The 1st INTERNATIONAL WORKSHOP RISQUE "FEU" 2015
April 7th & 8th 2015, Hassiba Benbouali University of Chlef, Chlef, Algeria

Laboratory Structures, Geotechnic and Risks (LSGR)

In association with/ En association avec
IPB Portugal and UBP (IP) France

FIRE SAFETY ENGINEERING: A DESIGN TOOL AT THE DISPOSAL OF CODES OF PRACTICE AND REGULATIONS

INGENIERIE DE LA SECURITE-INCENDIE: UN OUTIL DE CONCEPTION AU SERVICE DE LA REGLEMENTATION

Livre des Actes
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OBJECTIFS

Le workshop international risque « feu » vise à rassembler des universitaires, des chercheurs et des ingénieurs pour discuter des règlements, des bonnes pratiques et de derniers développements dans la conception des structures en acier, bois, béton et composites contre le feu. C'est une occasion pour focaliser l'attention sur l'apport des connaissances de l'ingénierie de la sécurité incendie et de son intégration dans la conception des structures.

*La première édition du workshop du laboratoire LSGR est sous le thème: «***INGENIERIE DE LA SECURITE-INCENDIE : UN OUTIL DE CONCEPTION AU SERVICE DE LA REGLEMENTATION***». Les expériences vécues et les leçons tirées des évènements passés au niveau international, constituent un apport appréciable dont il faut tenir compte dans toute action s'inscrivant dans la stratégie de protection des infrastructures contre le risque incendie : C'est là l'objectif technique et scientifique de ce workshop international.*

OBJECTIVES

The Workshop aims to bringing together academics, researchers and engineers to discuss buildings regulations, best practices and latest developments in the field design of steel, timber, concrete and composite structures against fire. It is an opportunity to focalise on what fire safety engineering knowledge and new advances in the field can provide to the design of building structures and infrastructures.

*The first edition of the workshop is under the heading: «***FIRE SAFETY ENGINEERING: A DESIGN TOOL AT THE DISPOSAL OF CODES OF PRACTICE AND REGULATIONS***». Experiences drawn from past events and lessons learned from international fire accidents is an added value to include in any fire protection strategy: it is actually one of the main goals of the workshop*

Programme du Workshop /WorkShop Program

Mardi 7 Avril /Tuesday, April 7th 2015

Matin/Morning

8h30-9h : Accueil et Inscriptions des participants / Registration

9h – 9h 30 : Cérémonie d'Ouverture du Workshop / Ceremonial Opening of the WorkShop

9h30 - 10h : Lieutenant-Colonel F. NECHAB, Directeur de la prévention, Protection Civile
PREVENTION ET SECURITE INCENDIE EN ALGERIE

10h-10h30 : PILOTO P., IPB Portugal
FIRE ENGINEERING OVERVIEW: THE EUROCODES AND THE PORTUGUESE FIRE SAFETY REGULATIONS IN BUILDINGS

Pause-café /Coffee break (Posters)

11h-11h30: BOUCHAIR A., UBP, IP France
ASSEMBLAGES ACIER-BOIS SOUS INCENDIE : MODELISATION ET EXPERIMENTATION

11h30-12h: MESQUITA L., IPB Portugal
FIRE PROTECTION OF STEEL MEMBERS WITH INTUMESCENT COATINGS

12h - 12h30 : LAMRI B., UHBC, Chlef
L'INGENIERIE INCENDIE : UNE NECESSITE POUR LA CONCEPTION MAIS PAS UN OBSTACLE

Déjeuner / Lunch

Après-midi/Afternoon

14h 30 - 15h PILOTO P. (IPB Portugal)
BENDING RESISTANCE OF PARTIALLY ENCASED BEAMS: EXPERIMENTAL TESTS AT ELEVATED TEMPERATURE

15h - 15h20 : HACHEMI S., OUNIS A. (UMK Biskra, Algérie)
EVALUATING RESIDUAL MECHANICAL AND PHYSICAL PROPERTIES OF THERMALLY DAMAGED CONCRETE

15h20 - 15h40 : BENLAKEHAL N., LAMRI B., KADA A., MESQUITA L., BOUCHAIR A. (UHB Chlef, Algérie)
NUMERICAL MODELLING OF INDUSTRIAL PORTAL STEEL FRAMES UNDER FIRE CONDITIONS

15h40 – 16h : GUENDOUZ M., DEBIEB F., KADRI E. H. (U. Médéa, Algérie)
EFFETS DE L'ELEVATION DE LA TEMPERATURE SUR LES CARACTERISTIQUES DU BETON DE SABLE A BASE DE DECHETS PLASTIQUES

Pause-café /Coffee break (Posters)

16h30-16h50: KADA A., LAMRI B., BENLAKEHAL N., MESQUITA L., BOUCHAIR A. (UHB Chlef, Algérie)
FINITE ELEMENT INVESTIGATION ON THE BEHAVIOUR OF STRUCTURAL STEEL BEAMS SUBJECTED TO STANDARD & PARAMETRIQUE FIRE

16h50-17h10: AGRED S. , BAROUS A., LOUKARFI L., NAJI H. (UHB Chlef, Algérie)
UN PROGICIEL POUR L'ANALYSE DE LA COUCHE DE FUMEES LORS D'UN INCENDIE DE COMPARTIMENT

17h10-17h30 : SERIKMA M., MITICHE-KETTAB R. (ENP Alger)
LE BÂTIMENT POMPIER

17h30 : **CLÔTURE ET RECOMMANDATIONS / CLOSING THE WORKSHOP-RECOMMANDATIONS**

Diner / Dinner

Le workshop portera sur les thèmes suivants /The workshop topics are:

TOPICS TO BE COVERED

- Fire resistance of structures and elements: Buildings, industrial structures, exceptional infrastructures (tunnels and chemical plants);
- Fire behaviour and fire reaction of materials at elevated temperatures (steel, concrete, composite, wood, masonry, other materials);
- Fire protection of structures (active and passive protection) and case of study on exceptional projects, tunnels or other infrastructures;
- Fire testing (standard and nonstandard);
- Fire regulations and national code aspects;
- Fire risk analysis.

THEMES À COUVRIR

- Résistance au feu de structures et des éléments : Bâtiments, structures industrielles, infrastructures exceptionnelles (tunnels et usines chimiques);
- Comportement et réaction au feu des matériaux à des températures élevées (acier, béton, composite, bois, maçonnerie, autres matériaux) ;
- Protection des structures contre le feu (protection active et passive) et étude de cas sur des projets exceptionnels, tunnels ou d'autres infrastructures ;
- Test d'incendie (standard et non standard) ;
- Règlements d'incendie de et aspects de codes nationaux;
- Analyse du risque incendie.

RISQUE FEU 2015, UHBC

Sommaire / Table of contents

Plénières
Plenary talks

FIRE PROTECTION OF STEEL MEMBERS WITH INTUMESCENT COATINGS

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Abstract

This work presents a set of 50 experimental fire resistance tests made in a pilot gas furnace and considering: (i) different member cross-sections (IPE, SHS, CHS, LNP), (ii) analysis at ambient temperature and fire conditions, (iii) application of a mechanical loading in a tree-point bending setup, (iv) different utilization degree level (30%, 50%, 70%) and (v) different intumescent thicknesses. Results show that increasing intumescent fire protection thickness an increase in fire resistance time is achieved. For the same nominal protection thickness the critical temperature and fire resistance time decreases with increasing degree of utilisation. The results from the unprotected fire tests are compared with the ones obtained by the Eurocode 3 part 1.2 simplified calculation method. Taking into account the nominal properties only the CHS section experimental results shows unsafe fire resistance times in comparison to the Eurocode values.
Key-Words: Fire resistance, Fire tests, Fire Protection, Intumescent Paint.

Introduction

Steel structures are widely used in building construction due to its high mechanical strength, ductility and execution times. However, due to deterioration of mechanical properties with temperature, it is essential that the whole structure and its elements have the necessary fire resistance to prevent a collapse caused by fire.

One of the measures used to design a structure with the required fire resistance but without applying any fire resistance material is to use higher cross-section elements, better quality steels or fire resistance steels. The alternative is the application of passive fire protection systems such as concrete, plaster boards, mineral fibbers or intumescent paints.

When protected, the steel temperature rise is mainly due to the conduction heat transfer mode, since the steel is not directly exposed to radiation from the fire or in contact with the surrounding gases [1]. The application of intumescent coatings as fire protection depends on its physical and thermal properties, member section factor and the required fire resistance time. An increase of the fire resistance time can be achieved applying higher intumescent dry film thickness (DFT), or for the same DFT using sections with smaller section factors.

The current methodology for fire design prescribed in the European standard [2], see Equation (1), does not take into account the material increasing thickness or the thermal and physical properties variation with temperature, not describing the real fire behaviour.

$$\Delta T_S = \frac{k_p A_p / V \left(T_g - T_S\right)}{c_s \rho_s d_p \left(1 + \phi/3\right)} \Delta t - \left(e^{\phi/10} - 1\right) \Delta T_g \quad ; \Delta T_S \geq 0 \; e \; \Delta T_g \geq 0 \tag{1}$$

In previous equation $\phi = c_p \rho_p d_p / c_s \rho_s \left(V/A_p\right)$ and $\Delta t \leq 30s$ for protected steel elements. When considering materials with thermal and physical temperature dependent properties an update is mandatory mainly on the thermal conductivity and protection thickness during the fire action, introducing $\lambda_p(t)$ and $d_p(t)$ over time or with the intumescent mean temperature.

Recent studies on passive fire protection materials present analytical results of temperature evolution of protected materials based on simplified differential equations [3-7]. In these formulae the protection layer thickness variation is not considered.

For elements subjected to fire conditions whose resistance is directly proportional to the steel yield strength, the critical temperature can be determined by the degree of utilization, μ_0, see equation (2). In other cases, elements subjected to instability phenomena, an iterative procedure must be used.

$$\theta_{a,cr} = 39{,}19 \ln\left[\frac{1}{0{,}9674\,\mu_0^{3{,}833}} - 1\right] + 482 \qquad (2)$$

For a particular design the minimum coating thickness of protection is normally recommended by the paints manufacturers and presented in tables or graphs for different critical temperatures, section factors and different fire resistance periods. These data are based on the fire resistance test results performed in fire resistance furnaces of certified laboratories using structural elements (beams and columns), with and without mechanical load. The results are usually kept confidential due to the coatings manufactures commercial nature, which limit a full characterization of the intumescent physical and thermal properties.

The aim of this work is to present a study made on steel elements protected with intumescent coatings. The protection efficiency is analysed considering elements with different cross sections (IPE, CHS, SHS and LNP), different utilization degrees (30%, 50% and 70 %) and protection thicknesses. The fire resistance tests are made in a fire resistance furnace under constant mechanical load and thermal conditions as prescribed by standard fire curve [8].

Experimental setup and element instrumentation

The set of experimental tests performed at the Polytechnic Institute of Bragança to evaluate the behaviour of beams in fire and assess the protection thickness and utilization degree influence is the presented in Table 1. For comparison and determination of the load capacity (collapse load) tests were also done in elements at room temperature and in fire without fire protection. The test consists into determine the load bearing element capacity, i.e., the element ability to support the test load and maintaining its stability when exposed to fire without exceeding a specified criteria, usually based on the deflection and/or deflection rate.

The elements are subjected to a constant mechanical load and subsequent fire action accordingly to ISO834 standard fire curve, determining for each degree of utilisation and fire protection thickness the corresponding critical temperature and fire resistance time. The elements have a total length (Lt) of 1370 [mm], a length between supports (L) of 1210 [mm] and a length exposure to fire (Lf) equal to 1000 [mm].

The mechanical load corresponds to a predetermined degree of utilization in bending where the design fire resistance at time t=0, $R_{fi,d,0}$, was based in the lateral torsional buckling resistance moment, for the sections IPE and LNP, and in the plastic moment resistance of the gross section in the case of SHS and CHS sections. The load is applied via an hydraulic jack with a load cell at its end. Its value depends on the desired degree of utilisation and is applied incrementally until it reaches the requested value and kept constant during the fire action.

Steel temperature are measured by thermocouples type K welded to the steel profile in three sections along its length, and in these at different cross section points, as specified in the standard prEN13381-8 [9]. As the standard does not specify the thermocouples location for angle sections the distribution adopted was two thermocouples in each leg side along the three longitudinal sections. The thermocouple wires are protected with a small steel angle (9x9 [mm]) to avoid exposure to temperatures higher than the ones at measuring points.

Additionally the top element horizontal (HD) and vertical (DV) displacements were measured by two LVDT and the mid-span displacement (D) at the load application point using wire potentiometric transducers.

Table 1 – Experimental tests set and results.

Section	Test n°	Ap/V [m^{-1}]	Fire Cond.	μ_0	Q [kN]	[µm] DFT	Std.dev.	Max.	Min.	EC3 Resist. T [°C]	t [s]	Exp. Resist. T [°C]	t[s]
IPE 100 S275	I1	387	RoomT.	-	31,84*	-	-	-	-	-	-	-	-
	I2	387	RoomT.	-	31,84*	-	-	-	-	-	-	-	-
	I3	387	ISO834	30%	5,34	-	-	-	-	663,78	745,56	751,20	1156
	I4	387	ISO834	50%	9,18	-	-	-	-	584,67	562,96	684,47	749
	I5	387	ISO834	70%	12,94	-	-	-	-	525,78	473,19	659,01	632
	I6	387	ISO834	30%	5,34	974	193	1253	445	663,78	-	722,71	2505
	I7	387	ISO834	30%	5,34	975	170	1287	576	663,78	-	727,57	2570
	I8	387	ISO834	50%	9,18	1012	185	1342	560	584,67	-	701,02	2331
	I9	387	ISO834	50%	9,18	1055	202	1528	490	584,67	-	701,88	2467
	I10	387	ISO834	70%	12,94	998	148	1268	653	525,78	-	695,31	2341
	I11	387	ISO834	70%	12,94	989	193	1360	501	525,78	-	690,21	2295
	I12	387	ISO834	50%	9,18	1824	156	2140	1440	584,67	-	676,52	2867
	I13	387	ISO834	50%	9,18	1832	194	2270	1440	584,67	-	747,46	3127
SHS 100x100x4 S235	S1	250	RoomT.	-	42,98*	-	-	-	-	-	-	-	-
	S2	250	RoomT.	-	42,98*	-	-	-	-	-	-	-	-
	S3	250	ISO834	30%	13,62	-	-	-	-	663,78	766,13	722,56	1032
	S4	250	ISO834	50%	22,25	-	-	-	-	584,67	583,56	641,95	693
	S5	250	ISO834	70%	30,09	-	-	-	-	525,78	492,36	594,02	573
	S6	250	ISO834	30%	13,62	1105	115	1310	854	663,78	-	687,79	2444
	S7	250	ISO834	30%	13,62	1094	113	1338	777	663,78	-	685,53	2411
	S8	250	ISO834	50%	22,25	1141	100	1309	944	584,67	-	617,08	2060
	S9	250	ISO834	50%	22,25	1141	104	1350	909	584,67	-	608,73	2047
	S10	250	ISO834	70%	30,09	1144	114	1482	886	525,78	-	555,69	1812
	S11	250	ISO834	70%	30,09	1131	92	1270	854	525,78	-	562,24	1836
	S12	250	ISO834	50%	22,25	1932	112	2210	1730	584,67	-	651,64	1967
	S13	250	ISO834	50%	22,25	1933	144	2310	1700	584,67	-	No Collapse	
CHS 101,6x4,05 S235	C1	246,9	RoomT.	-	29,37*	-	-	-	-	-	-	-	-
	C2	246,9	RoomT.	-	29,37*	-	-	-	-	-	-	-	-
	C3	246,9	ISO834	30%	9,31	-	-	-	-	663,78	769,61	602,27	540
	C4	246,9	ISO834	50%	15,20	-	-	-	-	584,67	587,01	499,42	376
	C5	246,9	ISO834	70%	20,56	-	-	-	-	525,78	495,56	255,64	164
	C6	246,9	ISO834	30%	9,31	997	114	1270	800	663,78	-	560,26	1414
	C7	246,9	ISO834	30%	9,31	1004	111	1187	818	663,78	-	562,23	1861
	C8	246,9	ISO834	50%	15,20	1026	143	1330	770	584,67	-	No Collapse	
	C9	246,9	ISO834	50%	15,20	1006	93	1140	810	584,67	-	472,24	1144
	C10	246,9	ISO834	70%	20,56	1071	143	1306	754	525,78	-	169,12	146
	C11	246,9	ISO834	50%	20,56	1120	178	1439	785	525,78	-	490,75	1411
	C12	246,9	ISO834	50%	15,20	1896	200	2190	1490	584,67	-	563,47	1378
	C13	246,9	ISO834	50%	15,20	1807	210	2270	1430	584,67	-	512,00	1261
LNP 100x50x8 S275	L1	250	RoomT.	-	21,69*	-	-	-	-	-	-	-	-
	L2	250	RoomT.	-	21,69*	-	-	-	-	-	-	-	-
	L3	250	ISO834	30%	5,84	-	-	-	-	663,78	766,13	822,55	1743
	L4	250	ISO834	50%	9,83	-	-	-	-	584,67	583,56	761,68	1297
	L5	250	ISO834	70%	13,61	-	-	-	-	525,78	492,36	745,66	1210
	L6	250	ISO834	30%	5,84	1041	91	1205	898	663,78	-	983,42	4692
	L7	250	ISO834	30%	5,84	1026	107	1309	850	663,78	-	1015,19	4655
	L8	250	ISO834	50%	9,83	1053	108	1318	898	584,67	-	747,38	3382
	L9	250	ISO834	50%	9,83	1063	96	1271	825	584,67	-	760,49	3533
	L10	250	ISO834	70%	13,61	1135	118	1420	882	525,78	-	756,97	3801
	L11	250	ISO834	70%	13,61	1114	110	1377	953	525,78	-	600,68	1937

The elements were spray painted following the manufacturer's recommendations, presented in the data sheet, applying several coats and controlling its thickness using a wet film thickness gauge. After coating, the elements were conditioned under controlled temperature (23 ° C) and humidity (50%) for 8 days. Following this curing time the dry film thickness was measured in five sections in the element length, complying with the prEN 13381-8 [9] requirements. Table 1 shows the fire protection

characterization, where the mean arithmetic dry film thickness, standard deviation, maximum and minimum measured values are presented.

Collapse criteria and fire resistance

An element is regarded as having a fire resistance equal to the elapsed time between the beginning of heating and the end of heating or until it fails to meet the load bearing capacity criterion, whichever occurs sooner. The standard EN 1363-1 [8] specifies a failure criteria for columns and beams. For the first type of elements failure occurs when both the following criteria have been exceeded: (i) vertical contraction, C = h/100 [mm] and (ii) rate of vertical contraction, dC/dt = 3h/1000 [mm/min], where *h* is the initial column height in [mm]. Beams are deemed to have failed when both of the following criteria are exceeded: (i) deflection of $L^2/400d$ and (ii) rate of deflection = $L^2/(9000d)$ [mm/min]. The rate of deflection limit shall not apply before a deflection of L/30 is exceeded.
For the studied sections, with d=100 [mm], the deflection limit criteria occurs when D=36.6 [mm], giving a displacement equivalent to L/33. From the analyses of time vs mid-span displacement curves one can see that the rate of deflection criteria is reached before the deflection of L/30 is exceeded, so the fire resistance is established by the time (rounded down to the nearest minute) when the deflection is equivalent to L/30.

Experimental tests in fire without and with fire protection

All sections in study were tested under fire conditions without fire protection and an applied constant mechanical load representative of the required degree of utilisation. The critical temperature determined from the Eurocode simplified calculation method, using equation (2), for degrees of utilisation equal to 30%, 50% and 70%, are 663.78 [C], 584.67 [C] and 525.78 [C], respectively. Using the simplified equation for the temperature evolution of unprotected elements gives a fire resistance time of 12, 9 and 7 minutes for the IPE100 section, respectively, and for the remaining sections, with section factors close to 250 [m^{-1}], a fire resistance of 12, 9 and 8 minutes, see Table 1. These values can be compared with experimental results, in time and temperature domains, where the collapse criteria were based on the L/30 equivalent displacement.

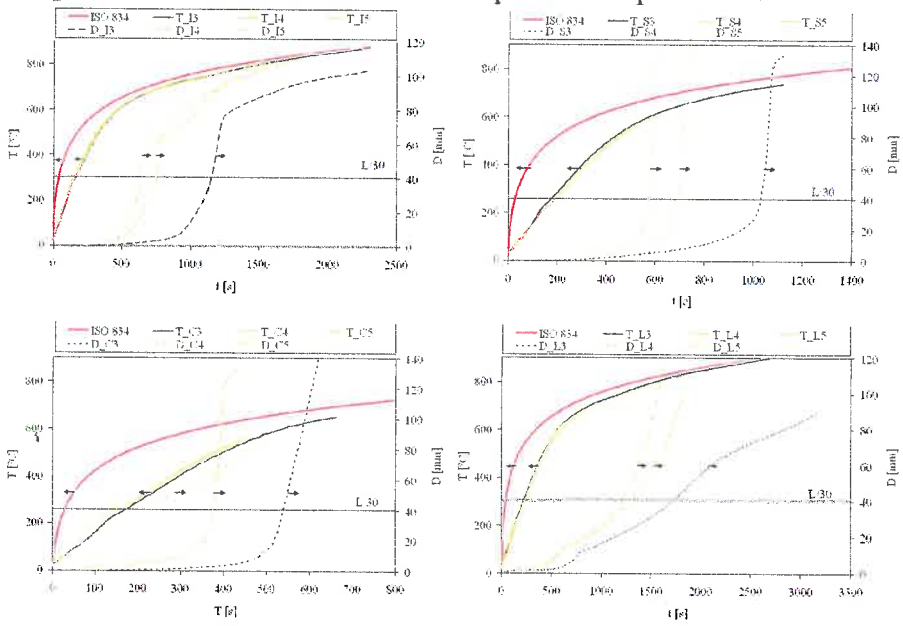

Figure 1 – Experimental steel temperature evolution and mid span displacement results of members without fire protection.

The results presented in Table 1 show that the critical temperature and the fire resistance time obtained from the IPE and LNP cross sections are higher than the ones determined from the Eurocode 3 part 1.2, despite the degree of utilisation. The critical temperature and fire resistance are inversely proportional

to the degree of utilisation applied in the element. Regarding the SHS and CHS sections the results from Eurocode 3 Part 1.2 are higher than those obtained experimentally, with a maximum difference of one minute fire resistance for the SHS. For the CHS the difference between both methods increases with the degree of utilisation, even comparing with the real geometric and material properties. Figure 1 presents the steel temperature evolution with time considering the arithmetic mean of all thermocouples in the three measuring sections.

The experimental setup and methodology used for the elements test with intumescent protection is similar to the one used in the tests without insulation. To avoid direct contact between the load application component and the protected element, a thermal insulation, consisting of ceramic fibber, was applied. However in the contact area the coating intumescence is limited.

The fire tests results of members protected with intumescent coating are presented in Figure 2 and Figure 3, where they can be compared with the tests results of members without fire protection. The temperatures presented are mean values of all measured temperatures in the element. The temperature behaviour of IPE sections show a clear distinction between the elements protected with nominal DFT of 1000 $[\mu m]$ and 2000 $[\mu m]$, and there is no clear influence of the degree of utilisation on the temperature evolution.

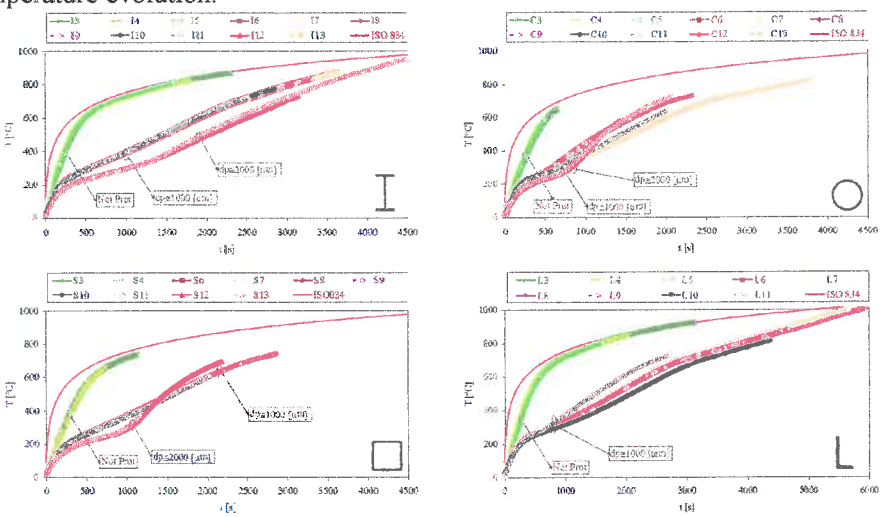

Figure 2 – Experimental steel temperature evolution of fire protected elements.

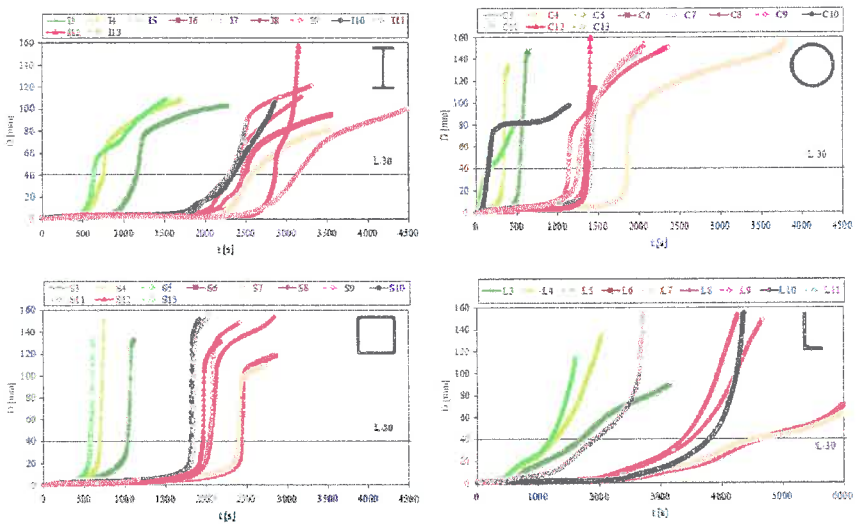

Figure 3 – Experimental mid span displacement of members with and without fire protection. a) IPE sections.

For SHS and CHS sections the influence of the protection thickness on the coating performance is only clear for short exposure times. When these elements are protected with 2000 [μm] nominal DFT, with increasing exposure times and the consequent intumescence char expansion there is a partial detachment, and sometimes total detachment, leaving the steel with a reduced fire protection or even with no protection at all. This becomes less favourable in comparison to thicknesses of 1000 [μm], resulting in higher steel temperatures.
Critical temperature and fire resistance time were determined by the collapse criterion, which corresponds to the steel temperature and the time when the mid span displacement is equivalent to L/30. The numerical values are presented in Table 1 and the displacement time evolution, for protected and unprotected elements, presented in Figure 3. The figure shows the protection efficiency by increasing fire resistance time when compared to the equivalent unprotected element and same degree of utilisation. As the real degree of utilisation of the sections CHS turns to be higher than the initially expected, e.g. the nominal 70% represents a real value of 90.32%, the C10 test reach the collapse criteria after only 146 [s], before the intumescent paint starts to react.

Conclusions

To study the influence of the intumescent coating thickness, the degree of utilisation and the cross section type, a set of 50 tests were done in a fire resistance furnace using elements subjected to bending. Of these, and for comparison proposes, 8 were performed at room temperature and the others under fire conditions using the standard fire curve and nominal degrees of utilisation of 30%, 50% and 70% applied in protected and unprotected elements. In the case of tests without fire protection a comparison is made between experimental results and the values obtained by the Eurocode 3 part 1.2 simplified method. Taking into account the nominal properties only the CHS section experimental results shows unsafe fire resistance times in comparison to the Eurocode values. Increasing intumescent fire protection thickness an increase in fire resistance time is achieved. For the same nominal protection thickness the critical temperature and fire resistance time decreases with increasing the degree of utilisation. In the SHS and CHS protected sections a partial detachment and intumescence shrinkage was sometimes observed leaving steel with reduced protection or even unprotected.

Acknowledgments

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