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MECHANICAL ANALYSIS OF STEEL BEAM PROTECTED BY OSB

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Abstract: *An unprotected steel structure in a fire does not exhibit significant fire resistance. Very often, structural collapse due to excessive deflections occurs within 15 minutes. Fire cladding by OSB appears to be the most environmentally friendly option. Wood in a fire, despite its flammability, is very good at resisting fire, and like char layer is a great insulator. This article focuses on the influence of standard values for the calculation of steel beam displacement. For validation, a large-scale experiment was performed on three steel beams, unprotected, protected by a single-layer OSB cladding and by a two-layer OSB cladding. Experiments have demonstrated the good functionality of the OSB cladding as a fire protective layer. This article presents the influence of input data on the correct approach to mechanical modelling and simulation of steel beam displacement. Experiments have shown the evolution of steel beam deflections. The article recommends sources for input data for simulations up to 600 °C and contemplates further necessary research for modelling.*

Keywords: Fire experiment, OSB cladding, FEM analysis, Fire protection, Steel beam.

1. Introduction

The low fire resistance of unprotected steel structures in the event of fire significantly limits its use of these solutions without the application of additional measures to protect the steel structure or to reduce thermal effects on the structure (Gnanachelvam et al., 2019; Li, 2019; Nie et al., 2020). The simplest way to protect a steel structure is to use cladding. When it is necessary to guarantee the ecology of materials and their life cycle, cladding with wood or wood-based materials (OSB, Oriented strand board) appears to be one of the most affordable materials, particularly from an ecological point of view (Stark, 2021). The only downside of this solution is the addition of flammable material to the fire site.

This paper presents results of experiments which were conducted to verify the development of heat through the cladding of the OSB-protected steel beam. The tested beams were also mechanically loaded to represent a real example of use and to study the mechanical behavior. The influence of pyrolysis on the evolution of temperatures around the protected beam was investigated as described (Ira et al., 2020; Reinprecht, 2016). An investigation of the development of heat transport by burning away the protective layer on small samples, was examined by Sejna (2021), in cases of larger claddings by Riola-Parada (2018) and Le (2019). This article shows in more detail the steel beam protected by one layer of OSB cladding which is 22 mm thick. It shows the effect of the removal of the protective cladding on the development of steel beam displacement. The article also presents a comparison of the experimental data with numerical simulations based on material models defined by the Eurocode EN 1993-1-2 and EN 1995-1-2.

2. Fire experiment

Three steel beams were placed in the horizontal furnace for fire resistance testing, unprotected as a reference, protected by one layer of OSB cladding 22 mm thick, and a third beam protected by two layers of OSB cladding. The experiment aimed to study the thermal and mechanical response of the beams. The

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profile of the beams was chosen to be a square hollow section of 100×100×6 mm, length 3700 mm. The spacing between the supports of 3500 mm was based on the dimensions of the experimental furnace. The mechanical load on the beam was carried out as a local load (Fig. 1). Thermal load followed standard temperature curve. During the test, the cavity of the hollow square profile was filled with insulation to prevent free flow of heated gas in the cavity and thus to make it easier to model in temperature and mechanical analysis. At the same time, filling the cavity with insulation did not increase the beam's bending stiffness.

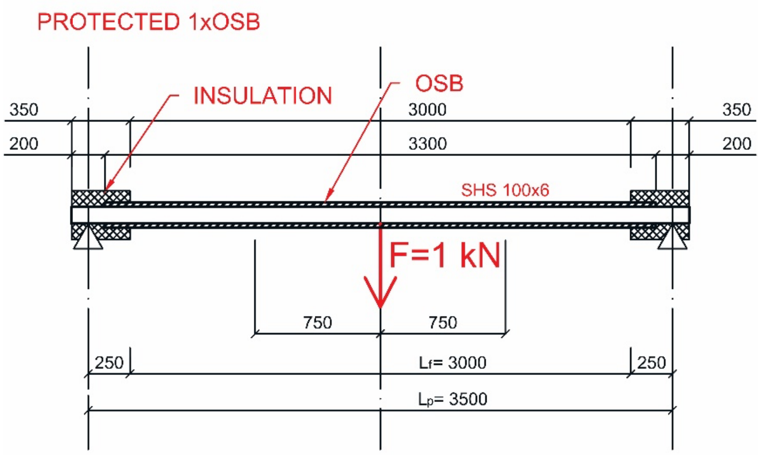

Fig. 1: Static scheme of steel beam protected OSB cladding thickness 22 mm.

The cladding of the beam was made from OSB plates of Kronospan 3. The joints were made using clips of 40 mm applied pneumatically. During the test, adiabatic surface temperature of tested elements was measured using plate thermometers and the gas temperature in the furnace as well as beam temperatures were measured using thermocouples fixed to the surface of the steel beam under the poultice. The cables of the thermocouples were conducted in isolation through the hole of the beam. A view into the furnace during the fire test is shown in Fig. 2.

The beam was heated relatively evenly in the furnace. The ends of the beam were at a lower temperature because of their insulation. The course of the furnace temperatures and the beam temperatures along the length is shown in Fig. 3.

Fig. 2: Beams in the furnace during the experiment.

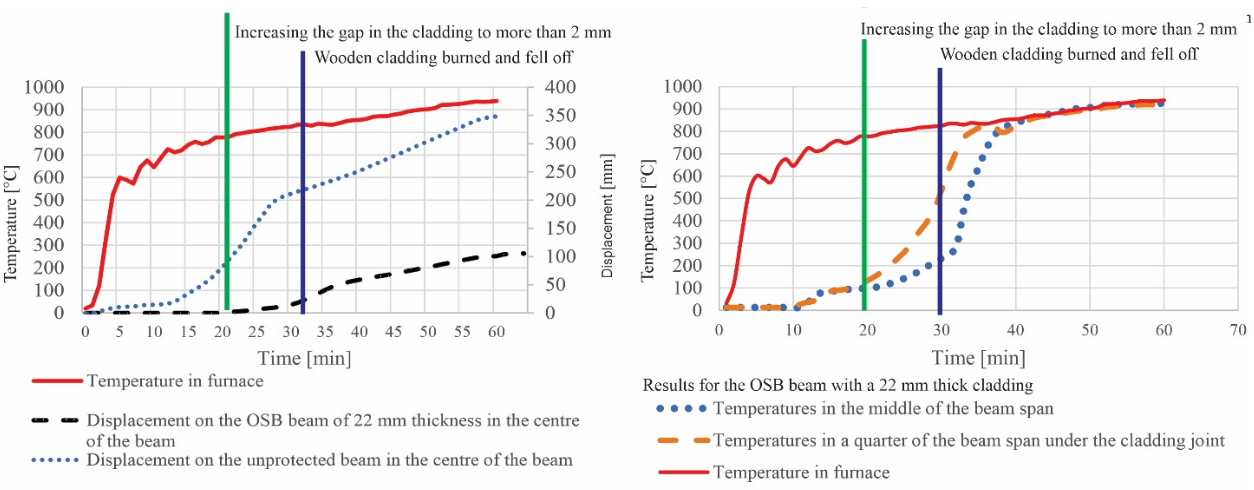

Fig. 3: Temperatures and displacement of steel beams measured during the experiment.

3. Numerical simulation and results

The aim of this article is to present a comparison of experimental results a beam protected by 22 mm thick OSB with results of a numerical model, input data being taken from Eurocodes EN 1993-1-2 and EN 1995-1-2. The numerical model was created in ANSYS mechanical using implicit analysis and FEM method (Stolarski et al., 2018). The size of the computational step, the influence of the reduced properties on the displacement were investigated by sensitivity analysis.

For the model the mechanical properties of steel, such as the strain-stress diagram of steel, temperature-dependent effective yield strength of steel, proportional limit of steel, temperature-dependent Young's modulus of steel, were taken from EC3 and the mechanical properties of OSB from EC5. Temperature fields from temperature simulations validated in the experiment were taken into account to calculate the reduction in thermo-mechanical characteristics. For simulations, the beam was tethered to a joint deposited as in an experiment.

The displacement results for the protected beam for which simulations have been performed are presented in Fig.4. The results clearly show that the behavior of steel changes significantly when reaching a surface temperature of 600 °C (in 35 min of the diagram). It is clear from the simulations carried out that the Eurocode rank calculation is highly inaccurate for calculation of deflection during fire and the effect of creep steel must at least be taken into account. The uneven heating of the beam along its length did not have a significant effect on the development of the shifts.

Using input data published by Wald et al. (2014), the variation in deflections is significantly smaller, considering mechanical analysis up to 600 °C. This temperature makes a more marked difference. For basic calculations up to 600 °C, data from already published results may be considered, but for higher temperatures, further investigations are required primarily to describe the influence of creep structural steel.

4. Conclusions

The experiment demonstrated that the possibility of performing OSB cladding as a fire protection for steel structures is not only possible but also very effective. The function of the fire cladding is influenced by the joints in the cladding. Large joints cause the cladding to fail. With proper design, the flammability of the cladding does not reduce its functionality.

Comparison of calculated and experimental data of deflection showed an underestimation of deflection and temperatures, as the EC5 model of wood thermal material cannot be taken directly for any wooden material, and heat signature burning should undergo further research. It has also been shown that the behavior of the steel material defined in EC3 does not take into account the time-dependent behavior of the steel material because there is a significant difference in shifts, which agrees with other existing studies and does not take into account the creep of the steel in these numerical simulations, which appears to be very pronounced. The possibility of modeling creep regular structural steel needs further research. From the study it is obvious that material description given in EC3 is appropriate to predict resistance of the beam, nor deflection of the beam.

This article provides experimental and numerical insights for the subsequent research in the field of creep steel and wood preservation of steel structures.

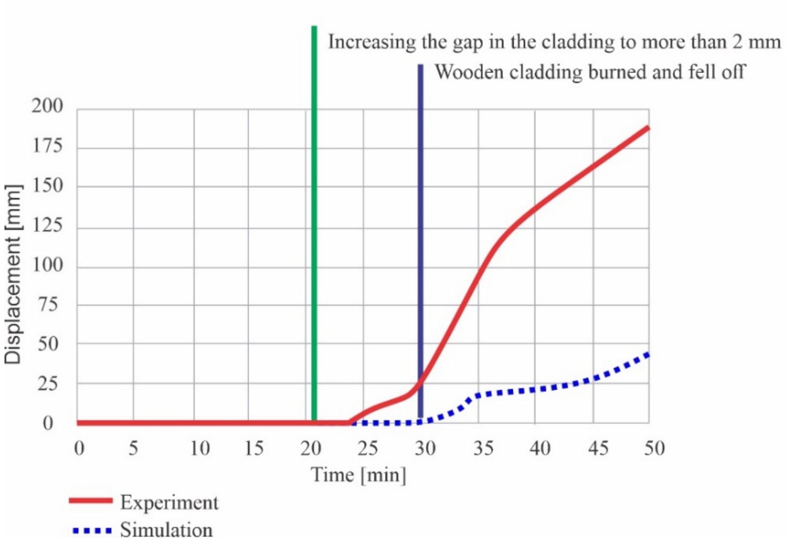

Fig. 4: Comparison of the experimental and calculated displacements for protected beam with OSB cladding 22 mm thick with characteristic from EC.

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