# IMPROVEMENT OF THE FIRE PROTECTION COVERINGS OF STEEL ELEMENTS IN TIMBER BUILDINGS

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## *ABSTRACT*

*Fire protection is an important part of timber buildings. After the revision of the Swiss fire protection regulations (January 2005), the area of application for combustible building material has been extended to a fire resistance of 60 minutes and therefore opened new markets especially for multi-storey timber buildings. Due to aesthetic and economic reasons the construction of the ceiling should always be built as narrow as possible. Based on heavy loads steel beams are therefore often used for the primary structure. Despite its non-combustibility, steel has a poor reputation relating to its fire resistance, as its strength and the coefficient of elasticity reduce via the increase of temperature. In the case of fire, steel members need to be protected effectively. In current practices, regulations for the fire protection coverings, in combination with timber members, are also being utilised to protect steel parts. The fire resistance of the protection-material is based on fire tests in combination with timber structures. As the thermal conductivity of steel is considerably higher than the thermal conductivity of wood, better behaviour of the covering material can be expected.*

*The following thesis will explore the influence of different fire protection material with thermal behaviour and will discuss the potential for improvement. In addition the load carrying capacity of the steel members will be calculated with relation to temperature increases.*

*Based on wood-concrete composite floors including steel profiles, analysis will be completed with the finite elements software ABAQUS. For material such as steel, wood and concrete, the thermal properties in relation to the temperature are specified in the EN-Codes. For the gypsum-boards no such data is specified in any standards. At ETH Zürich extensive research for fire engineering of timber buildings has been finalised. The thermal properties of gypsum-boards used in this thesis are based on their results.*

*The results of this thesis are based on the assumption that the protection coverings remain on the construction during the entire length of the fire. Under this condition a fire resistance of 60 minutes for a cladding protecting a steel member can be achieved with a single-layer. Compared to the required double-layer for a protection cladding in combination with timber members, considerable space for improvement was observed.*

## 1. INTRODUCTION

The aim of this thesis is to analyse the thermal behaviour of steel parts within timber-concrete hybrid-constructions located in multi-storey timber buildings. Based on these results the influence of combustible and non-combustible protection material on the temperature gradient of the steel members used in timber-concrete composite floors will be analysed. Additionally, the mechanical behaviour of steel parts that have been exposed to increased temperatures will be reviewed. These results will serve as basis for detailed research regarding static characteristics and the relationship of steel parts connections.

The data collected for this thesis was completed during an internship in 2012 at the Josef Kolb AG, Switzerland, a company specialised in fire engineering and timber constructions.

## 2. BASICS OF THERMODYNAMICS

The rise of temperature within a building element depends, regardless of the material type, on the physical properties and the thermal characteristics of the individual material. The thermal energy acting onto the element is the fire. The thermal transfer from the fire to the material occurs through heat radiation and thermal convection. Within the material the heat is being transferred by thermal conduction.

The thermal characteristics of the material highly affect the heat flow rate which is defined by the following properties:

- Density
- Thermal conductivity
- Specific heat

The thermal properties and thereby the fire resistance of a certain materials were determined by fire tests. In order to compare the results of different material, the tests had to be completed under identic thermal conditions. There are several existing fire curves (development of temperature in relation to the time) in the codes. The most common form is the ISO 834 standard heating curve. All the used data and therefore the results presented in this paper are based on the ISO-curve. [1]

## 3. THERMAL ANALYSIS

Fire tests are expensive and therefore computer simulations are used wherever applicable. Initially, appropriate software had to be selected. As the temperature, according to the ISO 834-curve and also all the material-specific data, varied with the time, the required capacity of the software was high. For the calculation purposes the finite element-software ABAQUS was used.

The first step involved the calculation of the material individually. Results were then compared to pre-existing for documented fire tests. After the results were analysed the selected parts of the timber-concrete constructions were integrated with steel profiles and then modelled. The amount of concrete covering the web was then tested by different FE-models. Based on these results different decisive structures and dimensions have been chosen for further research. In *Figure 1* an HEA 260 profile in combination with wood and concrete is shown with and without protection material. The temperature applies to a fire duration of 60 minutes according to the ISO 834 standard heating curve. [2] [4]

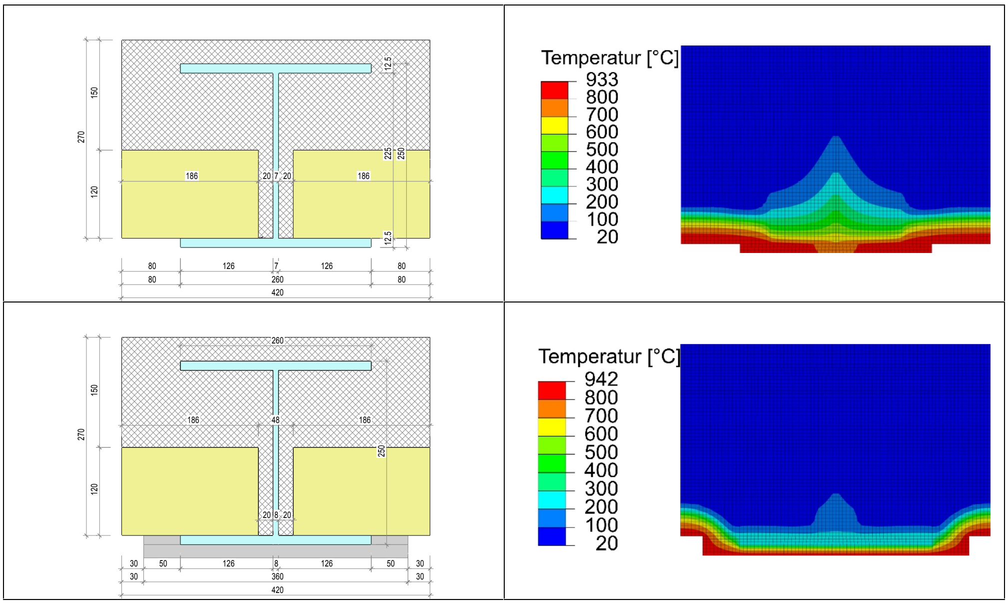


*Figure 1: Temperature distribution after 60 minutes of ISO 834-fire*

## 4. STRUCTURAL ANALYSIS

Due to high heat conductivity of steel in relation to the dimensions of web and flange of the profile, the temperature gradient increased rapidly in the case of a fire. Possible consequences of the static and thermal exposure include high deformations or even a collapse of the structure. Since the temperature gradient is irregularly distributed, the strength and the stiffness varied within the profile. In order to determine the load carrying capacity at increased temperature, the profile is subdivided in several sections. After 30 minutes of exposure to an ISO 834 fire, the maximal bending resistance of the profile is reduced up to 53 percent of its load carrying capacity under normal condition (*Figure 2)*. As the required resistance during a fire is reduced, an integration of a steel part in an uncovered condition is supposable. The final product ensures that the floor elements are only carried through the lower flange. This support fails rapidly as the steel temperature in this area increases within a short period of time and therefore additional carrying constructions become necessary.  [3]

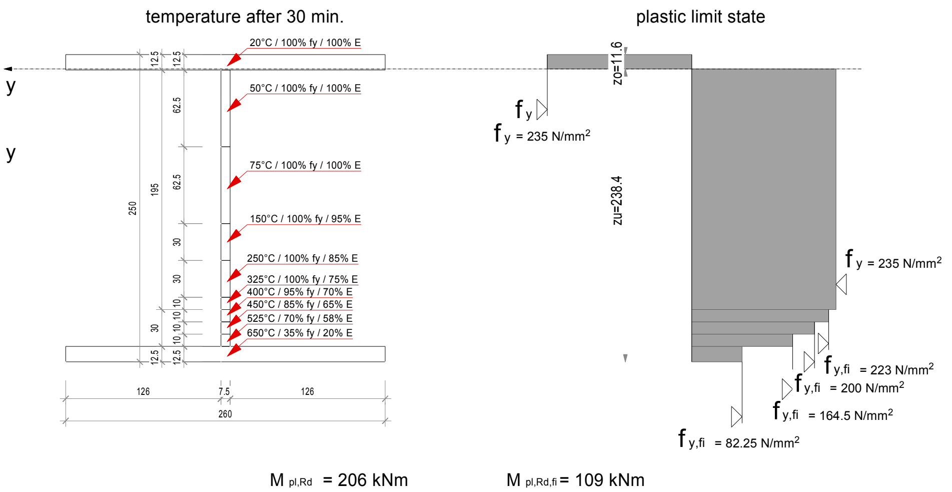


*Figure 2: Plastic limit state of a HEA 260 steel profile after 30 minutes of ISO 834-fire*

## 5. CONCLUSION

Through the research in the frame of the thesis it was possible to illustrate the potential for improvements concerning the number and the thickness of the protection claddings. The high thermal conductivity of steel causes comparatively lower temperature in the combustible and non-combustible protection material covering the steel members. As mentioned in the thermal characteristics it is necessary to cover steel parts with a single-layer of gypsum-boards. Concerning the combustible protection-material like wood there is also a positive effect to determine. If the thickness of wooden claddings is determined according to the "Lignum documentation for fire protection, part 3.1", the results are in a safe range.  In order to limit the temperature on the rear side to 270 °C after 60 minutes of an ISO 834 fire, the minimal thickness of a gypsum fibre board must be 15mm.
The strength of the steel at this temperature is still unreduced but the stiffness is reduced up to 80 percent. The reduction of the stiffness (reduced coefficient of elasticity) causes increased deformation, which could have a negative influence on the behaviour of the protection layers.
Through the 2D FE-models it was possible to determine the impact of the different kinds of materials on different temperature gradients. However, the deformation of the steel members can lead to joints. These have a negative influence on the temperature gradient and therefore additional research with 3D FE-models or real fire tests are necessary in order to determine the behaviour of the steel members. Through structural analysis it is apparent that without any protecting layers over the steel, the temperature will increase rapidly. A fire resistance of 30 minutes could at its best be achieved with large steel profiles. However, the load factor will be at a low level during the normal case and an integration of steel structures in an unprotected condition will only be appropriate in a few specific situations.

## 6. REFERENCES

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