive, SikaDur330, both obtained from Sika AG, Switzerland [2,3]. The adhesive layer thickness was 2 mm in each case. However, in the acrylic joints, extra 0.5 mm-thin layers of epoxy were added between the timber adherends and the acrylic adhesive to improve the adhesion between both. The tensile stiffness properties of all materials are summarized in Tables 1 and 2 and the true stress-strain rate-dependent response of the acrylic adhesive, which was obtained in a previous work [4,5], is shown in Fig. 2. Both joint types were subjected to axial tension and compression, under displacement-based mode and their performance has been compared. A non-linear response, higher ultimate loads due to the more uniform strain distributions along the adhesive layer and considerable ductility were observed in the joints subjected to tension with the ductile adhesive compared to those with the brittle adhesive. Thus, the experimental basis for the modeling of rate-dependent ductile adhesively-bonded timber joints has been established.

Concerning the modeling of the mechanical and structural behavior of ductile adhesively-bonded joints, only few studies have been established so far [6–11], and even fewer in the field of timber engineering [12,13]. In the latter case, works are limited to parametrical studies on the effects of geometry and material properties on the load capacity [12,13]. They do not specifically consider the adhesive's non-linear and viscoelastic nature; i.e. the high strain rate dependency in particular of the adhesive's structural response and ductility are not addressed. In the field of adhesively-bonded joints with fiber-reinforced polymer (FRP) adherends it has been shown that the strain rate can significantly affect the load-displacement behavior and joint strength [10,11,14], while the initial stiffness may be less influenced [10].

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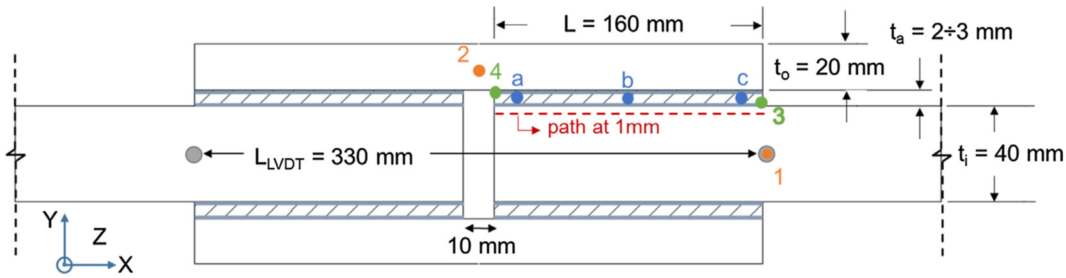

Fig. 1. Schematic joint representation and points selected for comparisons.

Table 1
Orthotropic tensile properties of spruce wood [15].

E_x (MPa)	E_y (MPa)	E_z (MPa)	ν_{xy} (–)	ν_{yz} (–)	ν_{xz} (–)	G_{xy} (MPa)	G_{yz} (MPa)	G_{xz} (MPa)
11,600	896	496	0.4	0.04	0.4	690	758	390

Table 2
Tensile properties of acrylic (rate-dependent) [4] and epoxy adhesive [16].

Adhesive	Displacement rate, $\dot{d}$(mm/min)	Eng. strain rate, $\dot{\varepsilon}$ (min^{-1})	E-modulus, E_1 (MPa)	Poisson ratio, ν (–)
Acrylics	2	0.0174	105	0.48
	10	0.0870	181	
	50	0.4348	251	
	100	0.8696	307	
	200	1.7391	309	
Epoxy	5	0.0625	4500	0.37

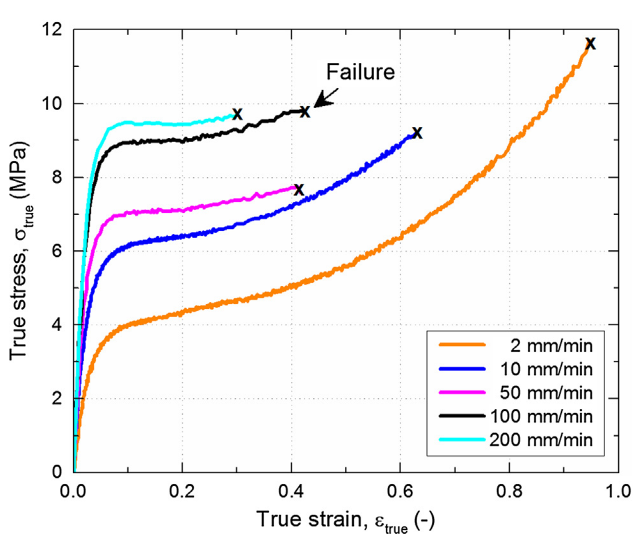

Fig. 2. Displacement rate-dependent true stress-strain curves of acrylic adhesive [4].

If the rate-dependency can affect the behavior of FRP composite joints, which are generally much stiffer than timber joints, rate dependency may also exhibit significant influence in timber joints. Furthermore, in timber applications, the applied rates may vary significantly depending on the load and structure type; much higher rates may apply for bridges or buildings in the case of vehicular or wind loads than in the case of pedestrian or snow loads.

The objective of Part 2 of this paper is thus to i) numerically model the experimentally observed load-displacement and load-strain responses and predict the ultimate loads of the ductile (acrylic) and, for comparison, brittle (epoxy) joints from Part 1. The highly non-linear and strain rate-dependent responses of the ductile adhesive are taken into account. The established and experimentally validated models will then be used to ii) assess the displacement rate effect on the load-displacement responses, ultimate loads and joint ductility in a parametric study.

2. Numerical models

Finite element (FE) models for both joint types were developed in the commercial Finite Element Analysis software Abaqus 6.14. Quadratic, 2D plane-strain solid 4-node elements with reduced integration (CPE4R) were used. The general element size was selected as 0.5 mm (equal to the minimum epoxy layer in the case of acrylic joints), but was increased to 5 mm further away from the interfaces or edges, see Fig. 3. These sizes were selected after conducting a mesh size sensitivity analysis.

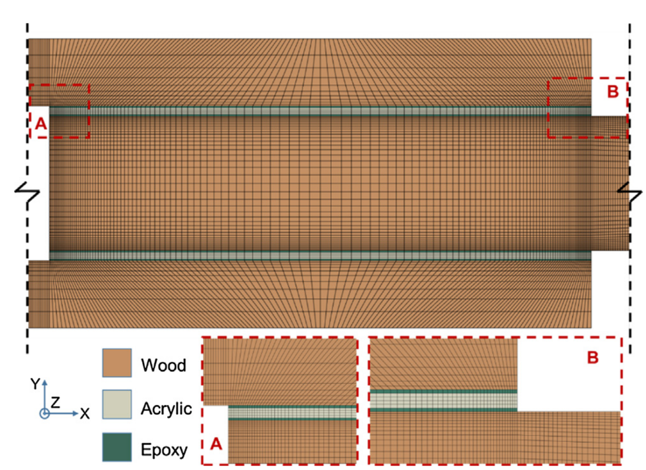

Fig. 3. Detail (one overlap) of FE model for acrylic joint specimens.