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THERMAL ANALYSIS OF WOOD-STEEL HYBRID CONSTRUCTION

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ABSTRACT

The main objective of this work is to provide the thermal analysis in wood-steel hybrid elements for building constructions under fire conditions. A transient thermal analysis with nonlinear material behaviour will be solved with ANSYS program. The use of wood-steel hybrid models has major advantages as increased fire resistance, and improved high strength. Wood is a lightweight material, easy to assemble, great architectural features, thermal and acoustic characteristics. However, the high vulnerability of wooden elements under fire action, involves evaluating their behaviour accurately. Its physical behaviour is conditioned by the charring layer formation, which may allow the insulation into the structural section. The steel is a current use material allowing high structural strength. However, steel is a non-combustible material, and when compared with wood is a very good conductor of heat. Consequently, the unprotected sections of steel under fire quickly heats, and the fire resistance decreases considerably. The numerical modelling of the hybrid models considers the analysis at high temperatures and the nonlinear material properties. Using a computer model, it will become possible to calculate the fire resistance of these hybrid elements, an important parameter for safety and design rules.

Keywords: wood-steel, hybrid construction, fire, numerical model.

INTRODUCTION

Steel is a traditional material construction widely used, due to extremely strong, durable and high structural strength. Steel material has many advantages over wood elements such as, strength, stability, resistance to woodworm, among others. But steel material loses strength when heated sufficiently. Steel is a good conductor of heat, which reduces the fire resistance, (Jan et al, 2002), (Barbosa et al, 2012). Also, steel has a higher labour cost, as a disadvantage. Steel material is used specially in construction for buildings, bridges, beams, industry, etc.

Wood is a renewable resource, recently attracted by public attention. Wood is a natural and the earliest construction material used by humanity, due to easy to use, durable, great architectural features, high strength, low weight, widely available and low cost. Wood is a combustible material, but the combustion is slower and regular. When exposed to accidental actions, such as fire conditions, wood has a surrounding charring depth. However, this layer can delay the heating process to the core section, acting as an insulating. According Eurocode 5 (CEN 2004), the temperature between the char-layer and the core section is 300ºC. Wood is used for building frames, bridges, utility poles, floors, roofs, trusses, beams, piles, etc.

The combination between wood and steel leads to economic and ecologic benefits, weight optimization, fire and structural resistance increase, and an efficient assembling. The performance of wood members under fire conditions is higher when compared to unprotected non-combustible material construction. Steel melts and collapse while the charred wood remains in place. The use of hybrid materials could increase the structural integrity of the construction elements. Hybrid wood/steel material is used for new building projects, bridges, slabs, etc. As represented in figure 1 there are many different applications of this type of elements in construction.

In this work wood-steel hybrid profiles subjected to fire are presented in order to verify the best solution used in design construction. The complexity of this analysis needs some numerical techniques with high performance, which is the case of the finite element analysis.

Fig. 1 – Applications of wood-steel hybrid constructions (*from Google images*).

THERMAL PROPERTIES

The thermal properties of wood and steel are function of the temperature and should be defined according the Eurocode 5 (CEN 2004) and Eurocode 3 (CEN 1995), respectively, see in figure 2. The density of the spruce wood material was considered equal to 450 kg/m^3 at room temperature. The density of steel is equal to 7850 kg/m^3. For wood material, the specific heat presents one peak at 100ºC due to the heating of water evaporation process; the thermal conductivity increases with temperature and the density decreases. For steel material, the specific heat presents one peak at 700ºC due to the allotropic process, the thermal conductivity decreases with temperature and the density is constant.

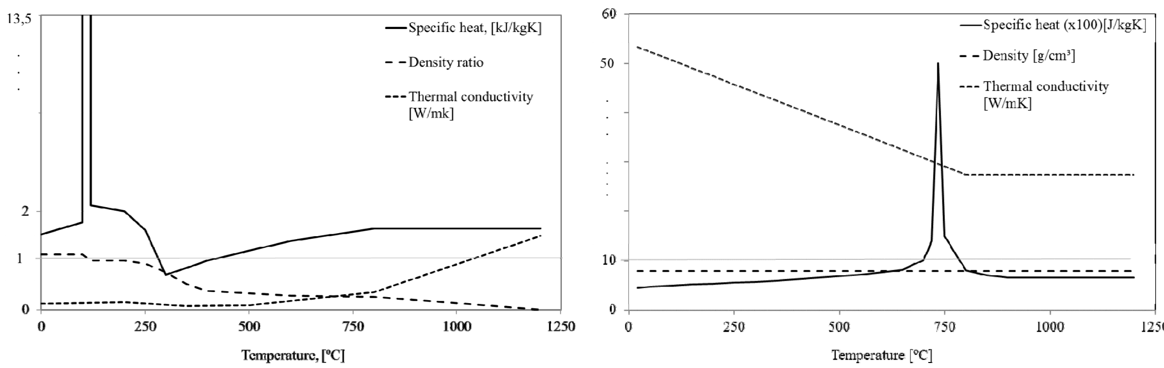


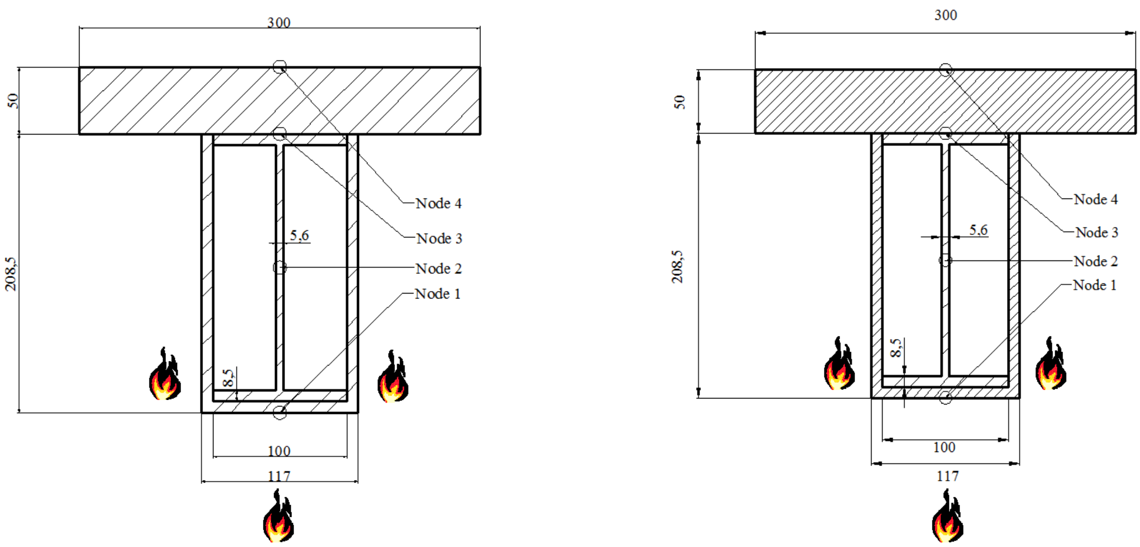
Fig. 2 – Wood and steel thermal properties.

The fire effect is considered using the appropriate boundary conditions due to convection and radiation. The temperature environment follows the standard fire ISO 834 curve, Eurocode 1 (CEN 2002), as presented in equation 1.

$$T_{\infty} = 20 + 345\log_{10}(8t+1) \tag{1}$$

GEOMETRIES AND NUMERICAL MODEL

In this study two different geometries (G3-Steel and G3-Wood/Steel) submitted to fire were analysed (3 sides - 3F), as represented in figure 3. Four nodal positions were considered to obtain the temperature during 1 hour of fire exposure for each model.



G3-3F-S (Steel externally and internally) G3-3F-WS (Wood externally and Steel internally)

Fig. 3 – Geometries submitted to fire.

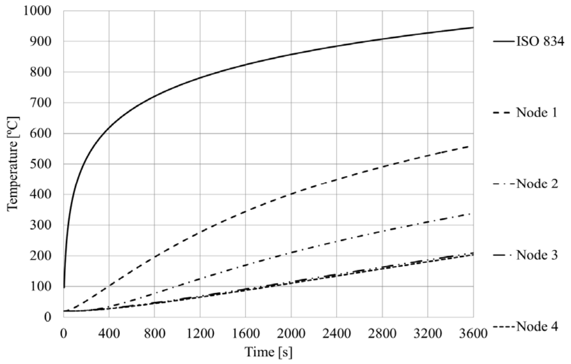
All models were developed by the finite element method. The numerical thermal simulation uses a transient analysis with ANSYS program. A plane finite element with 8 nodes and a solid element with 20 nodes are used, respectively for 2D and 3D analysis.

The main objective of the numerical simulations is to produce the temperature time history for two different design solutions submitted to fire, and verify the best constructive solution which increases the fire resistance.

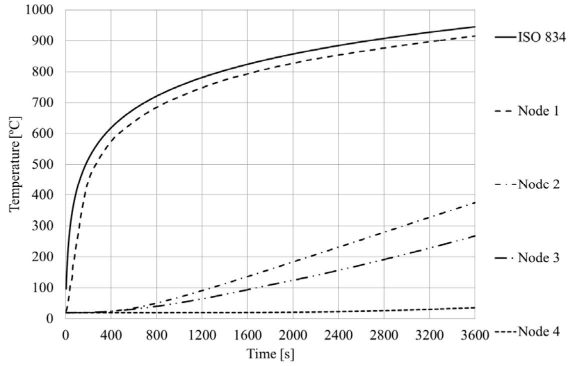
RESULTS AND DISCUSSION

Figure 4 represents the temperature evolution at 3600s, in all different nodal positions of the steel profile with or without wood insulation, using ANSYS program. All graphics are compared with the standard fire ISO 834 curve, Eurocode 1 (CEN 2002).

Figure 5 shows the results at the time instant equal to one hour of fire exposure, using the 2D numerical model.

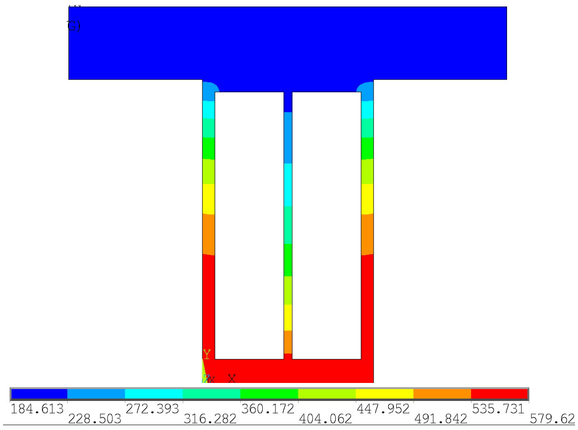


G3-3F-S

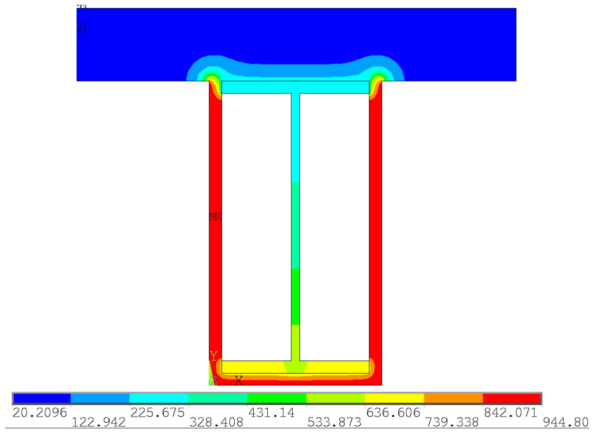


G3-3F-WS

Fig. 4 – Time history, 0s to 3600s.



G3-3F-S



G3-3F-WS

Fig. 5 – 2D model, temperatures at the end of 3600s.

In case where both parts (outside and inside of the model) are made of steel (G3-3F-S), the temperature in the inner profile is higher. When wood material is externally applied to the steel profile (G3-3F-WS), plays an important role as insulation, reducing the temperature inside steel, as verified in figure 5. Wood has a good fire resistance showing the ability to protect the steel. The use of hybrid wood/steel elements could increase both structural strength and stiffness.

During a fire, the interface between charred and noncharred wood material is the demarcation plane between black and brown wood material and is characterized by a temperature of 300ºC, according Eurocode 5. This type of occurrence will be simulated using the numerical model.

Figure 6 shows the 3D numerical model for G3-3F-WS profile and the obtained residual cross-section at different time instants (300, 600, 900s). As represented, the ash zone is the charred layer of the wood material. The steel profile is protected until 900s, the correspondent time for fire destroy completely the wood material. The steel temperature is below 144ºC at the end of 900s. At the time instant equal to 300s the temperature in steel is equal to 20ºC, and at the end of 600s the steel temperature has a value equal to 82ºC at the bottom surface.

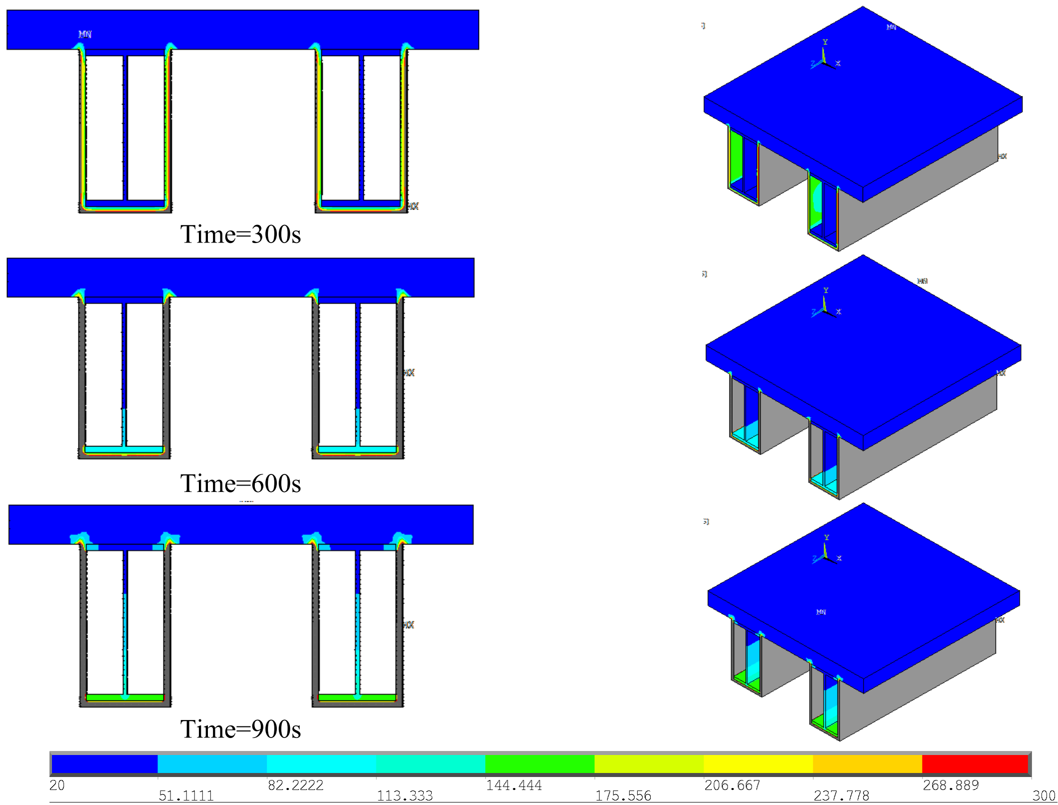


Fig. 6 – 3D model, residual cross-section at different time instants (G3-3F-WS).

CONCLUSIONS

Conclusions about the importance of the temperature field obtained in wood-steel hybrid sections using a finite element modelling are presented and discussed. According to the results, the wood-steel hybrid profile can to perform well under fire conditions. Regarding the design construction (outside wood of the steel profile), it is concluded that it has a good fire resistance, even for the three sides fire exposure, showing the ability of wood to protect the steel. Unprotected steel elements under fire condition may suffer serious damage.

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