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LOAD-CARRYING CAPACITY OF HYBRID STEEL-WOOD-STEEL DOWEL CONNECTIONS IN DOUBLE-SHEAR UNDER FIRE

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ABSTRACT

The main objective of this work is to present a methodology to design (S-W-S) Steel-Wood-Steel connections in double shear, with internal dowel steel fasteners, in fire conditions. Analytical methodologies according Eurocodes were used to determine the load-carrying capacity of the connections. To analyse the load-carrying capacity, different wood densities and steel dowels diameters will be investigated. The number of dowels is not considerably affected by the wood density of the species. To predict the fire exposure, a thermal and transient numerical analysis was performed to obtain the temperature field results in all studied connections.

Keywords: S-W-S connection, load-carrying capacity, fire, Eurocodes.

INTRODUCTION

The load-carrying capacity of the S-W-S dowel type fasteners connections can be described by the European Yield Model (EYM) based on a plastic limit state analysis. Johansen (1949) was the first researcher that assumed this model has an ideal rigid-plastic behaviour of the wood and steel dowel. This method predicts the strength of two or three-member dowel type connection, (Wilkinson, 1992).

Wood-steel connections are the fragile member for any structural construction. When submitted to fire conditions, an increased weakness occur due to the heat flow into the wood, driven by the steel fasteners or plates which cause faster wood charring (Martins and Fonseca, 2018; Abderrahim *et al.*, 2018). Both steel and wood materials behave differently and the interaction between the elements is even more complex to analyse.

The heat flow in wood leads to a thermochemical decomposition (pyrolysis) which results in the char layer formation, accompanied by mass loss. In wood members exposed to fire or high temperatures, char layer appears and increases in depth with the heat progression. According to Eurocode 5 (CEN EN1995-1-2, 2004) the isotherm of the char layer coincides to 300ºC. All of these phenomena were verified by different researches and also wood connections have been widely investigated to ensure their structural safe and integrity. Several researchers have presented experimental and analytical methods to estimate the wood degradation due to fire conditions, (Fonseca and Barreira, 2009; Fonseca and Barreira, 2011; Fonseca *et al.*, 2013). Also, empirical models for determining the charring rate and the heat transfer conditions were developed by (White and Nordheim, 1992).

The main goal of this work is to present analytical and numerical methodologies to predict the safe of S-W-S connections submitted to a fire, determining the time of fire resistance. Different constructive models (S-W-S connections in double-shear, joined by steel dowel and outer steel plates) will be analysed. This study brings results to the previous investigations by the authors (Fonseca *et al.*, 2020a; Fonseca *et al.*, 2020b; Fonseca and Leite, 2019), looking for the effect of the steel dowels and outside steel plates in the temperature evolution inside the wood member. The designed connections were evaluated for different applied tensile loads, parallel to grain, and different dowels diameters. The main dimensions of the connection are: width, height and thickness of the wood and steel plates, minimum spacing and edge/end distances between the dowels and the plates.

S-W-S CONNECTION IN ACCORDANCE WITH EUROCODE 5

The S-W-S connections were designed with the simplified equations from Eurocode 5 (CEN EN1995-1-1, 2004) and Eurocode 3 (CEN EN1993-1-1, 2005), at ambient temperature. Different wood species in homogeneous glued laminated specimens were considered for the S-W-S designed connections. To reduce the risk of failures modes, a minimum edge distance, and end spacing criteria for the connections, using different dowel diameters, were considered.

According to the simplified equations from Eurocode 5 (CEN EN1995-1-1, 2004), the characteristic load-carrying capacity per shear plane per fastener, $F_{v,Rk}$, is determined according to equation 1. This equation is only used for thin steel plates as the outer members of a double shear S-W-S connection.

$$F_{v,Rk} = min\begin{cases} 0{,}5\, f_{h,2,k}\, t_2\, d \\ 1{,}15\sqrt{2\, M_{y,Rk}\, f_{h,2,k}\, d} + \dfrac{F_{\alpha x,Rk}}{4} \end{cases} \tag{1}$$

t_2 represents the thickness of the wood middle member; $f_{h,2,k}$ is the characteristic embedment strength in wood member; d is the dowel diameter; $M_{y,Rk}$ is the characteristic yield moment of the fastener; calculated according the dowel diameter and the material strength; $F_{\alpha x,Rk}$ represents the characteristic withdrawal capacity of the fastener.

With the obtained characteristic load-carrying capacity it is possible to determine the number of dowels according the applied load design. The arrangement of the dowels will be in lines and columns. In this study, the number of columns was fixed to 3. The edge distances were calculated following the imposed standards.

Different parameters were considered: three dowel diameters (6, 8 and 10mm), three applied tensile load (10, 15 and 20kN) and three wood materials (GL24h, GL28h and GL32h), each one with different densities (380, 410 and 430 kg/m^3, respectively). The results are presented in figure 1, which represents the relation between the number of dowels depending on the applied load “Ed” and the dowel diameter. The wood density does not affect considerably the number of dowels. The same conclusions were reported by the authors of this work in previous publications, but for W-S-W and W-W-W designed connections (Fonseca *et al.*, 2019; Aissa, *et al.*, 2017; Fernando *et al.*, 2018; Martins and Fonseca, 2018).

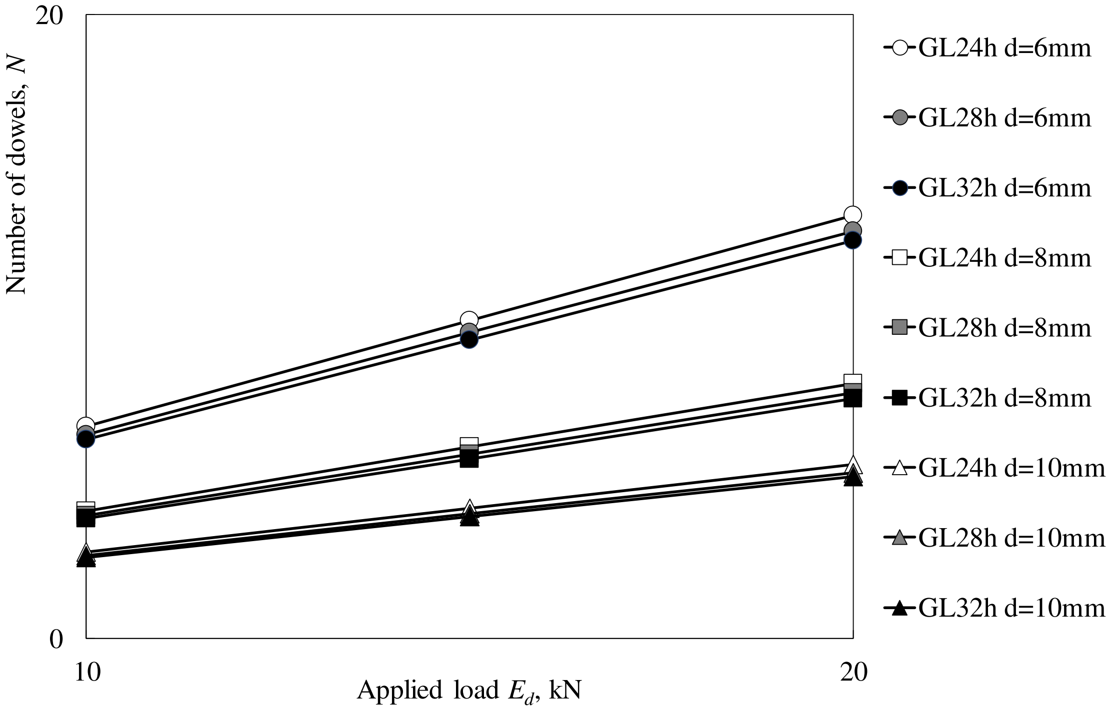

Fig. 1 - Number of dowels depending on the applied load, for S-W-S connections

S-W-S NUMERICAL MODEL

To simulate the thermal resistance of the S-W-S connection, a numerical program was used to produce simulations focused on thermal and transient analysis. This methodology allows to obtain the temperature field in the studied connections under fire and allows to calculate the char layer in the members with different wood densities.

All thermal properties (thermal conductivity, specific heat and density) used in the numerical model are based on standard codes. Steel behaviour is defined according to the Eurocode 3 (CEN EN1993-1-2, 2005), Eurocode 5 (CEN EN1995-1-2, 2004) is used for wood with different densities (GL24h, GL28h and GL32h). The material non-linearity due to the temperature effect was considered in the numerical simulation.

The numerical models were developed, using the designed connections obtained from the previous calculation at ambient temperature. According to the symmetry of the model connection, only a 2D quarter model of the S-W-S connection will be studied. The numerical calculation was performed for a plane of the connection including the dowels location, where the number of columns is fixed to 3. The finite element chosen has eight nodes and three degrees of freedom per node. The initial temperature in the numerical model was considered equal to 20ºC. The external surface of the connection is exposed to the standard fire curve ISO834 during 1800s and the convection coefficient is taken equal to 25W/m^{2}K. The fire emissivity is taken constant and equal to 1 for exposed side.

Figure 2 represents the connections in study (a quarter of S-W-S), with the applied mesh, time of fire resistance and temperature at 1800s.

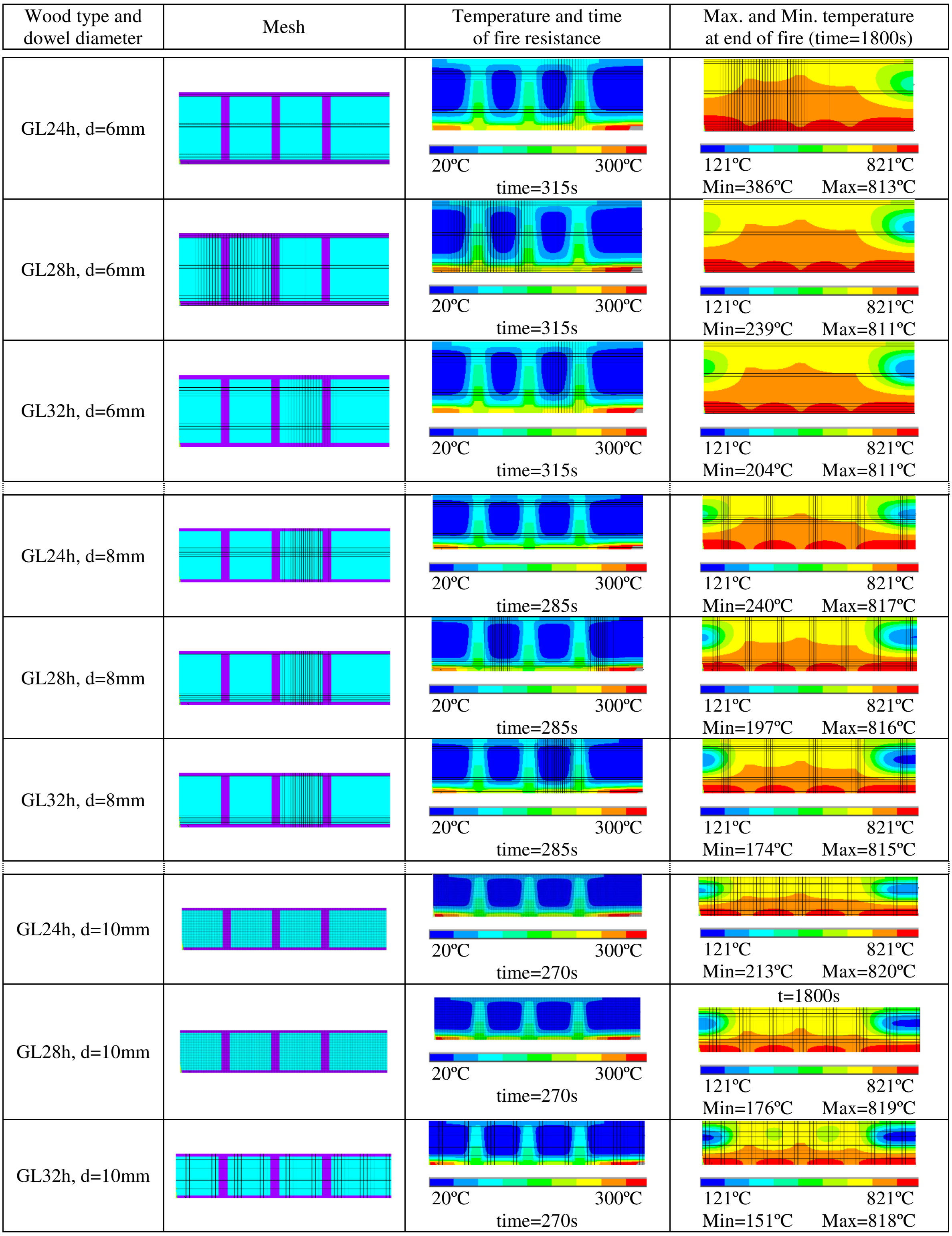

Fig. 2 - Time of fire resistance for S-W-S connections, and maximum and minimum temperature at the end of fire exposure

RESULTS AND DISCUSSION

A procedure with simplified equations was presented to assess the dimensions of the connections for any applied tensile load. The number of fasteners increases with load, according to standards at room temperature. Lower dowels diameter has a higher pronounced effect in the required number of fasteners. The mechanical effect due to the strength of material for GL24h, GL28h and GL32h is not significant, but the wood density variation affects the thermal behaviour.

A finite element program was used to produce the numerical simulations of S-W-S connections with the steel members exposed to fire, and including the non-linear material in transient analysis. The main objective is to obtain fire resistance (time) of the connection when the temperature reaches 300ºC in the wood material. The temperature field was also investigated in all connections, measuring the maximum and minimum temperature in the connections, where the material effect (steel and wood) and the timber density are important parameters to be considered. The numerical method shows a good solution process to understand the behaviour of the connection (both materials steel and wood) under fire exposure.

As a general conclusion, the combination of the largest wood density with the largest dowel diameter allows lower minimum temperatures inside the connection in a fire condition. However, a smaller dowel diameter in the connections leads to a delay in start the charring rate. The time of fire resistance is higher when compared with S-W-S connections with large dowels diameters. This is because the fire resistance time is measured when the first layer of wood charred, and in this way is independent of the material density.

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