Fire Safety Journal 96 (2018) 1–12

Contents lists available at ScienceDirect

Fire Safety Journal

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

Numerical simulation of the fire behaviour of timber dovetail connections

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ARTICLE INFO

Keywords:
Rounded dovetail connection
Timber connection
Carpenter connection
Finite element model
FEM simulation
ANSYS
Thermo-mechanical simulation
Numerical simulation

ABSTRACT

In this paper, the finite element method (FEM) is used in order to develop a simulation of the mechanical performance of timber rounded dovetail connections between joists and beams under a fire event. The simulation is developed using the commercial FEM software ANSYS, and it is validated using the results of several experimental tests. These experimental tests were performed on spruce specimens as per the European regulations, and lasted for 30 min.

The numerical simulation was developed using the methodology supported by the European regulations (Eurocode 5), and consisted of a transient thermal and static structural coupled system.

Numerical results show a good agreement with the experimental ones, so ANSYS and the described methodology prove to be good tools to simulate the performance of timber dovetail connections under a fire event. Traditional failure criteria, which are useful at room temperature, such as Tsai-Wu one, are used in the simulation in order to predict the failure time, but it was demonstrated that this failure criterion is useless at high temperatures, as the ones reached under a 30-min fire event.

1. Introduction

Under a fire situation, timber structural elements suffer a thermal degradation, which transforms the material. When it reaches 280–340 °C, it is gradually transformed into another material, charred wood. This material has no structural resistance, so in fact, fires on timber structural elements, such as beams or pillars, gradually decrease their cross-section. Eventually, this loss leads to the collapse of the element. The duration between the start of the fire and the collapse of the element is defined as bearing capacity of the element and is called R criterion as defined in Ref. [1].

Both European timber construction code (Eurocode 5) [2] and the Spanish one (Technical Building Code) provide regulatory methodologies for the calculation of a structural element with simple geometry under a fire situation, and also for fasteners, but they do not offer any methodology for carpenter connections.

Carpenter connections, also called traditional connections, are a set of solutions for joining the pieces of timber by carving them and reducing the use of other materials, such as iron or steel, to a minimum. In these type of connections, the forces are transferred from one piece to another through mortises or notches and pins, tenons or keys, transferring the axial forces through compressions and tangential forces. Dowel type fastener are often omitted, and if they are present, their mission, in general, is just securing the parts and preventing the disassembly of the joint [3].

In recent years, the use of carpenter connections has increased due to its appealing appearance, because this kind of connection does not use any metal fasteners, and the generalization in the use of Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) software and Computer Numeric Control (CNC) allows an easier designing and implementation of these connections.

The rounded dovetail connections are particularly useful in roof and floor framings, and transmitting loads from secondary structural elements, such as joists, to primary structural elements such as beams.

The mechanical behaviour of rounded dovetail connections at room temperature has been studied and is well known [4], but there is limited research about its performance under a fire event.

The goal of this research is to predict this performance using a simulation by the finite element method. This model is validated with experimental tests.

1.1. Rounded dovetail connection

1.1.1. Geometrical design

This connection is formed by a tenon carved in the joist and a mortise carved in the beam. The tenon can be divided into two different parts.

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https://doi.org/10.1016/j.firesaf.2017.12.005
Received 14 September 2016; Received in revised form 27 November 2017; Accepted 15 December 2017

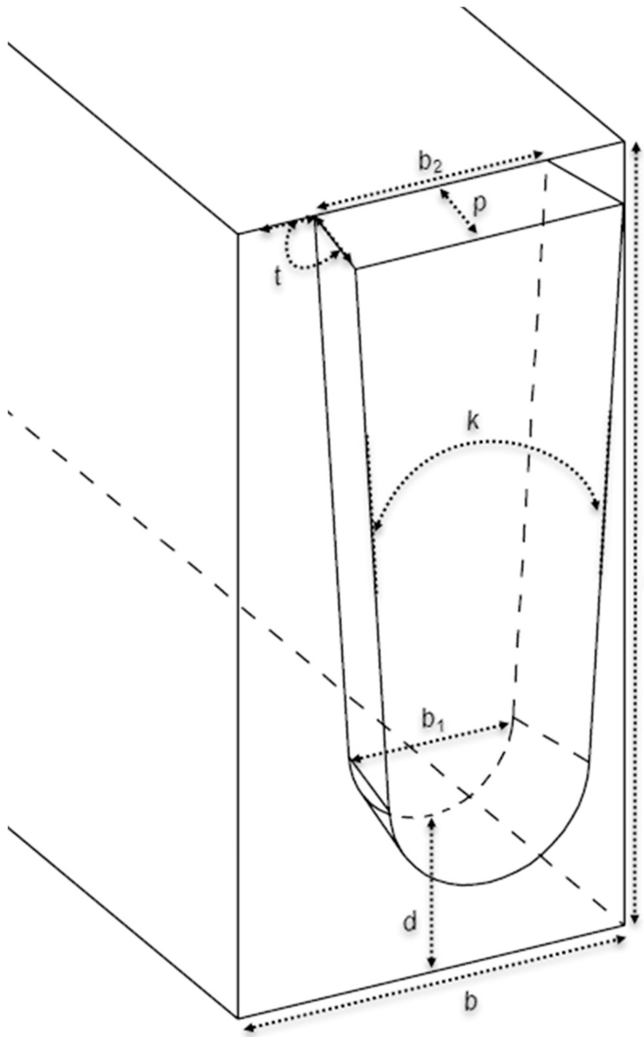

Fig. 1. Geometrical parameters of the rounded dovetail connection tenon.

The upper part consists of a vertical element with straight sides; this element is wider at the top than at the bottom, forming an angle between its sides. The lower part consists of a circular shape, which is tangent to the straight sides (see Fig. 1). There is also an angle between the plane containing the exterior of the tenon and the plane containing the base of the tenon and the exterior surface of the joist. This angle allows the transmission of tensile stress across the connection (see Fig. 1).

So, the design parameters of the tenon are as follows:

- Length of the tenon (p)
- Top width (b_2)
- Bottom width (if the angle k is designed, this parameter is obtained from that) (b_1)
- Angle between the sides (if bottom width is designed, this parameter is obtained from that) (k)
- Angle between front plane and back plane of the tenon (t)
- Height of the tenon. Usually, it is used the distance from the bottom of the tenon to the lower face of the joist (d)

From these parameters, these two ratios can be calculated:

- Tenon height to joist height ratio ($T_h = \frac{h-d}{h}$, where h is the joist height)
- Tenon upper width to joist width ratio ($T_w = \frac{b_2}{b}$, where b is the joist width)

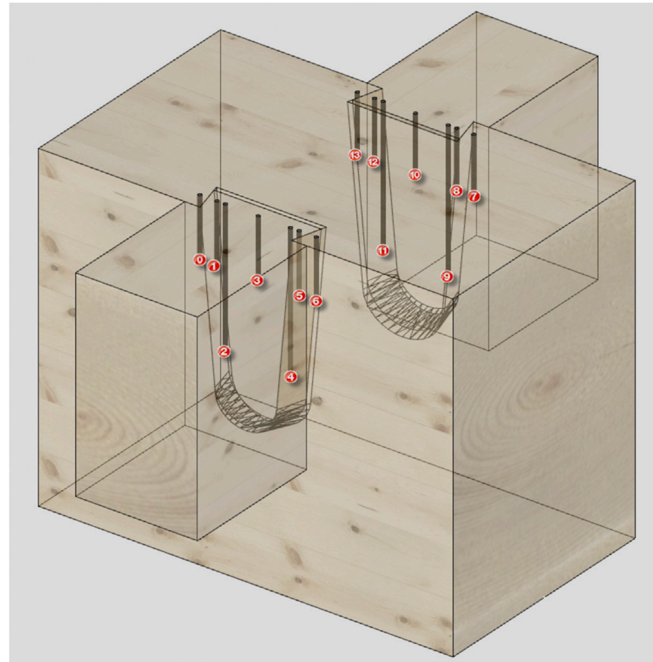

Fig. 2. Location of the thermocouples in the experimental tests.

The design parameters of the mortise are quite similar to that of the tenon. In fact, they are usually derived from the design parameters of the tenon. But there are a couple of parameters which should be individually considered:

- The spacing from the tenon's outer face to the mortise's inner face.
- The spacing at the bottom of the tenon. Usually, the bottom of the tenon is not resting directly on the mortise, and some inner space is left in between. The tenon lies on the mortise using just its lateral

Fig. 3. Setup of the experimental test.