COMPUTATIONAL MODEL FOR TIMBER CONNECTIONS EXPOSED TO HIGH TEMPERATURES

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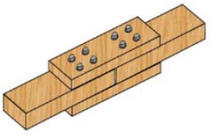
1- INTRODUCTION / OBJECTIVES

Introduction: The use of wood, as a structural material, continues to grow far beyond traditional application. Timber connections are considered critical due to their resistance and durability, mainly depend on the join design of the different structural elements. They are subjected to localized stresses and strains, and may expose the overall stability of the structure. For imposed thermal loads under fire conditions, it remains important to improve the knowledge of the connection behaviour.



Objective:

This study present an approach for wood-wood-wood (W-W-W) connections design in double shear at ambient and high temperatures, using dowelled fastener connectors. The designed connection will be considered unprotected at ambient temperature, and protected for high temperatures.

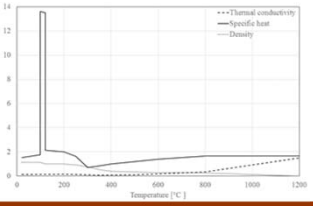
Keywords: W-W-W connection, dowel, insulation, thermal analysis, mechanical analysis.

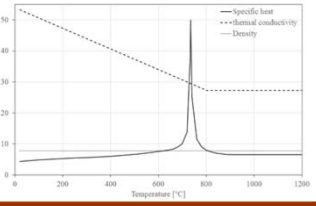
2- MATERIAL PROPERTIES

Orthotropic yellow birch wood GL28h (Glue Laminated Timber, GLULAM or GL) and isotropic hot-rolled low carbon steel S275 were used. Following the mechanical and thermal properties:

Strength Class	GL28h	
	Designation	Value
Bending strength	$f_{m,k}$	28 [MPa]
Tension parallel to the fibers	$f_{t,0,k}$	19,5 [MPa]
Modulus of elasticity parallel to the fibers	$E_{0,mean}$	12600[MPa]
Shear modulus	G_{mean}	780 [MPa]
Density	ρ_k	410 [kg/m³]

Steel grade	S275	
	Designation	Value
Characteristic value of strength at the max load	$f_{u,k}$	400 [MPa]
Yield strength	f_y	275 [MPa]
Ultimate tensile strength	f_u	430 [MPa]
Modulus of elasticity	E	210 [GPa]
Poisson's ratio	υ	0,3
Density	ρ_s	7850 [kg/m³]





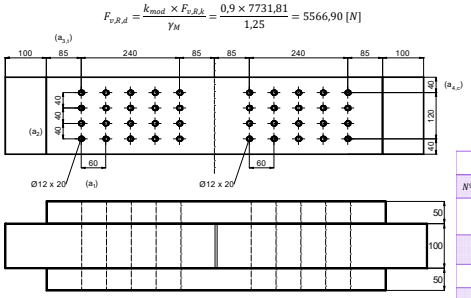
3- W-W-W CONNECTION UNDER ROOM TEMPERATURE

Connection is calculated according EC5, 4 plates from GL28h joined by steel dowels of ϕ12[mm]. Calculations determine cross-section size, number of bolts, spacing between fasteners, and load carrying $F_{v,R,d}$ per shear. Each side of the model is submitted to an applied force of 100[kN].

$$F_{v,R,d} = \frac{k_{mod} \times F_{v,R,k}}{\gamma_M} = \frac{0,9 \times 7731,81}{1,25} = 5566,90\ [N]$$

	Cross-section of wood
Designation	$A_s\ [mm^2]$
References EC5	Cap 6.1.2; equation (6.1)
Equation used	$\sigma_{t,0,d} = \frac{F_d}{A_s} \le f_{t,0,d} = \frac{k_{mod} \times f_{t,0,k}}{\gamma_M}$
Calculation results	7122,507 N
Considered results	7122,507 N

Number of dowels	Minimum spacing, mm			
$N°$ (in symmetry for the other side)	a_1	a_2	$a_{3,t}$	$a_{4,c}$
Cap 8.2.2; equation (8.7) $N° = \frac{F_d}{F_{v,R,d}}$	Cap 8.6; table (8.5)			
≈18	60	36	84	36
20	60	40	85	40



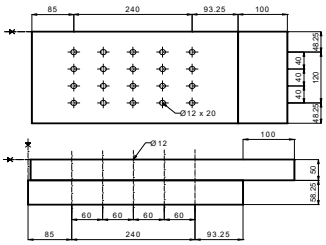
Front and top view: (the dimensions are in millimeters [mm])

4- W-W-W CONNECTION UNDER HIGH TEMPERATURE

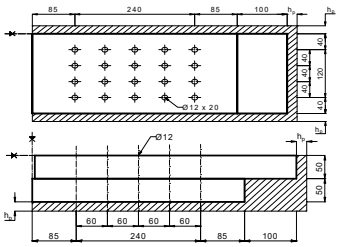
EC5 is used to determine an extra thickness of the unprotected connection, and panel thickness for protected connection.

Dimension	Initial dimensions	$F_{v,Rk}$ [1]	Exposure time	New dimensions	$F_{v,Rk}$ [2]
[mm]	[mm]	[N]	[min]	[mm]	[N]
Ø12	t_1 = 50 lateral t_2 = 100 internal	7731,81	30	t_1 = 58,25 t_2 = 100	8489,26

Dowels ϕ12	t_{req}	t_{ch}	h_p
	[min]	[min]	[mm]
Gypsum type A	30	20	12,1
	60	50	22,9
Gypsum type F	30	6	7,1
	60	36	17,9
Wood panelling	30	20	10
	60	50	25



Unprotected model (extra thickness)



Protected model (protective panel thickness)

5- MECHANICAL FEM ANALYSIS OF W-W-W CONNECTION

FEM permits to obtain the maximum critical load applied to the connection. Due the geometric symmetry and loading conditions, one quarter of the model is analyzed. An incremental tensile load will be implemented in direction parallel to the grain, representing a half of the applied load.

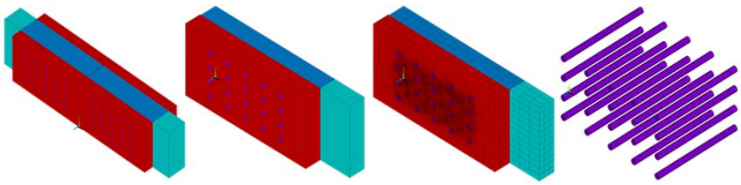


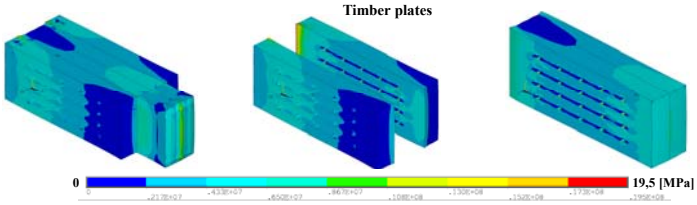
Figure represents the equivalent stresses when the predicted ultimate load from the numerical model is 132kN and permits to calculate a load carrying $F_{v,R,d}$ per shear and for each fastener (20 dowels) equal to 6,6kN.

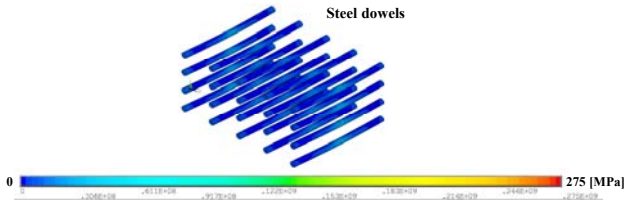
Calculated load carrying $F_{v,R,d}$ per shear and each fastener was equal to 5,57kN according EC5. Error estimation: 18,50 %

The maximum equivalent stresses was obtained in timber hole near of the middle connection.

Inside the timber holes the maximum stresses reaches the maximum value of yield stress material.

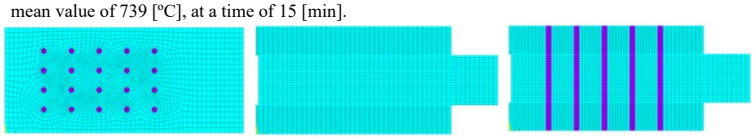
The steel dowels don't appear any damage due the lower equivalent stresses. But, due the deformed shape, the stresses concentrations are in middle of the dowels.



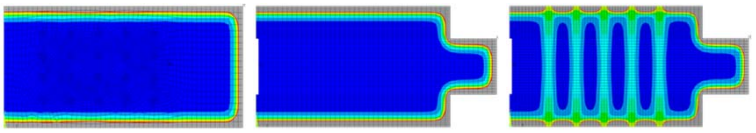


6- THERMAL FEM ANALYSIS OF W-W-W CONNECTION

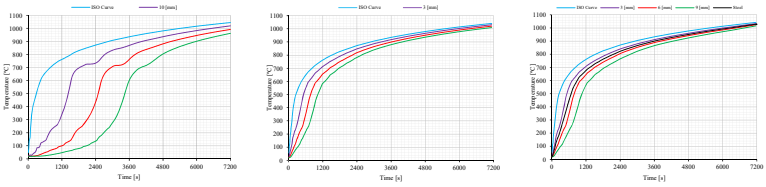
The ambient temperature development for fire situation is according standard curve ISO834. Figures below represent the mesh of the models and the char layer when the temperature reaches a mean value of 739 [ºC], at a time of 15 [min].



The meshing of the 3 simulated models: Front, Top and Top-section (**wood** in blue, **steel** in purple)



Model	FRONT						TOP						TOP-SECTION					
Temperature [ºC]	280			300			280			300			280			300		
Depth (d) [mm]	10	20	30	10	20	30	2,9125	5,825	8,7375	2,9125	5,825	8,7375	2,9125	5,825	8,7375	2,9125	5,825	8,7375
Time (t) [s]	1093,7	2023,7	3013,7	1133,7	2093,7	3073,7	300,25	520,25	740,25	320,25	540,25	760,25	305,23	515,23	745,23	325,23	545,23	775,23
Charring rate β	0,59	0,59	0,60	0,53	0,57	0,59	0,58	0,67	0,71	0,55	0,65	0,69	0,57	0,68	0,70	0,54	0,64	0,68
The average β	0,59			0,56			0,65			0,63			0,65			0,62		



7- CONCLUSIONS

The use of hybrid wood/steel elements need particular attention in design due the applied mechanical and/or thermal loading conditions.

Design equations from standards and also numerical models could be used to guarantee safety in these elements in building construction.

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