FINITE-ELEMENT MODELLING OF TIMBER-FIBRE CONCRETE COMPOSITE FLOOR IN FIRE

CALDOVÁ Eva [1], VYMLÁTIL Petr [2], WALD František [3], KUKLÍKOVÁ Anna [4]

Abstract

Timber-concrete composite structures are becoming very important because they are widely used as an effective method for refurbishment of existing timber floors and for floors of new multi-storey timber houses. New kind of such floor is that the usual reinforced concrete is replaced by steel fibre reinforced concrete (SFRC). One of the most important requirements of timber-fibre concrete composite is fire resistance. This paper presents 3D FE model developed to predict the thermal analysis of timber-fibre concrete composite floor in fire. All this modelling is done using a commercial programme Ansys 14. The results obtained in the numerical simulations are compared with results obtained from furnace test. Furnace test was performed on one full-size floor specimen at the Fire testing laboratory PAVUS in the Czech Republic. Floor specimen was 4,5 m long and 3 m wide, consisting of 60 mm fibre concrete topping on plywood formwork, connected to GL floor joists. It was subjected the standard fire for over 150 min.

Keywords: timber, fibre concrete, numerical analysis, fire

1. Introduction

The effective utilization of timber is urged from the point of preservation of natural resources and global environment. The effective mixture of timber and other materials is expected to extend the possibility of building structures because of the possibility to realize high performance in both structural safety and fire safety. For this reason it is necessary to gain a deeper knowledge of the behaviour of timber structures in fire, to remove all unknown and to ensure safe use for the intended purpose.

[1] CALDOVÁ Eva, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29 Praha 6, eva.caldova@fsv.cvut.cz

[2] VYMLÁTIL Petr, Designtec s.r.o., Žižkova 1990/59, 616 00 Brno, vymlatil.p@designtec.cz

[3] WALD František, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29 Praha 6, wald@fsv.cvut.cz

[4] KUKLÍKOVÁ Anna, Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7, 166 29 Praha 6, kuklikov@fsv.cvut.cz

In recent years, the use of timber-concrete structures has considerably increased especially in case of reconstructions and constructions of prefabricated residential houses. The current European and world standards insufficiently cover the possibility of connection these two composites. Design of these joints is purely empirical and conservative method and does not reflect the real behaviour of the structure (deformation of the timber beam, deformation of the concrete slab, slip of the connectors, etc.). The connections are very significantly oversized.

Analysis of behaviour of structural element or structural system can be carried out by experiments or numerical simulations. In the field of fire investigation, the numerical modelling constitutes important part. In view of the fact that current fire experiments are very costly and time consuming, the numerical analysis offers a possibility to study the influence of a large variety of parameters and a much faster option. The condition is implementation of material models accurately simulating real properties and implementation of simplifying assumptions that do not negatively affect results of numerical simulation with respect to the real structural behaviour. The results of numerical simulations must be verified by experiment. On the other side the experiment can help to calibrate parameters of the implemented material models and numerical models. In this case are experiments unavoidable. As soon as the numerical model is verified it can be used for optimization, case studies, reliable and probabilistic analyses. The aim is effective utilization of used materials together with providing of required reliability (Petrik & Broukalova, 2011).

In the concrete slab of the timber-concrete composite construction is necessary reinforcement for restrain caused by shrinkage of concrete and to obtain a sufficient resistance against tensile forces around the shear connectors. Consider the amount and the position of the reinforcement in the slab the thickness of the slab results in a minimum of about 60 mm which leads to an unnecessary high dead load of the composite floor. For this reasons several research studies during the last decades have been conducted, with focus on new timber-concrete composite floor. One of the new kinds of such floor is that the usual reinforced concrete is replaced by steel fibre reinforced concrete (SFRC). This innovative concrete with specific hardened concrete properties and fresh was developed to reduce the slab thickness and to help the construction procedure. With the use of fibres the experiment shows that the behaviour is more ductile and redistribution of stresses is better.

One of the most important requirements of timber-fibre concrete composite is fire resistance. The fire resistance of timber-fibre concrete composite elements is mainly influenced by the timber, the connectors and mixture of fibre concrete. The temperature inside the timber member depends particularly on the cross-sectional dimensions, on the density and moisture content of wood and on the fire load and temperature development during the fire. The temperature development in the place of the shear connection can be governed by the cross-sectional dimensions, particularly by the width, and by the sort of fire scenario. It is possible to use nominal, parametric or natural fire scenario. Fire resistance of SFRC can be increased by adding of plastic fibres (polypropylene, polyester) because the plastic fibres evaporate in temperature of 100 ° C and rise continuous water pore to escape from concrete in case of fire. The results indicate that the influence of steel fibres on the mechanical properties is relatively greater than the influence on the thermal properties and is expected to be beneficial to the fire resistance of structural elements constructed of fibre-concrete. Experimental and theoretical studies shows that the compressive strength at elevated temperatures of fibre-reinforced concrete is higher than that of plain concrete. The presence of steel fibres increases the ultimate strain and improves the ductility of fibre-reinforced concrete elements (Kodur, 1996).

Thermal and mechanical properties of fibre reinforced concrete at elevated temperature and modelling of timber-fibre concrete composite floor in fire will be the subject of further author´s works and papers. The results obtained in the numerical simulations are compared with results obtained from furnace tests, which were performed on one full-size floor specimens in the Fire testing laboratory PAVUS in October 2012. On the evaluating of results and comparing results and simulations author currently works.

2. Load-displacement behaviour of timber-fibre concrete composite specimens

High influence on the performance of this type of composite structures has the mechanical behaviour of shear connectors between timber and fibre concrete. The parameters required to define the non linear behaviour of the connections are often not available, therefore the model input data are based on connector properties obtained from the experimental tests performed in accordance with standard ISO EN 26891.

2.1 Push-out tests

In order to determine the stiffness and shear bearing capacity of connection system under application of fibre concrete 6 push-out specimens were tested, see Figure 1.

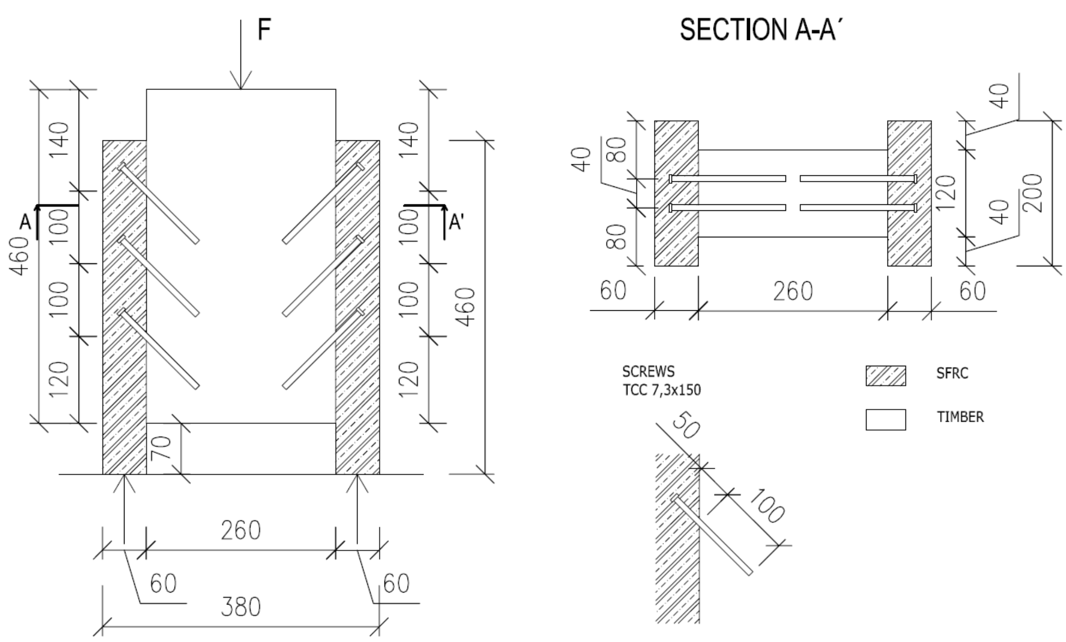

Fig. 1: Push-out specimen

The specimens were loaded in a servo-hydraulic testing machine and the loading regime was according to ISO EN 26891. For measure the displacement between timber beam and fibre reinforced concrete slab 4 LVDT´s were applied, see Figure 2.

Fig. 2: Testing machine with push-out specimen

The objective of these tests was identification and verification of parameters of contact elements that represent the connection so that they can be used in complex numerical models of whole systems.

2.2 Numerical simulation of push-out tests

Numerical simulations of the push-out test are currently generated to determine of a suitable numerical model, which will be applied in numerical analyses of the girder and complex models of combined structural systems.

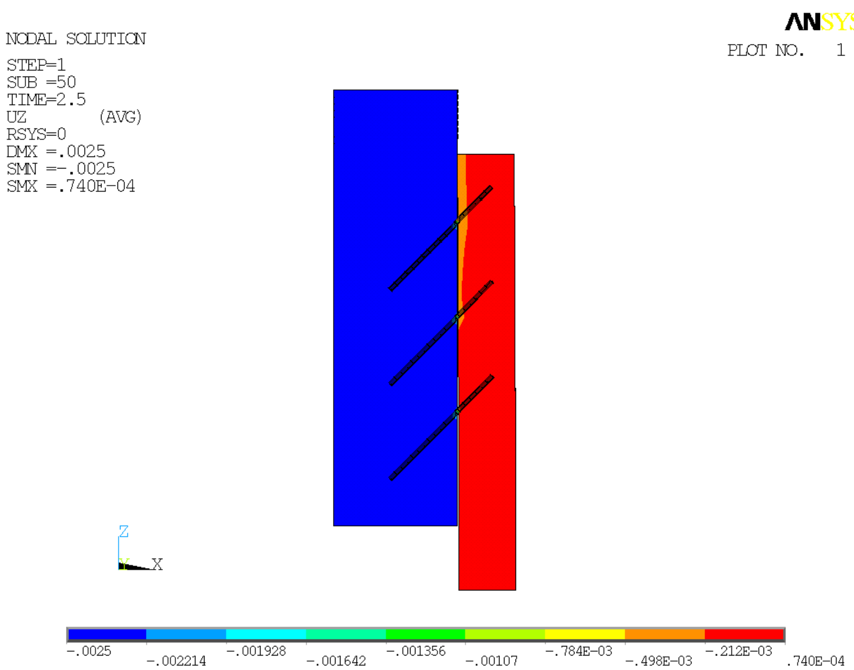

Fig. 3: Numerical model of timber-fibre concrete specimen

The numerical model is loaded by force. The resulting load is 260 kN which corresponds with the test results. In Figure 4 is plotted the experimental results together with the numerical results.

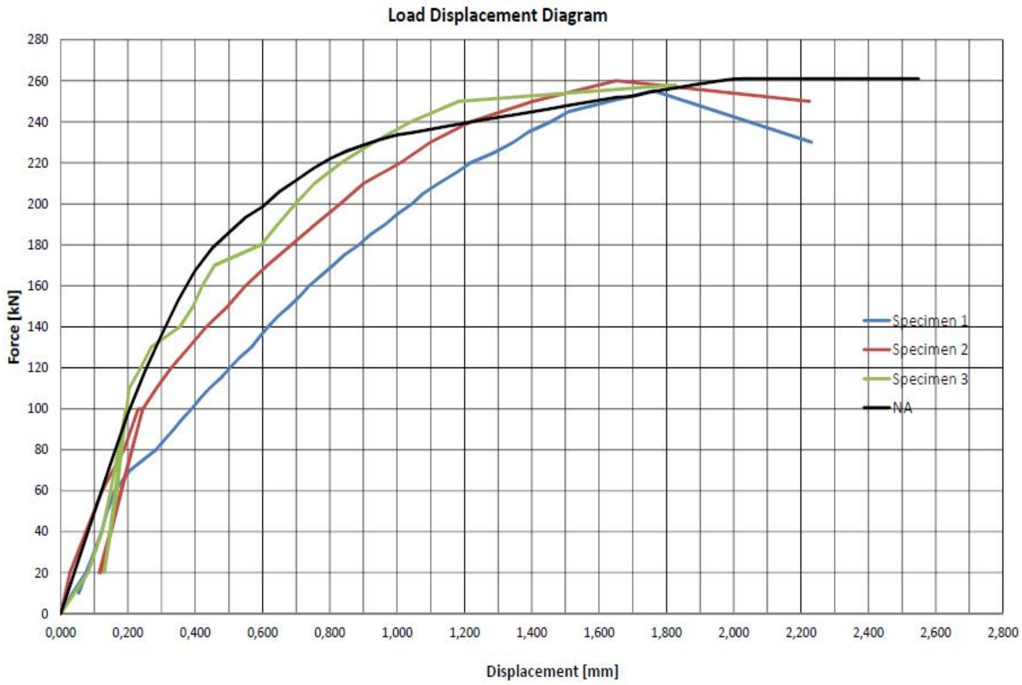

Fig. 4: Numerical model of timber-concrete composite specimen and experimental load-slip curves for A test series

3. Fire test of timber-fibre concrete composite floor

The full scale floor specimen was designed to span 3,5 m by 4 m according to the furnace interior dimensions. The arrangement of the test specimen is shown in Figure 5.

Fig. 5: Fire test set-up

The composite timber-concrete floor was composed of timber frame, two secondary beams and a 60 mm thick floor slab connected to glue laminated floor joists. Concrete slabs with a strength class 45/55 were reinforced by steel fibre only without added steel bars. The fibre content was 70 kg/m3 with type of fibres HE 75/50 Arcelor, which correspondents to nearly 1,0 % of dispersed fibres. As connectors were used TCC screws inclined 45 degrees to the beam axis in two rows, distance of screws in one row is 0,1 m. The timber frame was fire protected and the secondary beams in the centre of the floor slab were left unprotected. The design fire used in the tests was the standard fire and it was subjected the standard fire for over 150 min.. The mechanical load during fire was created by concrete blocks uniformly distributed over the floor.

The behaviour of the composite slabs in the furnace was recorded by 27 thermocouples and 13 deflectometers. 13 thermocouples were concreted in the composite slab at three different locations across the slab, 4 were located on timber beams and 10 recorded the gas temperature in the furnace and were located just below the floor, see Figure 6. Seven deflectometers measured the vertical deflections and six measured the horizontal deflections.

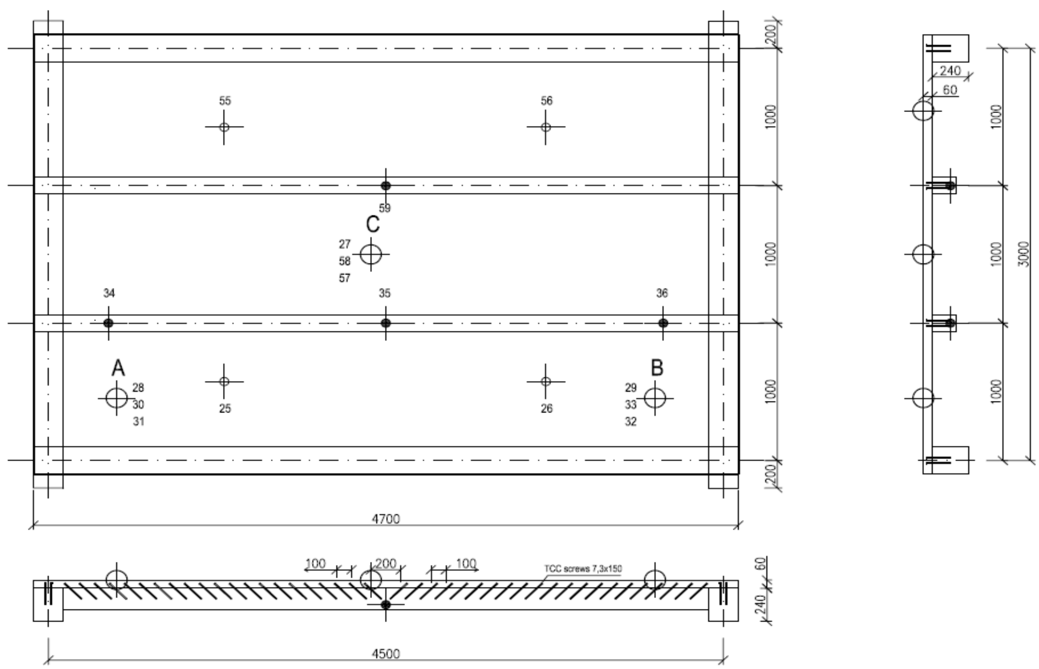

Fig. 6: Positions of the thermocouples during fire test

During the heating phase of this test, the standard fire curve was followed which lasted for 150 mins. The unprotected timber beams located at the middle of the floor were heated up to 250 °C. The maximum recorded temperature occurred after 45 mins at the centre span of beam. Then the secondary beams failed. Integrity of this slab was maintained during the first 100 mins, when the first crack opened. The full collapse of the test was reached at 154 mins due to damage of the fire protection of edge beams.

The temperature in the concrete slab continues to rise after the maximum atmosphere temperature, which occurred at 150 mins. The maximum temperature reached 845 °C in the middle of the slab 20 mm from the bottom surface of the slab. The temperature rise at the unexposed face of the composite slab after 150 mins of fire was slightly above 350 °C. The limit of 140 °C that defines the insulation criterion was exceeded at 52 mins.

4. Numerical simulation of timber-fibre concrete composite floor

The main objective of the FE models was to simulate and predict the behaviour of timber-concrete floor slab with screws. The complete model consists of four beams (GL24h 200/240, GL24h 120/160) 4,5 m long in spacing 1 m. Numerical analysis was performed with a rigid connection and linear elastic material models for both components.

In the 3D model were first defined points of the system, which were subsequently linked lines of that developed area. The area subsequently formed solid elements, which were assigned material properties. In the model have been used finite elements SOLID 45.

The model uses three parameters closely related with the most important joint properties: joint stiffness, joint strength and joint ultimate slip.

Mechanical behaviour of the timber-concrete composites in fire is very complex transient thermo-mechanical problem. This problem can be solved as one-way coupling between thermal analysis and mechanical analysis. Nonlinear transient heat flow consists of thermal load (fire) as radiation and convection, thermal material properties depend on time (nonlinear analysis) and timber charring effects. Numerical simulations are currently under preparation, which is the reason, why are in this paper presented only partial results.

The comparison of the temperatures at the depth of 20 mm from the numerical model with resulting temperatures from the test at three different locations is shown in Figure 6. The comparison of the temperatures at the depth of 40 mm and 60 mm from the numerical model with resulting temperatures from the test is shown in Figure 7 and Figure 8.

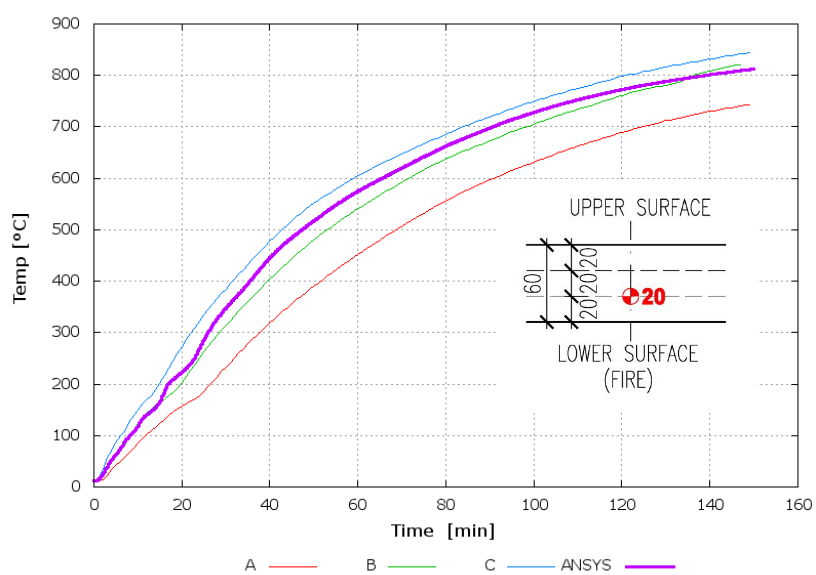

Fig. 7: Comparison of the temperatures at the depth of 20 mm from the numerical model with resulting temperatures from the test

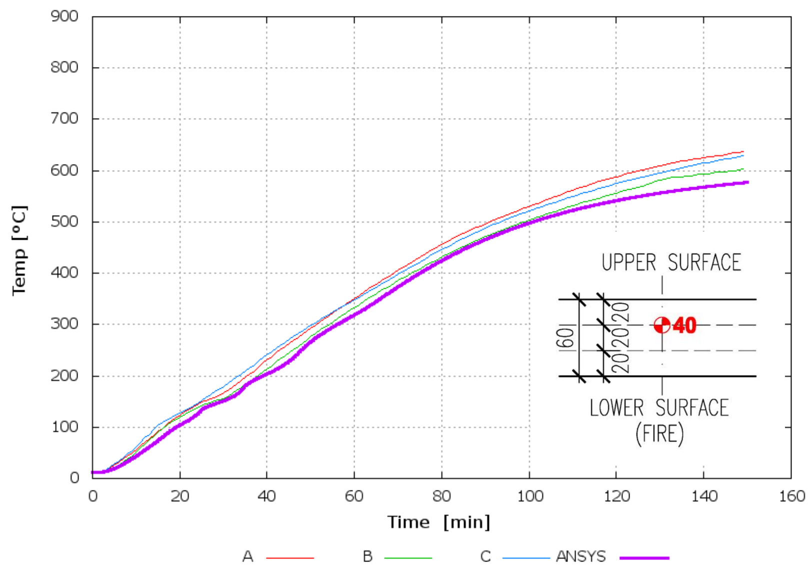

Fig. 8: Comparison of the temperatures at the depth of 40 mm from the numerical model with resulting temperatures from the test

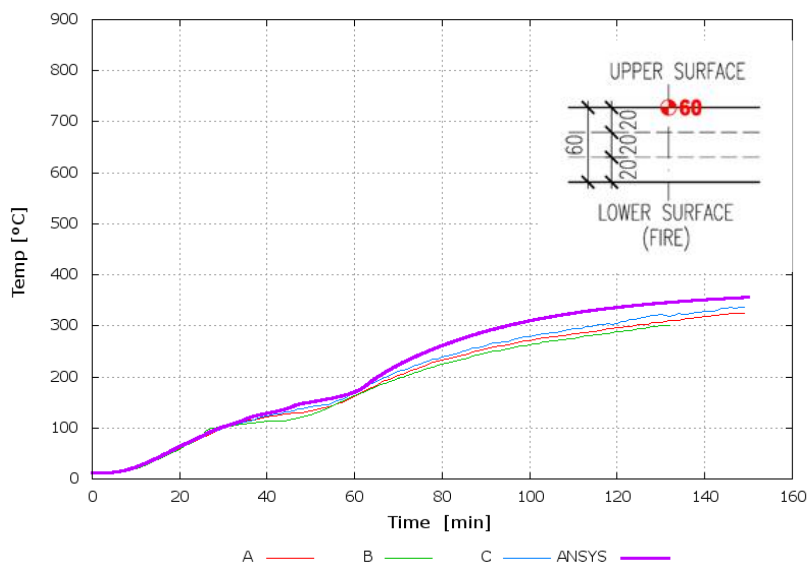

Fig. 9: Comparison of the temperatures at the depth of 60 mm from the numerical model with resulting temperatures from the test

5. Conclusions

The FEM models became a popular tool to predict and simulate the behaviour of timber-fibre concrete composite. The condition for an appropriate numerical simulation of real performance of the timber-fibre concrete structure is implementation of realistic material model, i. e. the stress-strain relation. Therefore the implemented material models will be verified on the basis of experimental results and will be used for non-linear analysis of timber-fibre concrete structure after successful verification of validity (Šlapka et al, 2011).

The numerical simulations showed that the use of the adequate material models is essential to obtain accurate simulations. Verification of implemented material models by numerical simulation of experiments shall be an integral part of the nonlinear analysis of the structural system. This process increases probability of accurate simulation of the combined structure behaviour.

From the push-out test was concluded, that the behaviour of specimen was more ductile and the steel fibres prevented the crack propagation and openings. From this reason it was still possible to distribute loads over the crack plains and redistribute loads to the other screws. The described FEM model of timber-concrete composite specimen compared closely with the measured deflection data for considered loadings is accurate for composite action (Holschmacher et al, 2002).

Acknowledgements

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