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SENSITIVITY ANALYSIS OF STEEL TO TIMBER JOINT EXPOSED TO FIRE

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Abstract: *The paper presents a part of research focused on a timber joint with an inserted steel plate under fire exposure. It brings results of an extensive sensitivity analysis which investigates the influence of various parameters on the heat transfer in the joint. Parameters chosen for the study include joint geometry, material properties, type and diameter of fasteners, thickness of the modification layer, and others. In order to study an effect of the parameters, several submodels are created in finite element model ANSYS. The results of the submodels are compared to the original model which is validated on experimental results. The analysis shows significant effect of several parameters on the heat transfer. The outputs of the analysis can be used for the joint design in order to increase fire resistance of the joint. For FE modelling of the joint authors also recommend timber properties which correlate well with a real behavior of the joint.*

Keywords: Steel to timber joint, Fire, Heat transfer, Numerical model, Sensitivity analysis.

1. Introduction

Joints with inserted steel plates, which are able to withstand higher loads comparing to timber joints only, have been popular within timber structures for a long time. These joints are called "steel-timber" joints according to the EN 1995-1-1 (2004). Based on recommendation in the standard EN 1995-1-2 (2004), the fire resistance of unprotected timber joints is limited to 30 minutes. However, several studies have shown that these joints can achieve higher fire resistance comparing to values given in the standard.

There are plenty of studies dealing with the load-bearing capacity of steel-timber joints at normal temperature. However, studies focusing on behaviour of steel-timber joints exposed to fire have rarely been undertaken. Frangi et al. (2009) conducted an extensive experimental study focusing on beam-column connections under normal temperature and fire conditions. They developed a numerical model to correctly simulate the deformation and temperature histories. Another study focused on fire resistance of steel-timber joints (Audebert et al. 2012) investigated the influence of the fasteners used. Pin connections with one bolt in each row of fasteners were proposed. From the data, the effect of the stud on the load carrying capacity was demonstrated. Papers (Audebert et al., 2014, Audebert et al., 2019) presented experimental or numerical study of steel-timber joints exposed to fire, differing in material properties, location of steel plate, type of fastener or mechanical loading. Palma et al. (2019) investigated the effect of joint geometry especially the spacing of fasteners during the fire. The test results show a significant dependence of the fire resistance of the designed joints on the width of the lateral elements.

In order to verify a thermal response of the steel-timber joint, a numerical model of bolted steel-timber joint at elevated temperature was created and described by Zeman (2021). Validation of the model on experimental results from a fire tests conducted in a medium-sized furnace presented by Vopatová et al. (2021) show a good ability of the model to predict residual cross-section, temperature of steel plate and bolts and temperature of timber elements. This paper presents results of an extensive sensitivity analysis which investigates the influence of various parameters on the heat transfer in the joint.

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2. Numerical model and submodels

For the sensitivity analysis several submodels which are built on the basis of original finite element model described in (Zeman, 2021) are created. The submodels developed in finitel element model ANSYS 19.R3 differ in geometry, material properties, or other parameters, keeping the main features of the original model unchanged. The results of the analyses are compared to the results of the original model (Zeman, 2021) and with the experimentally obtained results (Vopatová et al., 2021). The aim of the analysis is to study the influence of various parameters on the heat transfer in the joint.

The original model (Fig. 1) is composed of the C24 strength class grown timber element of a square cross-section with dimensions 140 mm x 140 mm. The steel plate of S235 steel class is located in the middle of the timber elements. It is 300 mm long, 6 mm thick, and 80 mm wide. Four M10 bolts are used on each side of each timber element. The bolt is held by an 8 mm high nut. Washers with a diameter of 30 mm and a height of 2,5 mm are used. The joint configuration including spacing between bolts has been designed in respect to EN 1995-1-1 (2004) and EN 1995-1-2 (2004) to meet fire resistance R30. A symmetrical half of the model is calculated using a tetrahedral computing mesh.

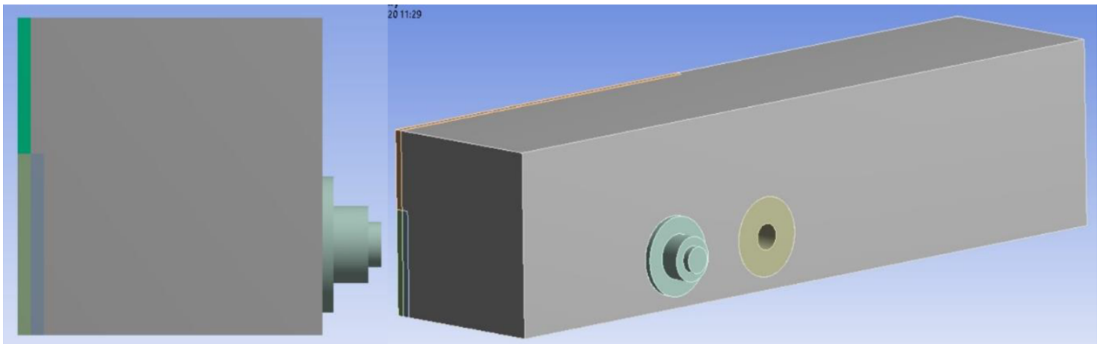


Fig. 1: Visualization of the original model of steel-timber joint with bolts.

Submodels used for the analysis of the influence of modification layer is created with thickness of this layer of 4, 5 and 6 mm comparing its results to the fire test and to the original model with 3 mm thick layer. The layer simulated close to the steel sheet is done in order to take into account the effect of accumulated water vapour thanks to the barrier formed by the sheet. Its modification lies in change of specific heat capacity of timber, as recommended by Audebert et al. (2014). The results of the analysis show that the layer thickness does not have significant influence on temperature of steel sheet and bolts. The influence on temperature in timber in the control point TC7 located 35 mm bellow sheet axis, in the region with no fasteners, is shown in Fig. 2. From the results it may be stated that the model with 3 mm thick layer correlates well with the experimental data.

For the analysis of material properties, submodels use timber properties given in (Janssens, 1994) and (Menis, 2012). Their results are compared to the fire test and original model with steel and timber properties taken from EN 1993-1-2 (2005) and EN 1995-1-2 (2004). The results of the analysis shown in Fig. 3 predict that any properties do not have significant influence on temperature of steel sheet and bolts. The influence on temperature in timber in the control point TC7 is significant. Based on the results it may be stated that the model with timber properties taken from (Janssens, 1994) correlates well with the experimental data.

In the next analysis focused on timber strength class four submodels with C20, C22, C24 and C27 class are created. Calculated results show that with higher strength class the temperature growth is slower. Temperature increase on steel sheet and bolts is negligible.

Then an influence of diameter of steel bolts on transport of temperature in the joint is studied. Bolts M10, M12 and M16 are compared using ANSYS submodels. Due to comparability of results, geometry of the joint and spacing between bolts are kept unchanged, regardless of the standard recommendation. The results of the submodels show that with increased bolt diameter, temperature in the sheet and bolts is increased too. Temperature of timber close to fasteners and the sheet is also affected. In the distant parts from fasteners the timber is not influenced at all.

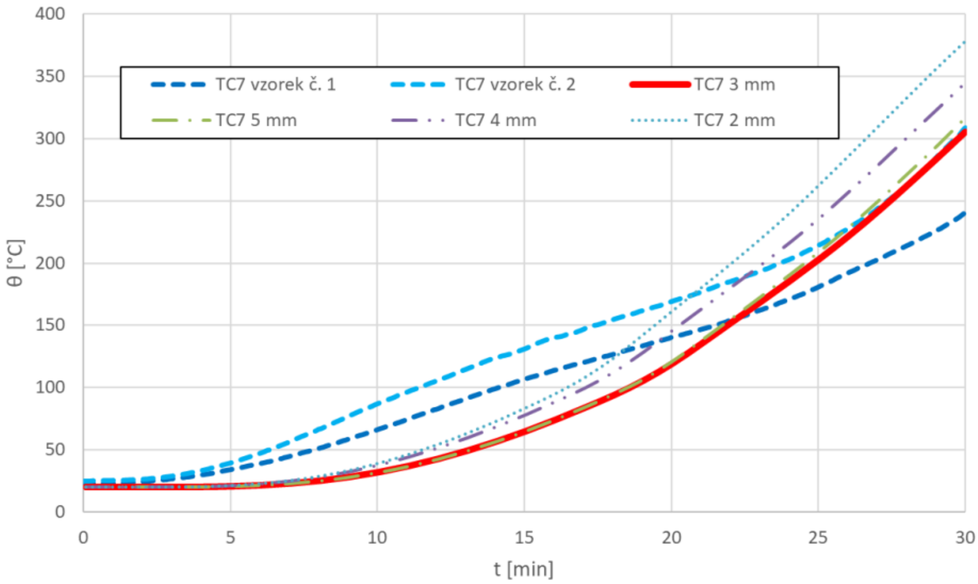


Fig. 2: Temperature in timber from models with different modification layer.

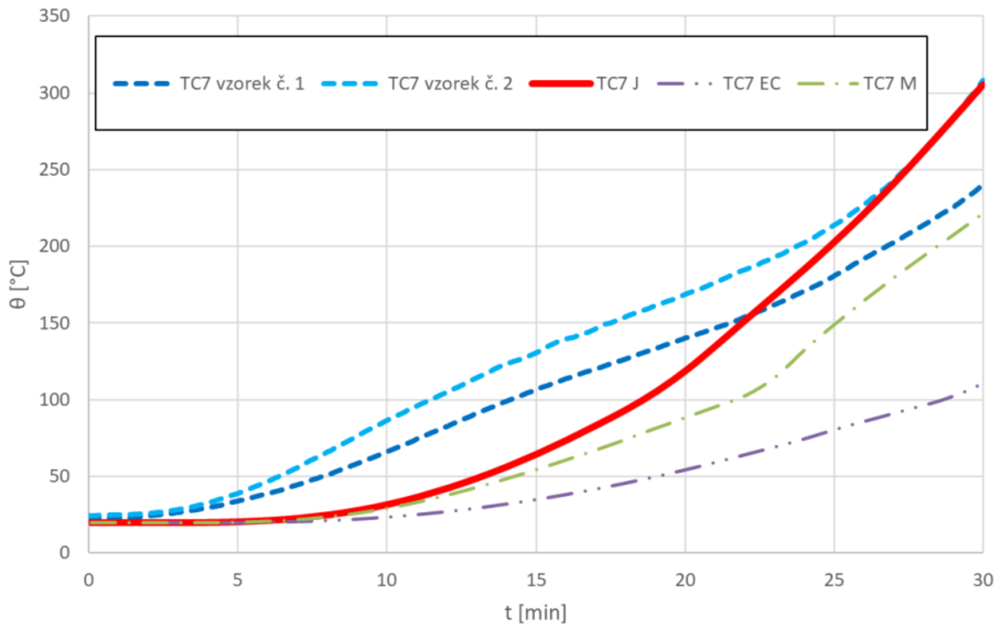
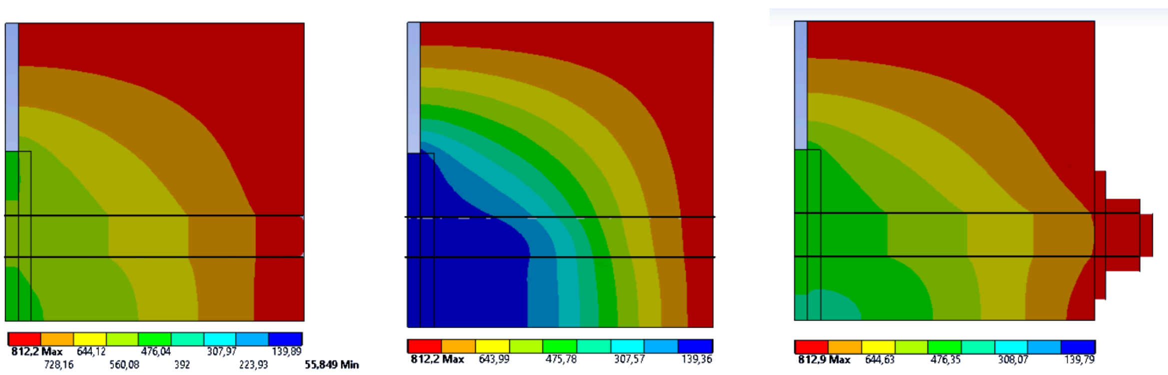


Fig. 3: Temperature in timber from models with different timber properties.



a) b) c)

Fig. 4: Temperature development in the joint with: a) steel dowel, b) timber dowel, c) steel bolt.

Material of fasteners has a major effect on the heat transfer in the joint. The original model with steel bolts is compared to a submodels with steel dowels and timber dowels of 10 mm diameter, 70 mm long. Timber dowels are made of beech, with properties taken from (Czajkowki et al., 2020). Steel dowels are made of S235 grade. The models take into account design rules of each type of the fastener. They differ in load-bearing capacity. The submodel with steel dowels has the highest temperature growth in each part of the joint. It is affected by small volume of steel dowels, which temperature increase is faster comparing to bigger volume of steel of bolts with nuts and washers. The smallest temperature is found in the submodel with timber dowels. Temperatures in all the submodels are shown in Fig. 4.

3. Conclusions

Based on the results of the sensitivity analysis the authors of the paper recommend to use timber properties according to (Janssens, 1994), including the modification layer of 3 mm thick for FE modelling of the joint. The fire resistance of the joint can be increased by bigger dimensions of the joint or by usage of higher timber strength class. Joint solution which may be beneficial for heat transfer at one hand, as timber dowels, has lower load-bearing capacity on the second hand. To optimize the joint design from fire safety view is therefore not an easy task and cannot be solved without a view on load-bearing capacity of the joint.

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