Construction and Building Materials 168 (2018) 257–265

Contents lists available at ScienceDirect

Construction and Building Materials

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

Bench-scale fire tests of Dark Red Meranti and Spruce finger joints in tension

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HIGHLIGHTS

- A bench-scale fire test for finger-joints in tension is proposed.
- Fire performance of two structural adhesives is evaluated.
- Dark Red Meranti is shown to have lower charring rate than Spruce.
- Factors affecting the charring rates of the finger-jointed specimens are discussed.

ARTICLE INFO

Article history:
Received 24 July 2017
Received in revised form 8 January 2018
Accepted 7 February 2018

Keywords:
Dark Red Meranti (*Shorea*spp.)
Spruce (*Picea abies*)
Finger joints
Bench-scale fire test
Charring rate
Secondary failure
Heat flux
Tensile strength
Phenol resorcinol formaldehyde
Polyurethane adhesive

ABSTRACT

This study investigates the secondary failure of Malaysian Dark Red Meranti (*Shorea* spp.) and Spruce (*Picea abies*) finger joints in a glulam beam in a fire test using a bench-scale test set-up. Secondary failure is the occurrence of failure of the bond lines due to fire and the falling off of the outermost tension layers, exposing the uncharred inner layers to a sudden increase of fire intensity. The lack of published work and the difficulties in describing the behaviour of the finger joints after the secondary failure in a full-scale fire test has identified the need for a simple bench-scale method, incorporating the conditions of the standard fire test. This paper focusses on the performance of the finger joints which together with other defects such as knots and splits are generally the weakest component in the glulam beam. The finger joints were bonded with structural adhesives, specifically phenol resorcinol formaldehyde (PRF) and polyurethane (PUR). They were tested in tension to imitate the failure of finger joints on the tension side of a standard fire test of a glulam beam. Constant heat flux was introduced to the finger-jointed specimens to replicate the secondary failure of a glulam beam in the standard fire test. The results of this study indicate a relationship between the charring rate and density of the specimens, with higher density Dark Red Meranti showing lower charring rate compared to the lower density Spruce specimens. Factors such as constant heat flux as opposed to the time-increasing heat flux exposure and specimen size influenced the charring rate of the specimens. The char rate was measured at the early stages of the fire test, which is known to have higher values since the build-up of the charred layers was not sufficiently substantial to protect the inner unburnt wood. Overall, the bench-scale fire test set-up was able to differentiate the fire performance of the adhesives, with PRF showing better fire performance compared to the specimens finger-jointed with PUR adhesive. In addition, tensile tests at ambient temperature showed no significant difference in tensile strength between finger joints bonded with different adhesives for the same wood species. The tensile strengths of the finger joints bonded with different adhesives were influenced by the temperature profile through the joint. The proposed bench-scale fire test was used to compare the quality of the adhesives in a fire situation, specifically with respect to secondary failure. The PRF was selected as the reference adhesive.

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https://doi.org/10.1016/j.conbuildmat.2018.02.041

1. Introduction

It is beneficial to improve the understanding of the behaviour of glue-laminated timber (glulam) when exposed to fire because any additional information related to fire performance will significantly improve fire safety design. Generally, glulam beams are tested in bending in a standard fire resistance test [1], where the outermost tension lamella experiences the highest stress and at the same time is suddenly exposed to fire [2]. The charred outermost lamella will lose its strength and relatively reduce the effective cross-section of the beam. This will increase the deflection of the beam and the tensile stress at the interface between the residual beam and the failed outermost lamella. Consequently, secondary failure may occur where the outermost lamella starts to delaminate and fall off from the beam. This will lead to increased fire intensity and charring rate on the uncharred inner lamellae because of the sudden exposure to fire when the outermost charred lamella no longer acts as a thermal insulator. At present, there is a lack of published work which describes the behaviour of finger joints following secondary failure incidents. In a standard fire test, it is extremely difficult to evaluate the conditions of finger joints because of the limited access and control of the material once the test starts and secondary failure occurs.

It is also well known that large-scale standard fire tests for glulam beams are time-consuming, expensive to set up and may not describe adequately the fire performance of the tested materials [3,4]. Attempts were made to introduce small-scale or bench-scale tests to investigate the performance of adhesives in finger joints and bonding lines at elevated temperature and in fire conditions. Craft et al. [3] reviewed some of the small-scale test methods available and proposed a new method to improve the shortcomings of the previous tests. The authors described the advantages of their small-scale test method, which simultaneously evaluates multiple finger-jointed specimens under tension in an oven. However, their method does not describe the behaviour of finger joints at secondary failure since it uses a relatively low temperature and longer set-up time (approximately 30 min for temperature recovery in the oven) rather than the sudden exposure to high temperature which occurs when the char layer falls away. Klippel et al. [4] conducted extensive tests on small-scale finger joints at elevated temperatures using 12 different adhesives. The results showed moderate decrease in tensile strength of the joints in relation to the testing temperature of between 20 and 140 °C. For temperature up to 220 °C, phenol resorcinol formaldehyde and melamine urea formaldehyde showed mostly wood failure indicating the wood itself was being tested rather than the adhesives. These tensile bench-scale tests must be further refined before they can be used as an alternative to full-scale fire tests but none describe the behaviour of finger joints in a secondary failure incident.

Tensile testing was used in this study to imitate the behaviour of the finger joints at the outermost tension lamella of a glulam beam which experiences the highest stress in a bending test in a standard fire test. Frangi et al. [5] performed tensile and bending tests to evaluate the performance of finger joints bonded with different adhesives at elevated temperature. They concluded that tensile tests were suitable for evaluating the influence of adhesives in finger joints when tested at elevated temperature but did not report any significant correlation between adhesive types and strength in bending.

Generally, the fire performance of timber structures can be described by the charring rate of the wood. The charring rate is subsequently influenced by factors including the material properties, namely density, moisture content, chemical composition and permeability, and test conditions particularly thermal exposure, scale/size effect and direction of burning [6,7]. In this paper, the influence of factors such as density, constant heat flux exposure and size effect on the charring rate of the specimens tested using a bench-scale fire test are described. This paper aims to analyse the fire performance of hardwood finger joints in tension when exposed to a constant heat flux from a bench-scale set-up. The objective is to observe the behaviour of the finger joints in the tension region when exposed to sudden high temperature which occurs following the secondary failure of the glulam beam in a standard fire test.

2. Materials and method

2.1. Finger joints preparation

Kiln-dried Dark Red Meranti (*Shorea* spp.) and Spruce (*Picea abies*) were used in this study. The average density of Dark Red Meranti (DRM) and Spruce was (659 ± 99) kg/m^3 and (462 ± 92) kg/m^3 with the average moisture content of 14 and 12% respectively. The wood pieces were conditioned in a conditioning room at a temperature of 20 °C and relative humidity of 65% before the cutting of the finger profiles.

Larger DRM and Spruce pieces with the cross-section of 51 × 99 mm and 44 × 115 mm respectively were used to create the finger-jointed specimens. Timber pieces with little or no defects were chosen to minimise their influence on the results. Finger profiles with length and pitch of 15 and 3.8 mm respectively, were cut from these pieces using a manual feed finger cutter. The length and pitch of the finger joints satisfied the requirements of the standard EN 14080 [8]. They were later pressure bonded with structural adhesives, namely phenol resorcinol formaldehyde (PRF) and polyurethane (PUR) adhesives respectively. These finger-jointed pieces were then left to cure for two weeks, allowing them to reach their optimum strength. They were then cut and ripped to the test specimen size of 10 × 42 × 300 mm with the finger joints located in the middle (Fig. 1). A total of 84 finger-jointed specimens were produced for different types of test conditions (Table 1). The test specimens were kept in the conditioning room prior to being tested, to minimise any changes in moisture content.

2.2. Bench-scale fire tests

The preparation of specimens for the bench-scale fire tests is shown in Fig. 2. The ends of the specimens were reinforced with plywood and holes were made for anchoring purposes. These reinforcements were made to prevent failures at the gripping sections. Stone wool was used to protect both faces of the specimen against heat exposure, allowing the exposure of the specimen edge from one direction only. A load of 2.5 kN was introduced at the start of the test. This load was determined based on the load ratio of 14% (Spruce) and 8% (DRM) of the ultimate load of the reference finger-jointed specimens tested in tension at ambient temperature. The 2.5 kN load was used for both species so that comparison can be made between the fire performance of the Spruce and DRM. Furthermore, the aim was to differentiate the time to failure of the adhesives by extending the time of the test when using smaller load values. A constant heat flux of 50 kW/m^2 was introduced at the start of the test. Prior to the tests, a heat flux gauge was used for calibration. Previous tests exposed with 50 kW/m^2 incident radiant heat flux [9] have led to a charring depth of approximately 40 mm in one hour, which matches with the charring depth expected in standard fire resistance tests. The heat flux of 50 kW/m^2 was also found to correspond well with the ISO 834 and EN 1363-1 standard time-temperature curve for the first 30–40 min of the fire resistance tests [10–12].