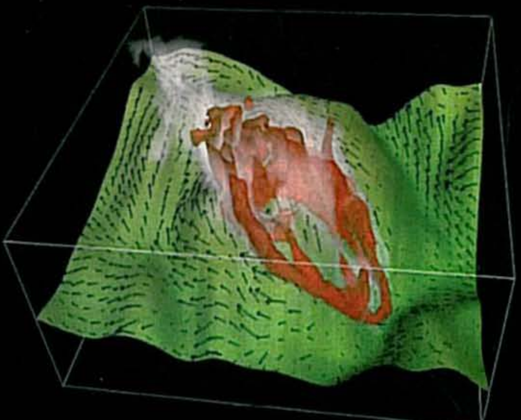

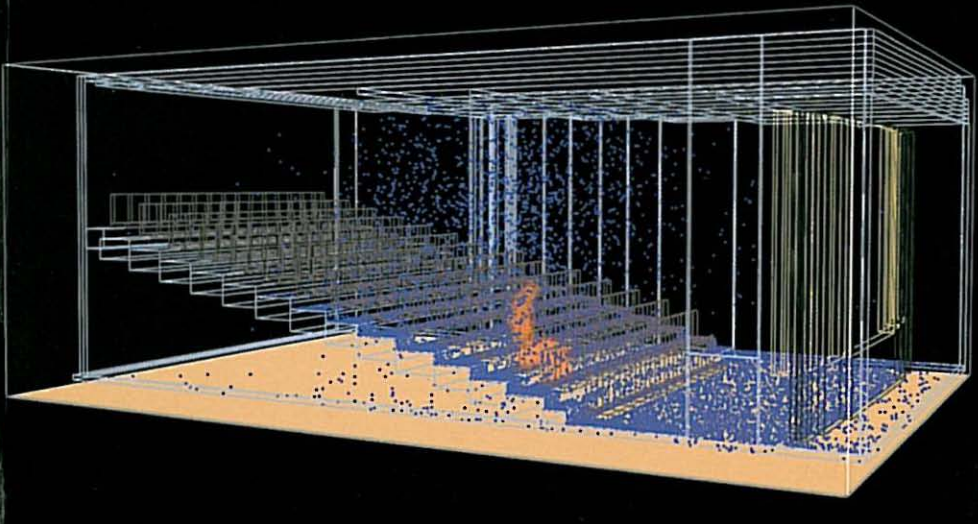

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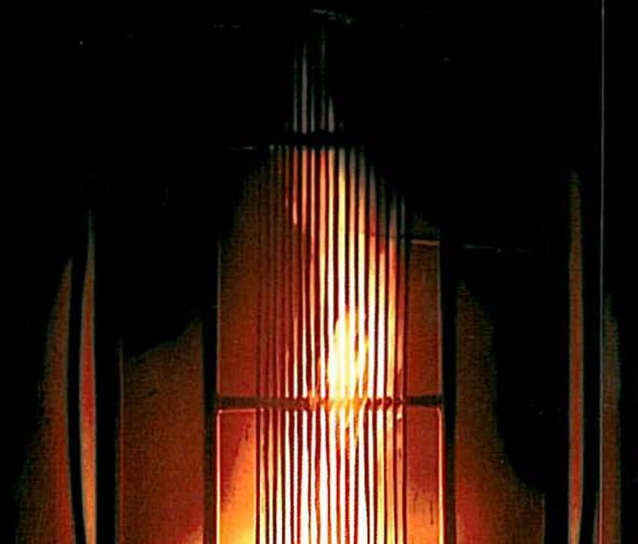

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POSTER SESSION

Preface

The International Congress "FIRE COMPUTER MODELING", on which this book is based, took place at University of Cantabria, Santander, Cantabria, Spain on October 19, 2012. The goal of the International Congress is to bring together experimental and numerical practitioners, and foster discussion and exchange of knowledge.

There were 35 Papers selected for the International Congress and representing different countries (USA, UK, Canada, Japan, Sweden, France, Finland, Germany, Russia, Slovakia, Italy, Greece, Portugal, Spain, etc.). The Invited Lecture about "NUMERICAL SOOT MODELLING IN TURBULENT JET FLAMES AND POOL FIRES" was given by Prof. Dr. Michael Delichatsios, University of Ulster (UK).

We express a special recognition for the work developed in the selection of the papers to the Scientific Committee of the International Congress, integrated by the out-standing Professors and Researches, Dr. Orlando Abreu (GIDAI, Univ. of Cantabria, ESP), Dr. Daniel Alvear (GIDAI, Univ. of Cantabria, ESP), Dr. Vytenis Babrauskas (Fire Science and Techn., USA), Dr. Jorge A. Capote (GIDAI, Univ. of Cantabria, ESP), Dr. Wan-Ki Chow (Hong Kong Polytechnic Univ., China), Dr. Pedro J. M. Coelho (Instit. Sup. Técnico de Lisboa, PRT), Dr. Michael Delichatsios (Univ. of Ulster, UK), Dr. Nick Dembsey (Worcester Polytechnic Institute, USA), Dr. Bogdan Dlugogorski (Univ. of Newcastle, AUS), Dr. Sergey Dorofeev (FM Global, USA), Dr. Dougal Drysdale (Univ. of Edimburgh, UK), Dr. Carlos Fernández-Pello (Univ. of California, Berkeley, USA), Dr. Charles M. Fleischmann (Univ. of Canterbury, NZL), Dr. Pedro L. García (UNED, ESP), Dr. Steve Gwynne (Hughes Associates, UK), Dr. George V. Hadjisophocleous (Univ. of Carleton, CAN), Dr. Yuji Hasemi (Waseda Univ., JPN), Mr. Morgan J. Hurley (SFPE, USA), Dr. Marc L. Janssens (Southwest Research Institute, USA), Dr. Francisco J. Jimenez (Univ. of Córdoba, ESP), Dr. Grunde Jomaas (Technical Univ. of Denmark, DK), Dr. Timo Korhonen (VTT, FI), Dr. Chris Lautenberger (Reax Engineering, USA), Dr. Mariano Lázaro (GIDAI, Univ. of Cantabria, ESP), Dr. Gregory T. Linteris (NIST, USA), Dr. Amable Liñán (Polytechnic Univ. of Madrid, ESP), Dr. Richard E. Lyon (FAA, USA), Dr. Andre Marshall (Univ. of Maryland, USA), Dr. Julio M. Marti (Technical Univ. of Catalonia, ESP), Dr. William E. Mell (U.S. Forest Service, USA), Dr. Bart Merci (Ghent Univ., BE), Dr. Frederick W. Mowrer (Univ. of Maryland, USA), Dr. Eugenio Oñate (Techn. Univ. of Catalonia, ESP), Dr. Richard D. Peacock (NIST, USA), Dr. Paulo Piloto (Instituto Politécnico de Bragança, PRT), Dr. David Purser (Hartford Environmental Research, UK), Dr. James G. Quintiere (Univ. of Maryland, USA), Dr. Guillermo Rein (Imperial College, UK), Dr. Stanislav I. Stoliarov (Univ. of Maryland, USA), Dr. Takeyoshi Tanaka (Kyoto Univ., JPN), Dr. José L. Torero (Univ. of Edinburgh, UK), Dr. Arnaud Trouve (Univ. of Maryland, USA), Dr. Patrick Van Hees (Lund Univ., SWE), Dr. Vittorio Verda (Politecnico di Torino, ITA), Dr. Domingos X. Viegas (Univ. of Coimbra, PRT), Dr. Sergey Vyazovkin (Univ. of Alabama, USA) and Dr. Jennifer Wen (Kingston Univ., UK), whose scientist, contribution has allowed to reach a International Congress with the highest quality.

We want to express our gratitude to the authors and speakers who have dedicated their time and effort to bring us in their presentations, experiences, methodologies and scientist - technical advances in the Fire Computer Modeling.

Prof. Jorge A. Capote
Congress Chairman
GIDAI – Fire Safety – Research and Technology
Universidad de Cantabria

Santander, Spain
October, 2012

Temperature Analysis and Validation of Partially Encased Beams Submitted to Elevated Temperature

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ABSTRACT

Temperature assessment of Partially Encased Beams (PEB) was performed based on the frame work of the experimental bending tests at elevated temperatures. The heating rate of these composite elements was 800 °C/h in the first stage, followed by a steady stage. This second stage was defined to sustain temperature level while increasing mechanical load. The main objective was to calculate the bending resistance of PEB at different temperature levels (200, 400 and 600 °C).

This paper present the experimental result of 12 tests of a more general study of 27 tests, considering the objective addressed to analyse and validate the numerical model to predict temperature rise of both materials (concrete and steel), in particular the time required to heat the beams with almost constant temperature. This validation is fundamental for the general proposal of simple calculation methods.

Good agreement was achieved between experimental and numerical results, obtained by nonlinear thermal transient analysis.

1 INTRODUCTION

Partially Encased Beams (PEB) achieve higher fire resistance when compared to bare steel beams. The increase in fire resistance is due to the encased material, reducing the exposed steel surface area, introducing concrete which has a low thermal conductivity. Higher fire resistance can also be achieved by increasing the amount of reinforcement to compensate for the reduction of steel strength in case of fire, as reported by several researchers.

According to EN1994-1-2 [1], member analysis under fire conditions may be verified using either tabulated data, simplified or advanced calculation models.

Tabulated data refers only to composite beams rather than PEB, depending on load level, and is only valid for standard fire exposure and simple supporting conditions. A simple calculation model may be used to determine fire resistance of PEB without shear connection to the concrete slab. The rules for composite beams may be applied to PEB, assuming no mechanical resistance of the reinforced concrete slab, and establishing reduced effective areas of the cross section, [1]. This model depends on the temperature field over the cross section.

An advanced calculation model is also suitable to analyse any type of cross-section in general and partially encased sections in particular. This methodology was used to predict the temperature field in both materials, when submitted to elevated temperature.

PEB have been widely tested at room temperature, but only a small number of tests are reported under fire or elevated temperature. The most relevant tests were developed by Kindmann et al [2], proving the importance of the reinforced concrete between flanges for bending resistance. Lindner and Budassis in 2000 [3] developed a new design proposal for lateral torsional buckling at room temperature. Maquoi et al [4], improved the knowledge on the elastic critical moment and on the lateral torsional buckling resistant moment. Makamura et al. [5], tested some partially encased girders with longitudinal and transversal rebars (W and NW) to flanges, concluding that bending strength of the PEB was almost two times higher than conventional bare steel girders and specimens with rebar not welded to flanges presented a decrease of 15 % for maximum load bearing when compared to the welded rebar (W) specimens. Piloto et al [6] corroborate the conclusion about the bending resistance at room temperature of PEB and bare steel beam, but were unable to detect differences between the PEB load bearing, using stirrups welded (W) and not welded (NW) to the web of the profile at elevated temperature.

This paper intends to analyse and validate the thermal behaviour of PEB submitted to elevated temperature under four point bending test, characterizing the temperature field before loading. This analysis was important to validate the bending tests.

2 PARTIALLY ENCASED BEAMS

PEB were constructed by filling the space between the flanges of an IPE100 steel profile with reinforced concrete (RC). Figure 1 represents the nominal dimensions of the composite cross section.

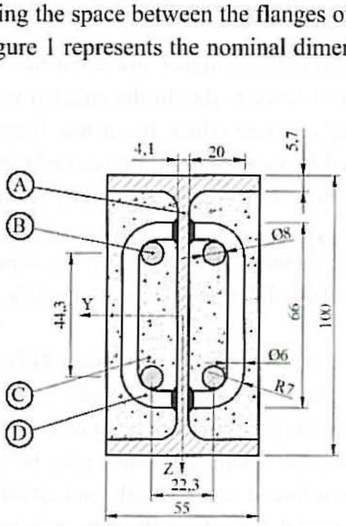

Fig. 1. Cross section geometry (A-steel profile, B- longitudinal reinforcement, C- Concrete, D– Stirrups).

PEB were made of IPE100 with steel S275 JR, using C20 encased concrete with siliceous aggregates. Four longitudinal steel B500 rebar were used with diameter of 8 mm. Stirrups were designed with B500 rebar with a diameter of 6 mm, spaced every 167 mm. Stirrups were also partially welded to the longitudinal steel reinforcement, as represented in figure 1.

PEB were casted in the laboratory, without the need of formwork. Specimens were tested after more than 60 days, with respect to the first casting phase, to ensure normal bond adhesion. The second casting phase was performed one week after the first. This time delay did not influence the behaviour of PEB, because the second casting used the same concrete composition and the same environmental conditions. Both casting phases had sufficient cure time and concrete presented the same resistance in both stages.

The surfaces of materials had no special treatment and were used as delivered by manufacturers. Steel elements were cut from long steel bars, using traditional machinery. Stirrups were welded to the web of steel profile (W).

2 EXPERIMENTAL TESTS

Twelve specimens were selected to validate temperature on PEB. Tests were grouped in four series to compare temperature evolution. Series 1 and 3 were prepared for the same temperature level (400 °C) using different PEB lengths (Lt=2.5 m and Lt=4.0 m). The other series were prepared to be tested at 200 and 600 °C, see table 1. Each specimen was identified with a reference number, temperature level, total length (Lt), length between supports (Ls), length between load (Ll) and length exposed to elevated temperature (Lf).

Series	Specimen	Lt [m]	Ls [m]	Ll [m]	Lf [m]	Temperature level [°C]
1	B/2.4-01 B/2.4-02 B/2.4-03	2.5	2.4	1.5	1.3	400
2	B/2.4-04 B/2.4-05 B/2.4-06	2.5	2.4	1.5	1.3	200
3	B/3.9-01 B/3.9-02 B/3.9-03	4.0	3.9	3.0	2.8	400
4	B/3.9-04 B/3.9-05 B/3.9-06	4.0	3.9	3.0	2.8	600

Table 1. List of tested partially encased beams (specimens with welded stirrups).

Specimens were tested using a reaction portal frame, see figure 2. Two heating stages were defined for PEB. The first transient stage was used to increase temperature level, under constant heating rate. A second stage was define to kept temperature as uniform as possible over the cross section.

Five different cross sections were defined to evaluate temperature over each PEB beam length (S1, S1A, S2, S3A and S3).

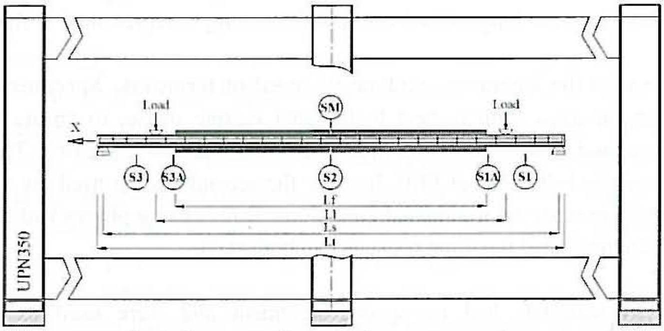

Fig. 2. Testing conditions and main cross sections.

Tests developed at elevated temperature used HTC device to increase and sustain temperature during loading, see figure 3. This device used electro-ceramic resistances applied on the top and on the bottom of each specimen, according to figure 4.

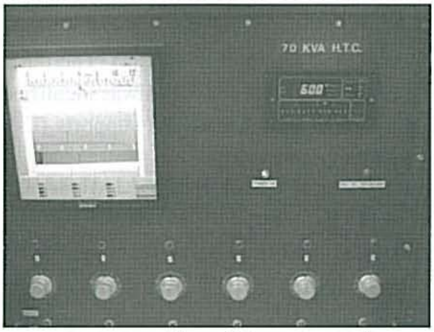

Fig. 3. Heating Thermal Centre (HTC) device.

Fig. 4. Electro-ceramic resistances.

A heating rate of 800 °C/hour was applied, which lead to the first stage period of 15, 30 and 45 minutes, for 200, 400 and 600 °C tests, respectively. An insulation ceramic mat was applied to increase heating efficiency and to promote uniform temperature distribution. Free thermal elongation was allowed before adjusting both supports. Supports were adjusted and load was applied after temperature stabilization (60, 90 and 120 minutes, after the start of heating).

2.1 Instrumentation

Thermocouples type K were distributed inside cross section and along the length of each specimen, according to figure 5 and 6. Thermocouples were spot welded to steel for measuring temperature in steel. Small steel washers were used to measure the temperature of concrete, wrapping them in positions (Si-IC and Si-OC) during the casting phase.

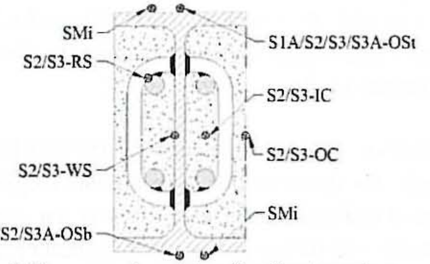

Fig. 5. Thermocouple positions for all main sections.

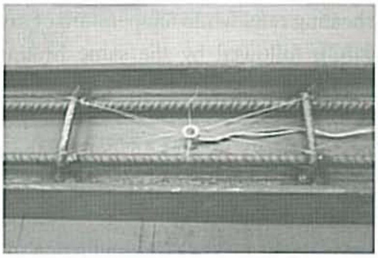

Fig. 6. Thermocouple for position Si-IC.

Thermocouples were also used to control the electrical heating process (SMi). These thermocouples were directly connected to the control unit of the Heating Thermal Centre device (70 kVA maximum power). The Heating Thermal Centre was able to deliver heat by Joule effect, using special electro-ceramic resistances. Temperature was controlled in real time by the control unit, measuring temperature in two and four points, for medium (series 1 and 2) and large test series (series 3 and 4) respectively.

Figures 7 and 8 represent the result of infrared thermography analysis for the ultimate bending limit state at the end of tests B/2.4-04 and B/3.9-05, respectively. Both figures demonstrate the heat flux at the beam extremity and the efficiency of the insulation.

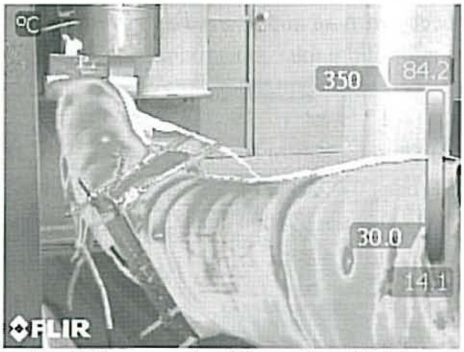

Fig. 7. Thermography of the specimen B/2.4-04 (before removing thermal insulation).

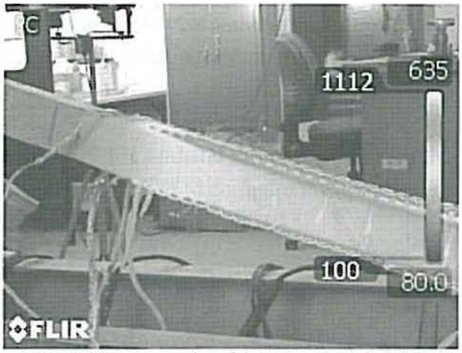

Fig. 8. Thermography of the specimen B/3.9-05 (after removing thermal insulation).

The heating process was controlled to determine thermal steady conditions (second stage), before loading. Temperature distribution along each PEB was also monitored, using discrete temperature readings by thermocouples and also field readings by infrared thermography.

2.2 Temperature measurements

Temperature was registered in both stages (transient – first stage and steady – second stage). Figures 9, 11, 13 and 15 were chosen to represent the temperature evolution of each series.

These results were plotted for section S2. Temperature evolution in steel follows the trend of the heating rate, while temperature of concrete presents the traditional effect of humidity (near 100 °C), followed by the same heating rate. Temperature is almost uniform in the cross section during the steady state (constant temperature level).

Figures 10, 12, 14 and 16 collect the temperature data from output steel (Si-OS) in each specimen of each series, over the PEB length, for three specific time instants (beginning, intermediate and steady stage). Temperature distribution along each PEB is not constant because the heat flows by conduction to the beam extremities, the length of the beam exposed to elevated temperature (Lf) is 52% and 70% with respect to the total length of the beam (Lt), for the medium and large series respectively and finally the insulation near the beam extremities was not efficient.

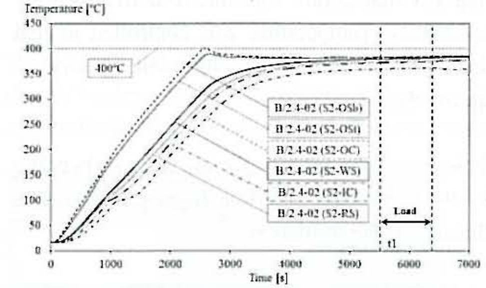

Fig. 9. Heating for test B/2.4-02, section S2.

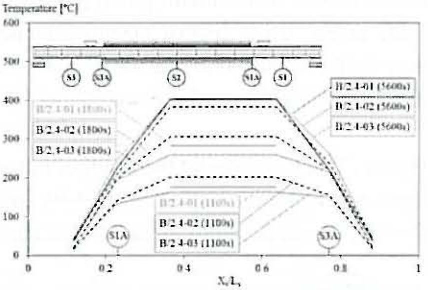

Fig. 10. Temp. distri. and evolution for test series 1.

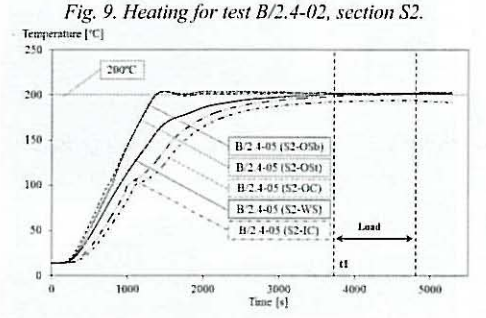

Fig. 11. Heating for test B/2.4-05, section S2.

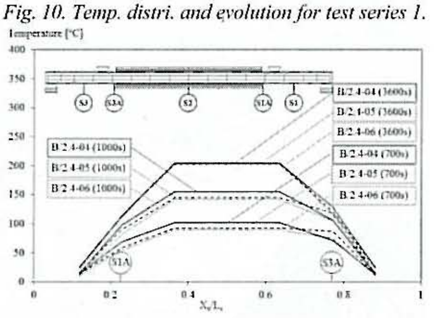

Fig. 12. Temp. distri. and evolution for test series 2.

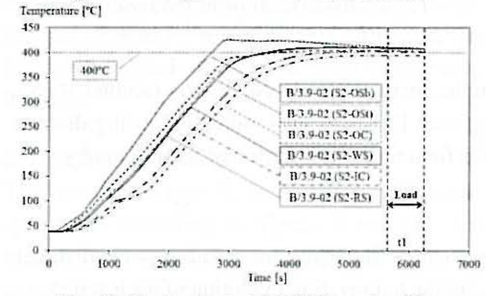

Fig. 13. Heating for test B/3.9-02, section S2.

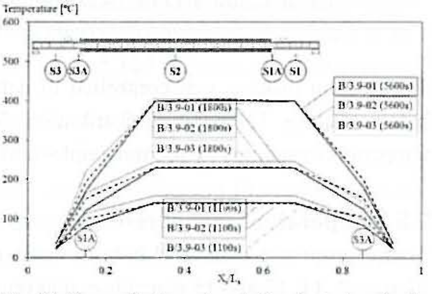

Fig. 14. Temp. distri. and evolution for test series 3.

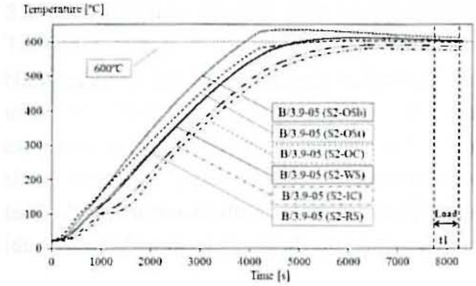

Fig. 15. Heating for test B/3.9-05, section S2.

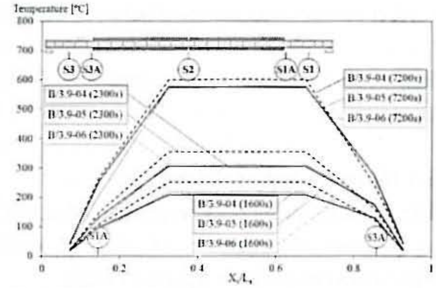

Fig. 16. Temp. distri. and evolution for test series 4.

3 NUMERICAL MODEL

The numerical model used two dimensional linear finite elements (Plane 55) from Ansys, with transient and nonlinear material behaviour, [7]. The element used four nodes with one degree of freedom (temperature at each node) and linear interpolating functions.

The model was refined to allow for the best convergence solution between experimental and numerical results. Figure 17 represents the finite element mesh, used to simulate reinforcement, concrete and steel. The mesh presents 3430 finite elements and 3514 nodes.

The boundary conditions were defined in the top and in the bottom of the profile, following the experimental heating curves (prescribed temperature). The initial condition was also selected from experiments, taking into to consideration the starting temperature in the cross section.

Three cases were selected to represent the behaviour of PEB at different temperature levels. The specimen tests B/2.4-06, B/3.9-03 and B/3.9-05 were selected to compare the temperature results for 200, 400 and 600 °C, respectively.

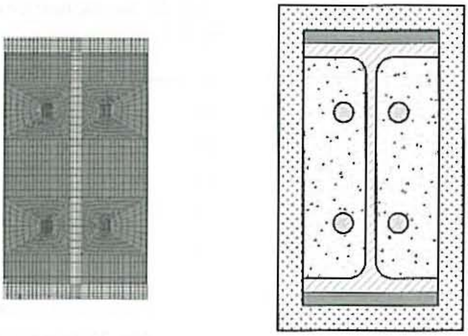

Fig. 17. Finite element mesh and physical model.

Perfect contact was assumed between both materials.

Three dimensional thermo-mechanical model is under development to validate full experiments.

3.1 Material properties

The material properties were defined according to Eurocodes, for both materials [8,9]. The temperature dependence of thermal conductivity, specific heat and specific mass is represented in the next figures (17-22).

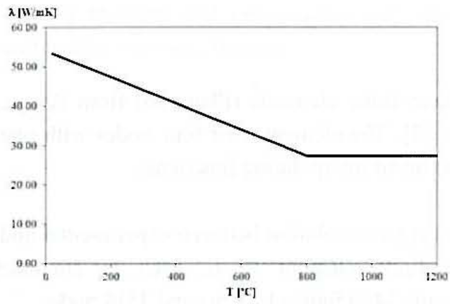

Fig. 17. Conductivity for steel.

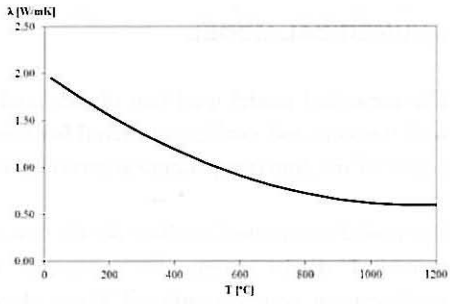

Fig. 18. Conductivity for concrete.

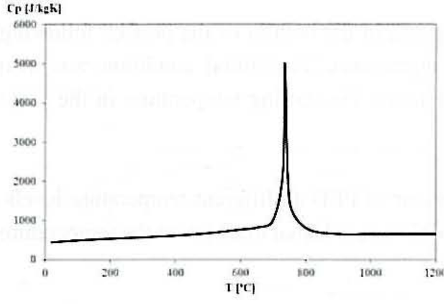

Fig. 19. Specific heat for steel.

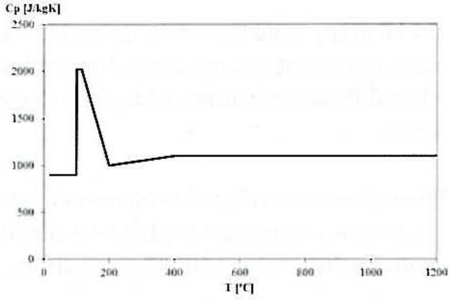

Fig. 20. Specific heat for concrete (3% humidity).

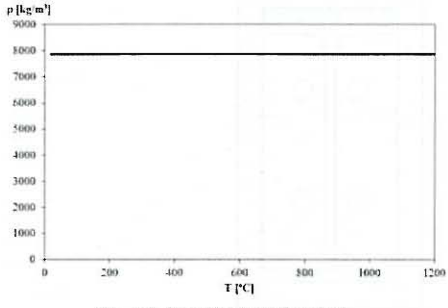

Fig. 21. Specific mass for steel.

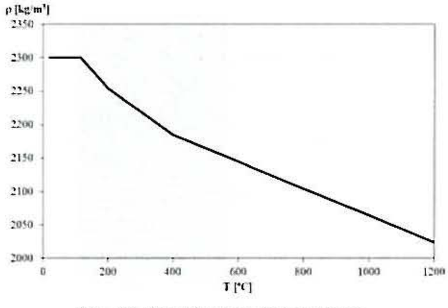

Fig. 22. Specific mass for concrete.

3.2 Temperature results and comparison

The temperature results were determined for every node of the cross section, but the time history for each node location was defined according to the position of each thermocouple used for comparison. Figures 23-28 present the comparison between the temperature evolution in both materials (steel and concrete) for tests at 200, 400 and 600 °C. The results show good agreement between the experimental results and the numerical results. Maximum temperature difference between experimental measurements and numerical results is also identified for each material.

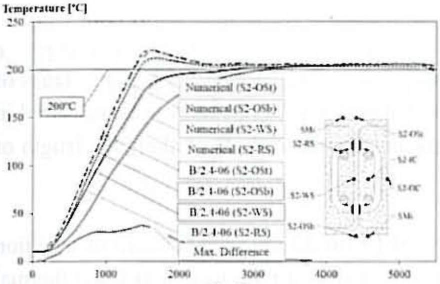

Fig. 23. Temperature evolution for steel, B/2.4-06.

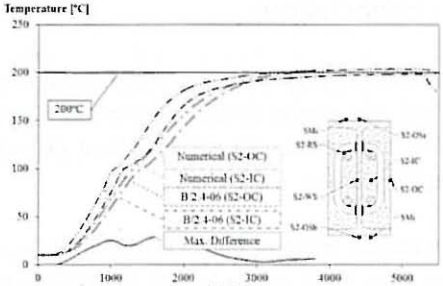

Fig. 24. Temperature evolution for concrete, B/2.4-06.

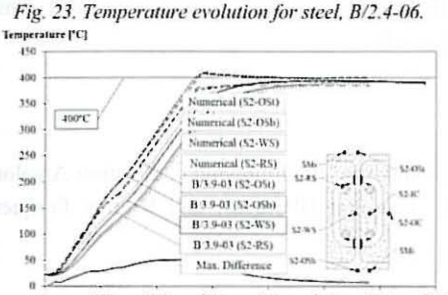

Fig. 25. Temperature evolution for steel, B/3.9-03.

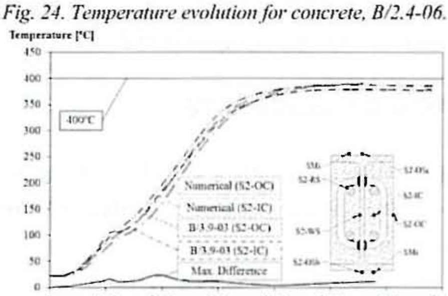

Fig. 26. Temperature evolution for concrete, B/3.9-03.

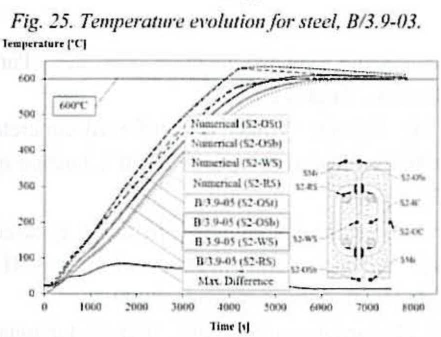

Fig. 27. Temperature evolution for steel, B/3.9-05.

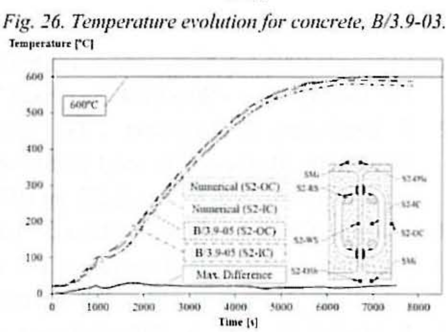

Fig. 28. Temperature evolution for concrete, B/3.9-05.

The numerical simulations validated the time required to achieve the steady state condition and were able to predict temperature evolution in both materials (steel and concrete). Small differences between numerical results and experimental measurements were detected and may be explained by the boundary conditions. The numerical model also used perfect insulation while experiments presented some residual heat loss across the ceramic fibre insulation material. Perfect contact was also considered between steel and concrete, which can modify the heat flow and adhesion between both materials and finally, the material properties were not measured and were assumed from references.

4 CONCLUSIONS

Thermal analysis of twelve experimental tests was presented, regarding two heating stages of PEB submitted to elevated temperatures (200,400 and 600 ºC). Temperature was measured in five different sections which allowed analysing the heating thermal effect along the length of each specimen.

Nonlinear transient finite element analysis was used to validate the temperature distribution over the cross section S2 and also used to predict the required time to establish the thermal steady condition, previously stage to apply the mechanical load. Good agreement was determined between experimental and numerical results.

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