International Congress

FIRE COMPUTER MODELING

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Hybrid wood/steel elements under fire

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ABSTRACT

The main objective of this paper is to present a computational model for the fire resistance of wood/steel hybrid elements. Different design solutions will be presented. The most important factors for fire safety in hybrid elements are the thermal effects degradation and the charring depth formation in wood materials, and also the heat conduction extremely well in steel material. Unprotected steel elements under fire condition may suffer serious damage. The use of hybrid wood/steel elements could increase both structural strength and stiffness. Wood could be considered as an insulating material, the core section could remain at low temperature, function of fire exposure time and element cross section size. All presented results will permit to evaluate different design solutions, which facilitates the fire design of wood/steel hybrid elements. The presented study was conducted in order to articulate the best constructive solution using the finite element method.

1 INTRODUCTION

In the past, buildings have been entirely constructed with steel or entirely with wood, but recently have begun to integrate with both different materials, using hybrid wood/steel solutions, [1-2].

Hybrid structure does not merely indicate a framework member composed by a combination of different materials, but a construction using different methods according specific structural functions [2]. For this reason, the use of hybrid materials could increase the structural integrity. Steel material has many advantages over wood elements, strength, stability, resistance to woodworm, among others. Steel is incombustible and most of the times it can full recover strength after fire. However, steel has one significant disadvantage over wood, steel material conducted heat extremely well, [3]. Wood is a renewable resource, recently attracted by public attention, as an environmentally friendly material. This product is a building material with attractive attributes, as architectural and structural aspects. The wood when exposed to accidental actions, such as fire conditions, has a surrounding charring depth. However, this layer can delay the heating process to the wood core section, acting as an insulating. By comparison with other traditional materials applied to the building construction, wood exhibits an exceptional strength, contrarily to that occurs with steel elements, where the structural collapse may result from the deterioration of mechanical properties with temperature increase. [4].

The combination between wood and steel leads to economic and ecologic benefits, weight optimization, fire resistance increase, earthquake resistance and an efficient assembling [5]. Recently building codes and standards have been increasing the performance of structures in fire. Several researches have presented experimental and numerical models for the study of wood degradation in presence of high temperatures [6-8]. The charring rate of softwood or hardwood material exposed to fire conditions has been studied by researchers in different countries, [9-16]. Also, several studies have been presented to investigate the behaviour of steel elements under fire conditions, [17]. The greatest opportunity in fire research is the development of computational fire resistance models and experimental methodologies for hybrid materials submitted to natural fire scenarios [18]. In this work the first objective was to produce the temperature time history in different design solutions submitted to different fire scenarios. The second objective is to verify the best constructive solution and compare the fire resistance. All models were developed by the finite element method using ANSYS.

2 MATERIAL PROPERTIES

The most important factors for structural strength in wooden elements submitted to fire are the material properties degradation and the charring depth formation. The wood density decreases with the material degradation caused by the pyrolysis process, in the presence of high temperatures. For wood temperatures around 280[°C] to 300[°C] are generally prescribed as the start of pyrolysis, [19]. Wood burns leading to material degradation and decomposition. The wood thermal properties are strongly affected by temperature and moisture content levels. The thermal behaviour of wood is complex, but has been well documented. Eurocode 5 [20] provides the design values for wood thermal properties, for density, thermal conductivity and specific heat, figure 1. The values below about 350[°C] represent the properties of wood and above 350°C represent the properties of charred layer. The specie (Spruce) considered in this study presents a value of density equal to 450[kg/m^3].

The thermal properties of steel are function of the temperature and should be determined from Eurocode 3 [21]. The density of steel is considered constant and equal to 7850[kg/m^3]. The specific heat and the thermal conductivity of steel are represented in figure 2, [21].

Figure 3 gives the thermal properties of the air with temperature dependence for specific heat, thermal conductivity and density, [22].

The evolution of fire temperature (θ_α in [°C]) over time (*t* in [min]) was defined by standard fire curve. In this work the standard ISO834 fire curve was adopted, with the expression 1, according the Eurocode 1 [23]:

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

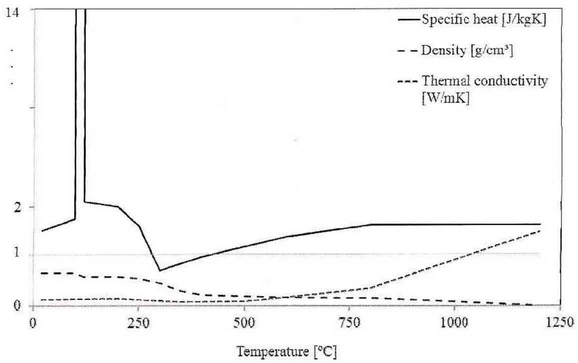


Fig. 1. Thermal properties of wood.

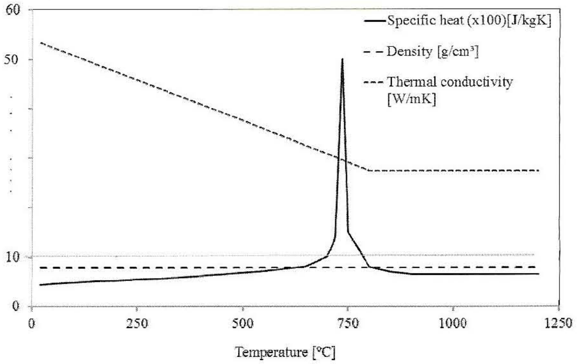


Fig. 2. Thermal properties of steel.

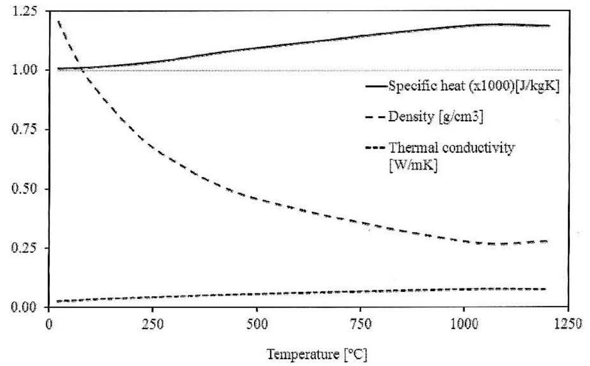


Fig. 3. Thermal properties of air.

3 STUDIED MODELS

Table 1 represents three different geometries in study (G1, G2 and G3), and the fire scenario, considering one side (1F) and three sides (3F). For each model, four different nodal positions were chosen to obtain the temperature evolution during one hour of fire exposure.

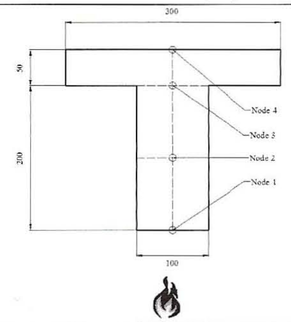
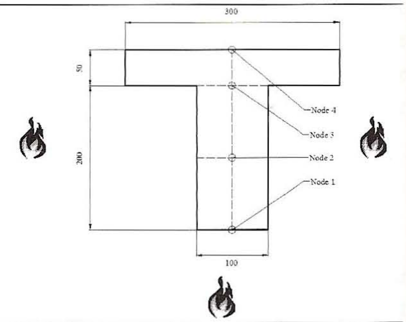
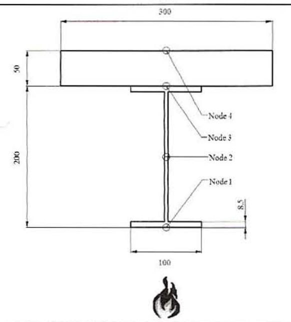
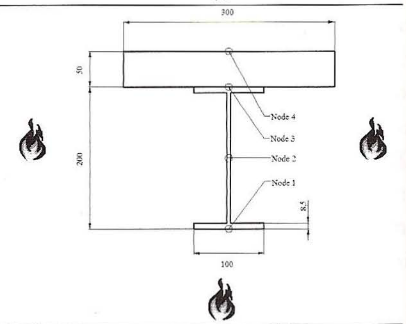
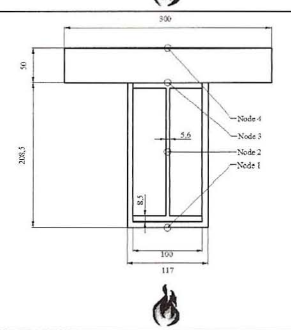
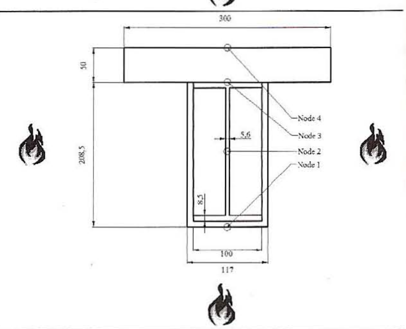
Geometries	Fire at one side (1F)	Fire at three sides (3F)
G1		
G2		
G3		

Table 1. Geometries and nodal locations.

Table 2 represents all different combinations according to the material for each model (Wood, Steel, Wood-Steel). According to the fire scenario and the material combination, 24 different models were considered in this study. Four of these models were considered with air in the internal cavity. The air modelling permits to verify the heating conduction inside the void.

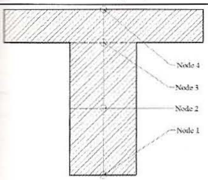
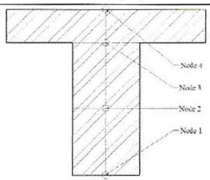
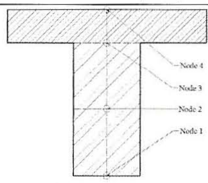
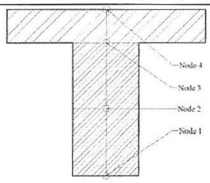
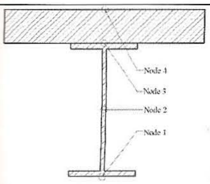
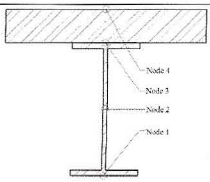
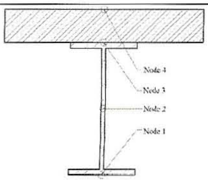
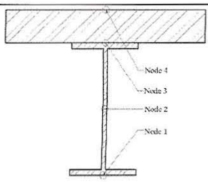
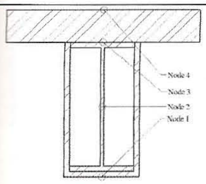
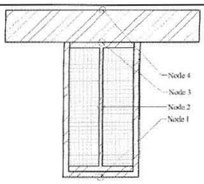
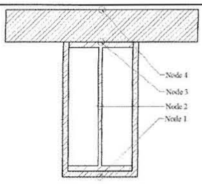
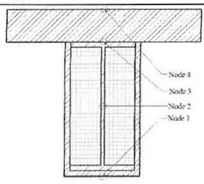
Wood (W)	Steel (S)	Wood-Steel (WS)	Steel-Wood (SW)
 G1-1F-W G1-3F-W	 G1-1F-S G1-3F-S	 G1-1F-WS G1-3F-WS	 G1-1F-SW G1-3F-SW
 G2-1F-W G2-3F-W	 G2-1F-S G2-3F-S	 G2-1F-WS G2-3F-WS	 G2-1F-SW G2-3F-SW
 G3-1F-S G3-3F-S	 G3-1F-S-air G3-3F-S-air	 G3-1F-WS G3-3F-WS	 G3-1F-WS-air G3-3F-WS-air

Table 2. 24 models and fire action.

The boundary conditions considered in all analysis are convection and radiation, according to the temperature evolution in fire. A transient thermal analysis was defined with ANSYS. A two dimensional finite element with eight nodes (PLANE77) was considered. All temperatures were obtained during one hour of fire exposure.

Tables 3 to 8 represent the results for each model in analysis, according to the time history for each chosen node and the temperature field distribution at 3600[s].

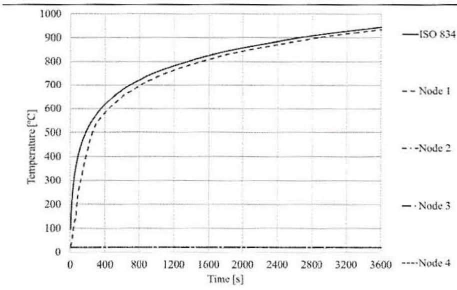
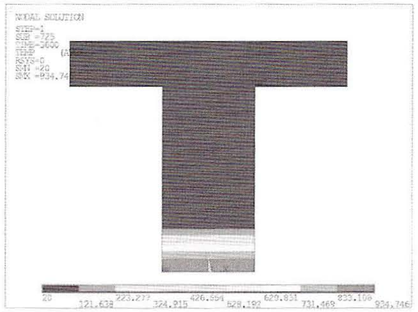
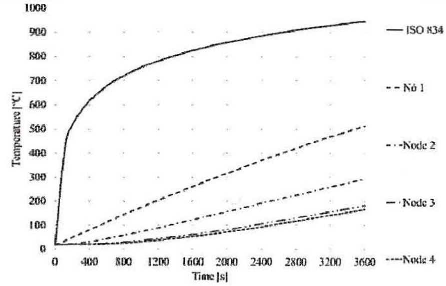
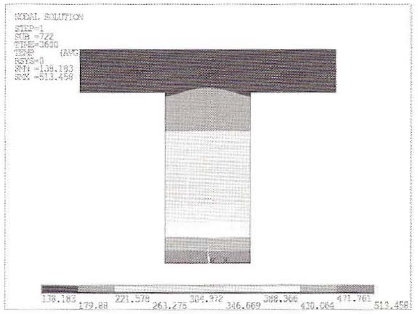
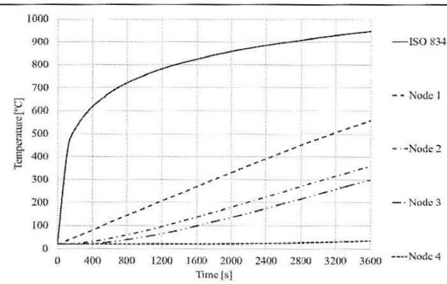
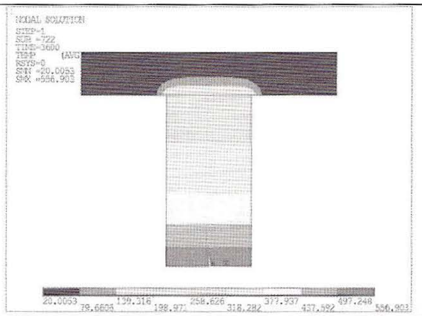
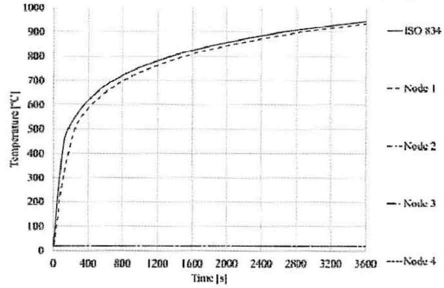
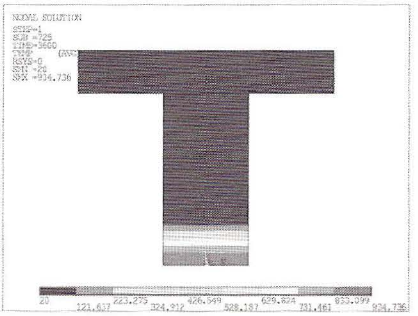
Time history, 0 to 3600[s]	Temperatures at the end of 3600[s]
 G1-1F-W	
 G1-1F-S	
 G1-1F-WS	
 G1-1F-SW	

Table 3. Model G1 and fire scenario (1F).

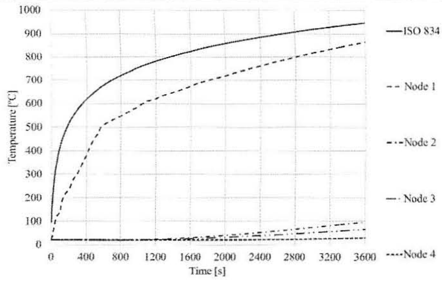
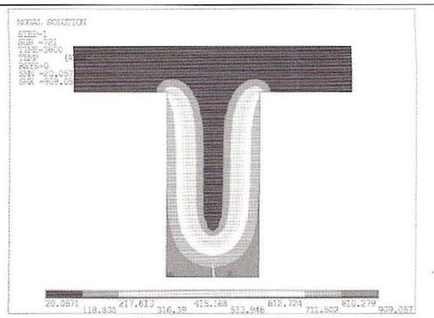
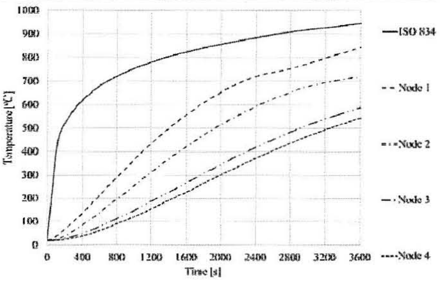
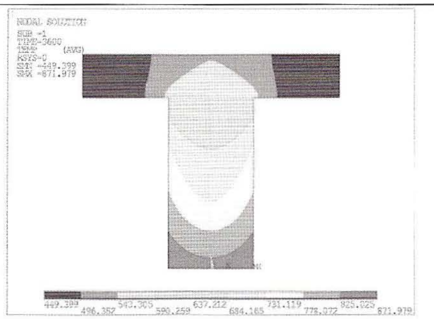
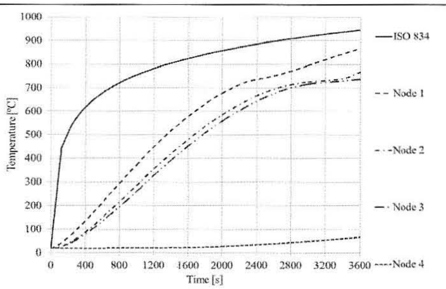
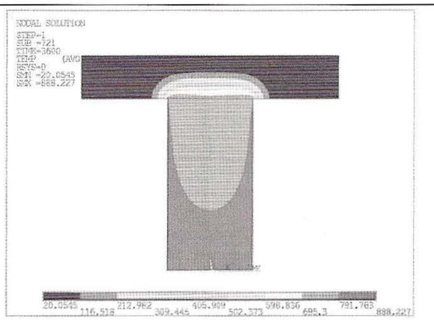
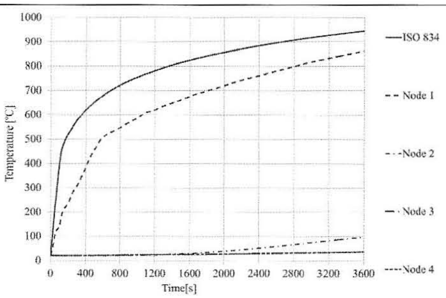
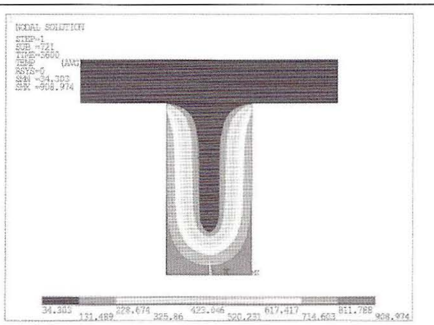
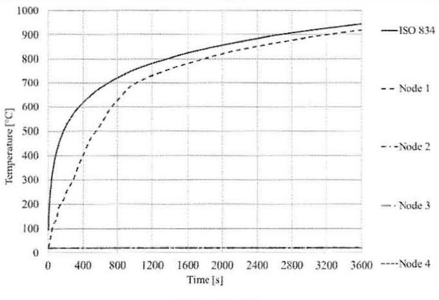
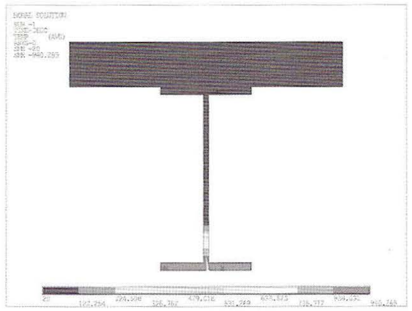
Time history, 0 to 3600[s]	Temperatures at the end of 3600[s]
 G1-3F-W	
 G1-3F-S	
 G1-3F-WS	
 G1-3F-SW	

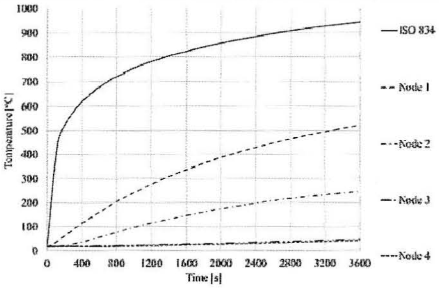
Table 4. Model G1 and fire scenario (3F).

Time history, 0 to 3600[s]	Temperatures at the end of 3600[s]

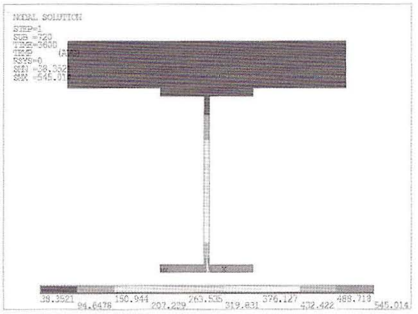


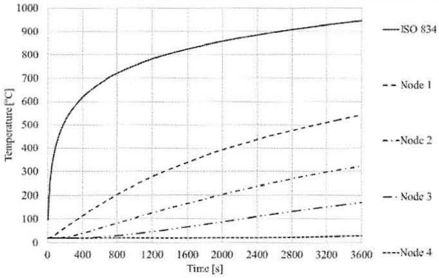
G2-1F-W



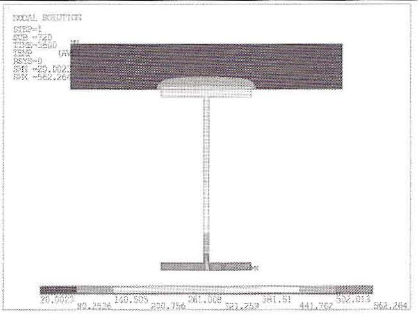


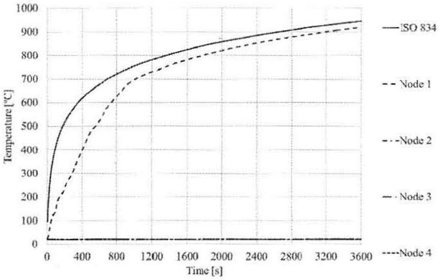
G2-1F-S





G2-1F-WS





G2-1F-SW

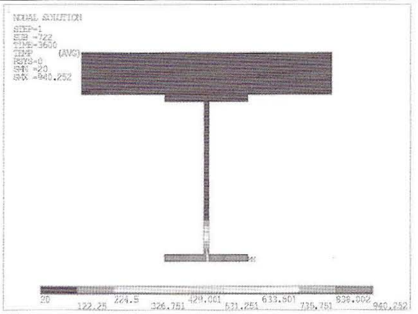


Table 5. Model G2 and fire scenario (1F).

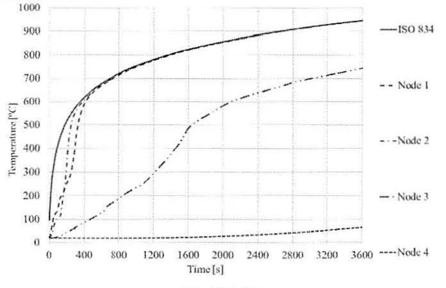
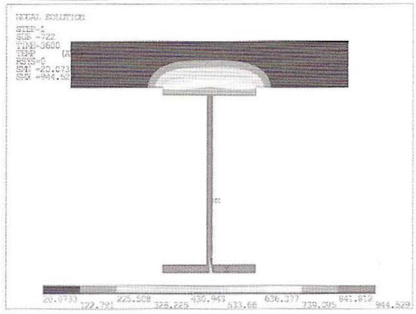
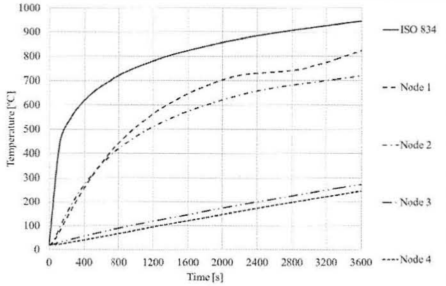
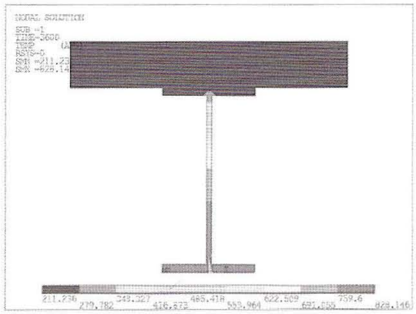
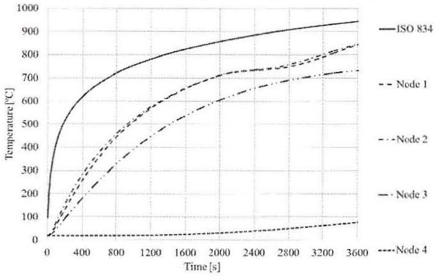
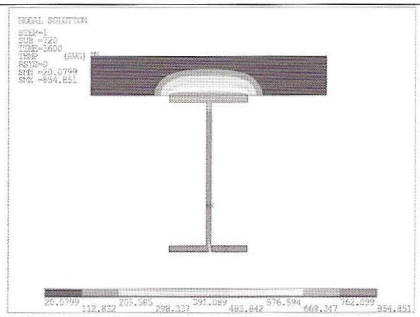
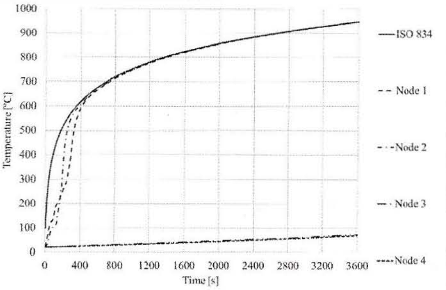
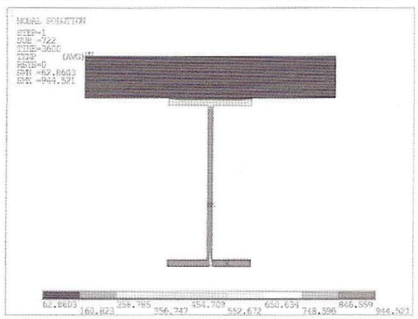
Time history, 0 to 3600[s]	Temperatures at the end of 3600[s]
 G2-3F-W	
 G2-3F-S	
 G2-3F-WS	
 G2-3F-SW	

Table 6. Model G2 and fire scenario (3F).

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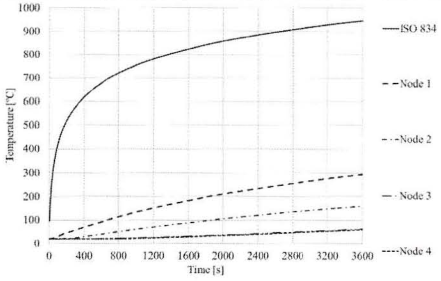
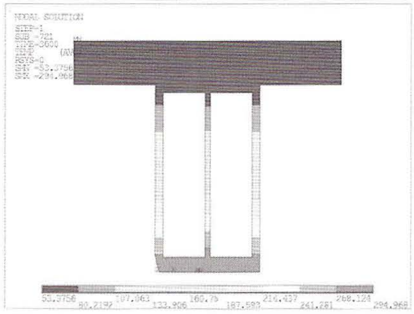
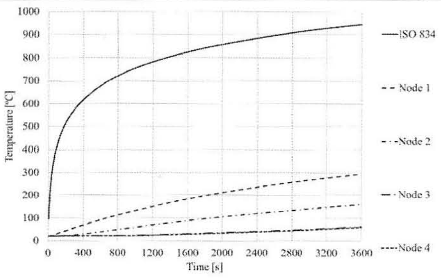
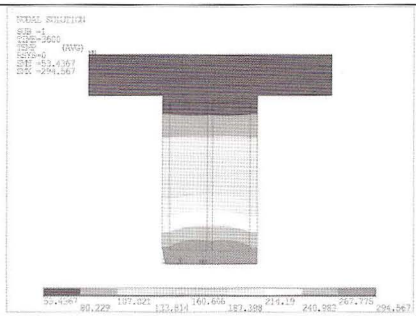
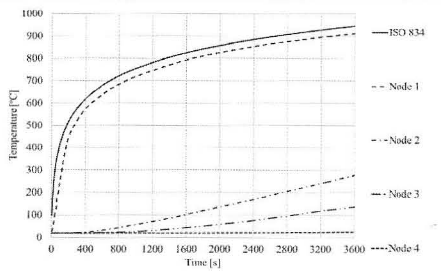
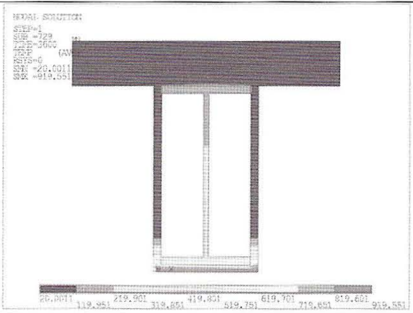
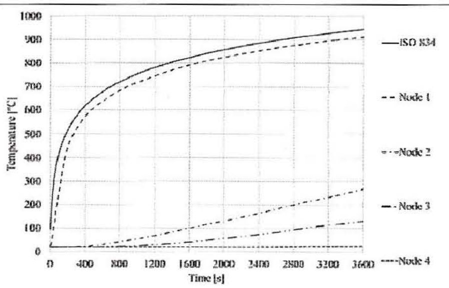
<tr><td>

G3-1F-S</td><td></td></tr>
<tr><td>

G3-1F-S-air</td><td></td></tr>
<tr><td>

G3-1F-WS</td><td></td></tr>
<tr><td>

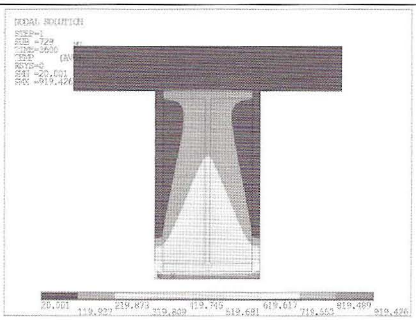
G3-1F-WS-air</td><td></td></tr>
</table>

Table 7. Model G3 and fire scenario (1F).

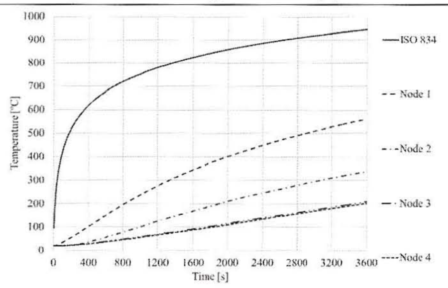
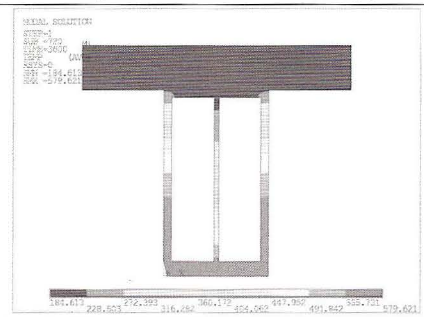
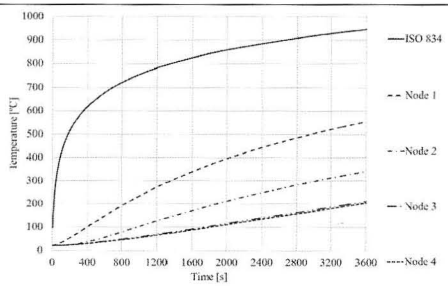
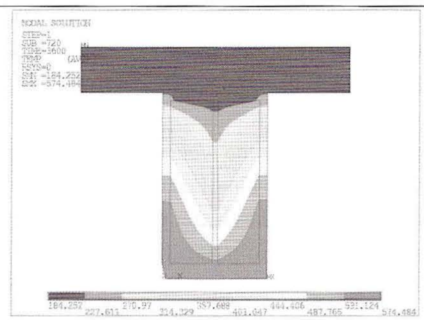
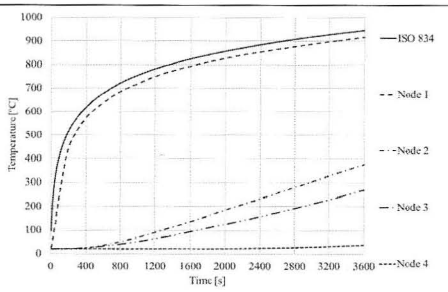
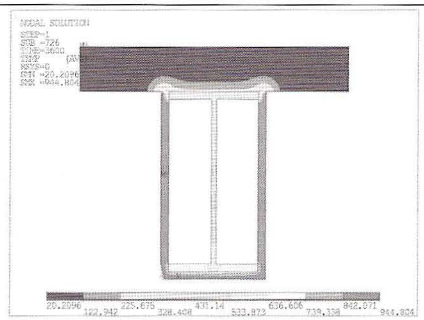
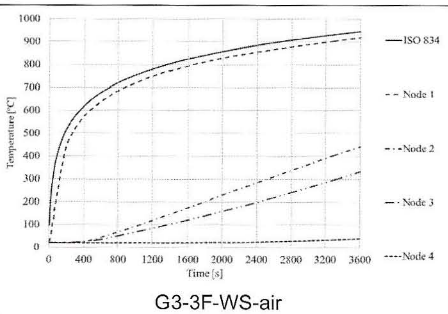
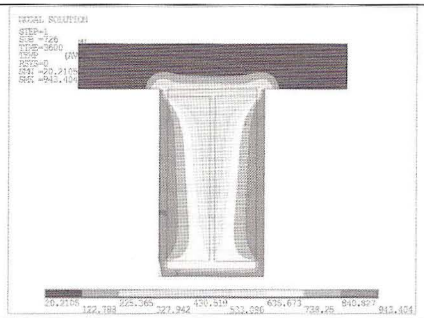
Time history, 0 to 3600[s]	Temperatures at the end of 3600[s]
 G3-3F-S	
 G3-3F-S-air	
 G3-3F-WS	
 G3-3F-WS-air	

Table 8. Model G3 and fire scenario (3F).

4 RESULTS AND DISCUSSION

After all simulations it is possible to identify different conclusions. The fire exposure at three sides is the worst situation. For the same period of time, the temperature increases, in all elements. The interface between charred and noncharred wood is the demarcation plane between black and brown material and is characterized by a temperature of 300°C, according Eurocode 5 [20].

Considering all different geometries and materials:

-For model G1, the elements that have wood in front of the fire exposure, protects the core section. For materials with steel in front of the fire, the heat conduction is very high and quickly heats all components.

-In the model G2, the wood elements in front of the fire are very thin, and quickly lose their resistance due the char layer formation, compromising the remaining structure. In this model the steel material has better performance.

-For model G3, when wood material is externally applied to the steel profile, plays an important role as insulation, reducing the temperature inside steel. In the cases where both (outside and inside of the model) are made of steel, the temperature in the inner profile is higher, than the previous solution.

According to these results, it can be seen that wood elements present lower temperatures than steel, and the maximum temperature in the model is always inside the char layer. The hybrid model can perform well under fire conditions. Regarding the best design solution for all studied models, it is concluded that the hybrid model 3F-G3-WS has a good fire resistance even for three sides exposure, showing the ability of wood to protect the steel.

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