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Fire resistance of joist hanger connections for timber structures

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Despite current political initiatives to support the use of timber and the several advantages of build with timber there are still large concerns and limitations by authorities and design codes related to fire safety. Furthermore engineers often facing the problem of limited knowledge about the fire behaviour or missing normative design rules for typical connections used in timber structures, like engineered joist to beam and joist to column connections. To overcome this gap of knowledge a German research project [2] was conducted which sought to investigate the thermal and structural performance of typical engineered connections for timber structures in the event of fire. Primary focus has been laid to investigate the fire behaviour of connections with joist hangers and screwed connections with fully threaded screws.

The following article comprises only the investigations and results for joist hangers. The experimental and numerical investigations for connection with fully threaded screws will be subject of additional articles by the authors and will be published in due course.

Figure 1. Unloaded test specimen after fire exposure.

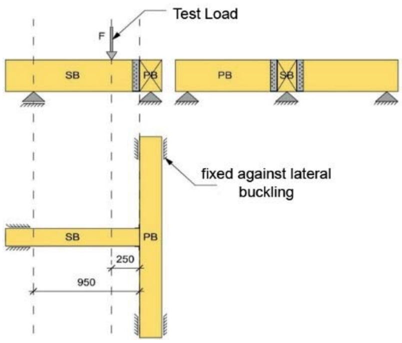

Figure 2. Principal setup in the loaded tests, ambient and fire.

Figure 3. Loaded fire test with joist hanger.

The investigations conducted in this research project were based on three steps, see Fig. 1 - 3:

(1) unloaded small scale fire tests to assess the influence of geometry and material interaction,

(2) mechanical testing of the connections at ambient conditions under consideration of the results gained in step (1),

(3) loaded full-scale fire tests of optimized connection systems, based on the results gained in the previous steps (1) and (2).

The test configuration for the unloaded fire test consisted of a U-shaped specimen made of 100 mm CLT panels, with 300 mm long glulam beams mounted on their inner sides, as illustrated in Fig. 1. Two sizes of 2 mm thick galvanized zinc coated joist hangers (W x H =100 mm x 240 mm and 200 mm x 300 mm) were investigated, each for internal and external wings. To fix the joist hangers to the beam sections and CLT wall elements, rink shank nails with a diameter of 4 mm and screws with a nominal diameter of 5 mm were used as fasteners. Both types were 50 mm and 70 mm in length respectively. The connections were equipped with type-K thermocouples to measure the temperature formation within the connectors, joints and fasteners.
In comparison the mechanical loaded tests (fire and ambient) showed a typical T- shape and were assembled each of a primary beam (PB) with a length of 2000 mm and a secondary beam (SB) with a length of 1200 mm, see Fig 2. The cross section of the beams varied in subject to the type of the connection, see Table 1. All specimen were supported on two points of the primary beam (pinned) and one point of the secondary beam (roller) and were fixed against lateral buckling. The T-shaped specimens were placed in a diesel fired furnace and exposed to standard fire over 30 minutes in accordance with EN 1363-1. A comparable setup, considering the requirements of EN 26891 and ETAG 0015 also was used to determine the load displacement behaviour and failure load at ambient conditions for each connection type as basis for the loaded fire tests.
In the fire tests a constant load of 40 % of the estimated capacity after fire exposure was applied during the time of fire exposure by a force controlled hydraulic jack. At the end of the designated exposure time (30 minutes) the load was increased until the connection reached failure.

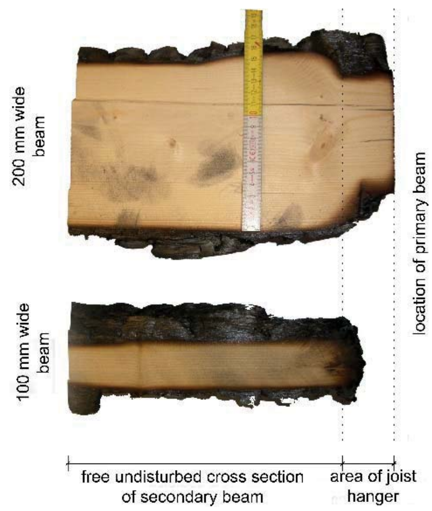

Figure 4. Horizontal section through fire exposed secondary beams.

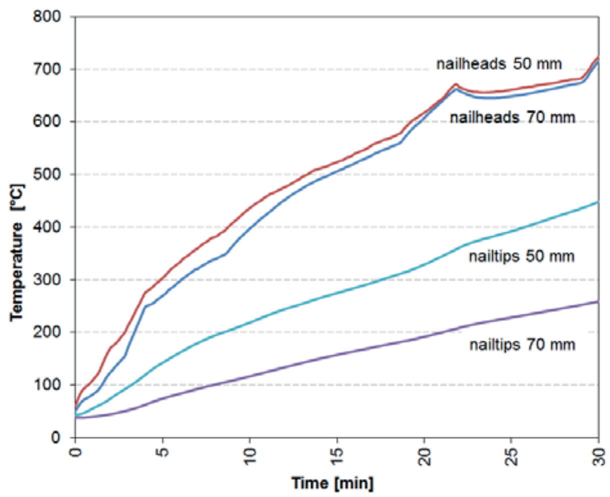

Figure 5. Temperature formation in rink shank nails 4x50 and 4x70 (mean values).

The conducted series of fire tests with joist hangers showed, that the type of fastener mainly influences the charring of wood, which is in contact with the metal fasteners. The unprotected fasteners conducted the heat from the surface into the interior of the timber members, resulting in a larger charring depth compared to free undisturbed areas of the beams not adjacent to the fasteners (see Fig. 4).
The examined screws with a nominal diameter of 5 mm (3.3 mm core diameter) performed better than the 4 mm nails with same length, resulting in more slowly heating curves within the temperature measurements of the screw tips.
A comparison of the temperatures at the fastener tips showed that the 50 mm long fasteners heated up more quickly than the 70 mm long fasteners, if the same fastener type and diameter was used, see Fig. 5.

All conducted loaded full-scale fire tests showed a similar behaviour to each other, which can be described as follows:
After a few minutes, the connections start to deform. After approximately 15 minutes, the rate of deformation started to increase significantly. All specimens showed relative displacements between primary and secondary beam of about 30 mm towards the end of the fire exposure, collapse occurred at about 40 mm displacement. The fasteners had been considerably deformed and the connections failed after pulling out of the fasteners. The sheet metal itself failed in no case.

Connections using the number of fasteners required according to ETA [1] reached a lower load bearing capacity than connections with the maximum number of fasteners possible by the number of punched holes. The obtained maximum load bearing capacities are summarised in Table 1.

Table 1. Overview of investigated connection setups and obtained results after 30 minutes fire exposure.

Speci-men	**secondary beam [mm]**	**Fastener/ nailing pattern**	**Failure load R_{fi} [kN]** [a]	**$R_{k,20}$ [kN]** [b]	**μ $R_{fi}/R_{k,20°C}$**
B1	120 x 160	rink shank nails 4x60 mm/ according to ETA	0	39.9	0
B2	120 x 240	screws 5x60 mm according to ETA	7.7	94.6	0.08
B3	140 x 200	screws 5x70 mm according to ETA	17.8	85.4	0.21
B3 a	140 x 200	screws 5x70 mm all holes used	26.2	79.0	0.33
B4	140 x 200	rink shank nails 4x75 mm all holes used	14.9	76.6	0.19

[a] *characteristical load bearing resistance according to ETA [1] at ambient conditions,*
[b] *R_{fi} represents the measured value at the connection in the moment of failure,*

Based on the results the connection of joist hanger to the secondary beam appears as the critical area under fire exposure and will govern the failure. The results show that unprotected 50 mm long fasteners are not long enough to embed in the residual timber cross section after 30 minutes. The position of the wings has no essential influence, although internal wings are positively affecting the strength of the connection at the main beam. In the interest of a maximum in strength during fire exposure, the gap between the timber beams should be as small as possible.

Connections with joist hangers exposed to fire on four sides over 30 minutes are able to bear loads of 0,33·$R_{k,20}$, when designed according to the following recommendations:

- joist hangers Type 05 according to ETA 08/0264 [1], or equivalent
- minimum cross section of joist of 140 mm x 200 mm
- screws 5 x 70 mm in all holes, in two rows over the entire height of the joist hanger
- maximal gap between primary and secondary beam 4 mm
- both inside and outside position of the wings possible
- a/h >0,7 (according to EN 1995-1-1)

Identical connections, but made up with ring shank nails 4 x 70 mm instead of screws are able to bear loads up to 0,19·$R_{k,20}$. The lower load bearing capacity can mainly be explained by the lower pull-out resistance of the nails.

It is assumed, that bigger cross sections of joists lead to a better load bearing ratio, as side influences from the upper and lower edge declines and the calculated load bearing capacity increases linearly with the height of the joist. Furthermore, an increase of the sheet metal thickness will not negatively influence the fire resistance of a connection, due to the increased heat storage capacity and reduced heating up.

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[1] ETA 08/0264. 2013. GH Joist hangers type TOP, 04 Kombi, 04 Kombi I, 04 I schmal, 05 Kombi, 05 Kombi I,

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