Research Fund for Coal & Steel

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FISHWALL

FIre and Seismic performances of Hybrid fire WALLs in case of single-storey industrial and commercial steel buildings


L'ENVELOPPE MÉTALLIQUE DU BÂTIMENT
ASSOCIATION DES FABRICANTS DE PANNEAUX, PROFILS ET SYSTÈMES

JORISIDE THE STEEL FUTURE

PAVUS FIRE TESTING INSTITUTE

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CTICM l'ingéniosité au service de la construction métallique

CTU CZECH TECHNICAL UNIVERSITY IN PRAGUE

UNIVERSITY OF TRENTO

Experimental campaign – Results and exploitation of fire tests)

- Steel members protected by sandwich panels
- Clifford CHINAYA
- Efectis France

Introduction

- **Any structural member supporting the partition fire wall solidly attached to the building steel structure should also have the same fire resistance as that required for the wall to preserve the integrity and insulation performance of the separating element.**
- **Fire resistance is frequently achieved by applying fire protection to the structural steel members with passive fire protections, such as sprayed materials, boards or intumescent coatings.**
- **Sandwich panels forming the partition fire wall could also be used as an encasement fire protection system for its supporting steel members, as alternative to common passive fire protections, avoiding the involvement of any other subcontractor.**

- **In this context, 2 fire resistance tests and a numerical analysis according to the standard EN 13381-4 "*Test methods for determining the contribution to the fire resistance of structural members - Part 4 : applied passive protection to steel members*" were planned.**

Definition of the tests – according to EN 13381-4

- **Assessment of fire protection applied on steel members is made using:**
  - Tests on loaded profiles, with their associated unloaded profiles usually called “reference”, for both minimum and maximum thickness of the range to valid
  - Tests on a variety of short unloaded profiles with:
    - Different thickness of the fire protection system (minimum, maximum and two intermediate thickness)
    - Different section factor of steel profiles to select in order to fit the range to valid

Table 5

Section Range Factor (K_s)	Thickness Range factor (K_d)			
	0,0 (d_{min})	0,2 to 0,5	0,5 to 0,8	1,0 (d_{max})
0,0 (s_{min})	✓	✓	✓	
	✓ptp			
0,2 to 0,5	✓		✓	✓
	✓ptp			
	✓ptp	✓ptp		✓ptp
0,5 to 0,8	✓	✓	✓	✓
		✓ptp	✓ptp	✓ptp
		✓ptp	✓ptp	✓ptp
1,0 (s_{max})		✓	✓	✓

Definition of the tests – according to EN 13381-4

- **During the test design, it was planned to test:**
  - Range from 100 to 300 mm to cover most of thicknesses of the sandwich panel.
  - Range from 51 to 220 m^{-1} to cover most of the section factors used in storey building.

Specimen	Cross-section size	Section factor A_p/V (m^{-1})	Section range factor k_s	Range of k_s	Panel thickness d_p (mm)	Thickness range factor k_d	Range of k_d
LBmin	IPE 400	121.0	0.414	0.2 to 0.8	100.0	-	-
RBmin	IPE 400	121.0	0.414	0.2 to 0.8	100.0	-	-
LBmax	IPE 400	121.0	0.414	0.2 to 1.0	300.0	-	-
RBmax	IPE 400	121.0	0.414	0.2 to 1.0	300.0	-	-
SIC1	HEM 280	51.0	0.000	0.0	100.0	0	0
SIC2	HEM 280	51.0	0.000	0.0	175.0	0.375	0.2 to 0.5
SIC3	HEM 280	51.0	0.000	0.0	240.0	0.700	0.5 to 0.8
SIC4	HEA 300	110.0	0.349	0.2 to 0.5	100.0	0.000	0.0
SIC5	HEA 300	110.0	0.349	0.2 to 0.5	240.0	0.700	0.5 to 0.8
SIC6	HEA 300	110.0	0.349	0.2 to 0.5	300.0	1.000	1.0
SIC7	HEA 220	140.0	0.527	0.5 to 0.8	100.0	0.000	0.0
SIC8	HEA 220	140.0	0.527	0.5 to 0.8	175.0	0.375	0.2 to 0.5
SIC9	HEA 220	140.0	0.527	0.5 to 0.8	240.0	0.700	0.5 to 0.8
SIC11	IPE 200	220.0	1.000	1.0	175.0	0.375	0.2 to 0.5
SIC12	IPE 200	220.0	1.000	1.0	240.0	0.700	0.5 to 0.8
SIC13	IPE 200	220.0	1.000	1.0	300.0	1.000	1.0

LB : loaded beam – RB : Reference unloaded beam – SIC : Short unloaded I column

k_s and k_d are defined in the test method EN 13381-4

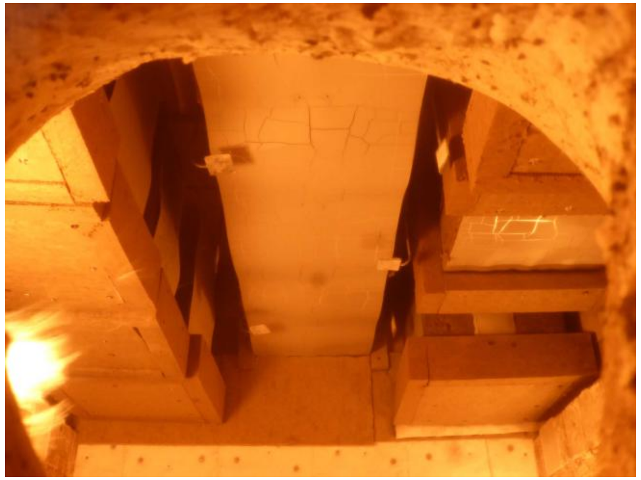
Installation of the protection system

Tests results

- **Fire resistance test #1:**
  - This test included:

Specimen	Cross-section size	Section factor A_p/V (m^{-1})	Panel thickness d_p (mm)
LBmax	IPE 400	121.0	300.0
RBmax	IPE 400	121.0	300.0
SIC6	HEA 300	110.0	300.0
SIC8	HEA 220	140.0	175.0
SIC9	HEA 220	140.0	240.0
SIC10	HEA 220	140.0	300.0
SIC12	IPE 200	220.0	240.0
SIC13	IPE 200	220.0	300.0

  - But, unforeseen shadow effects have affected advantageously the heating of steel profiles during the test, by limiting it, because of the small space separating the protected steel specimens



Some changes were needed for the second test in order to be able to conduct a thermal analysis of test results according to the standard EN 13381-4 for at least the minimum thickness

Tests results

- **Fire resistance test #2 - modification of the test package:**
  - Since the specimens were already mounted and a complete modification of the setup was impossible, it was decided to only change the panel thickness applied around some specimen, changing the thickness to 100 mm on one specimen in order to fit the requirement of the standard EN 13381-4, ensuring also sufficient spacing between specimens.

Specimen	Cross-section size	Section factor A_p/V (m^{-1})	Panel thickness d_p (mm)
LBmin	IPE 400	121.0	100.0
RBmin	IPE 400	121.0	100.0
SIC1	HEM 280	51.0	100.0
SIC2	HEM 280	51.0	175.0
SIC3	HEM 280	51.0	240.0
SIC4	HEA 300	110.0	100.0
SIC5	HEA 300	110.0	240.0
SIC7	HEA 220	140.0	100.0
SIC11	IPE 200	220.0	175.0

→

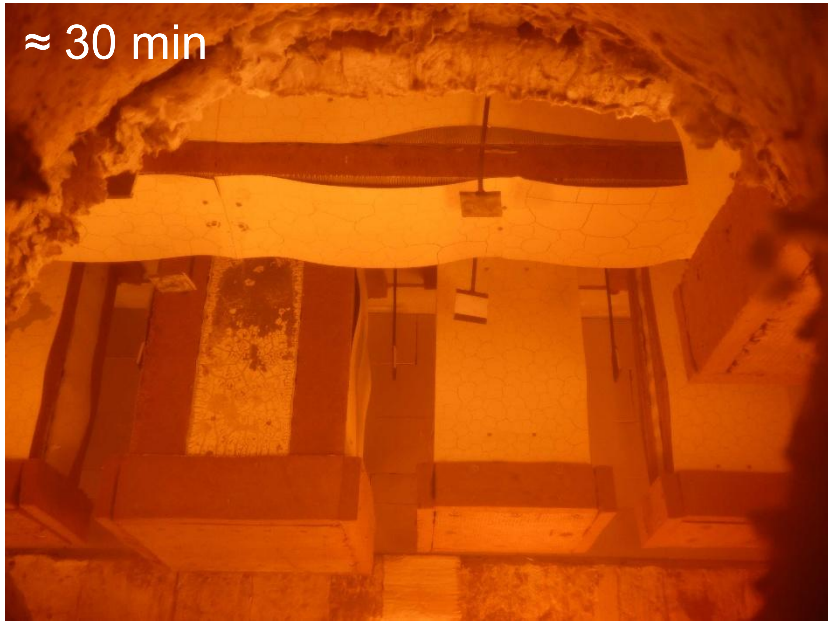
Specimen	Cross-section size	Section factor A_p/V (m^{-1})	Panel thickness d_p (mm)
LBmin	IPE 400	121.0	100.0
RBmin	IPE 400	121.0	100.0
SIC1	HEM 280	51.0	100.0
SIC2	HEM 280	51.0	175.0
SIC3	HEM 280	51.0	240.0
SIC4	HEA 300	110.0	100.0
SIC5	HEA 300	110.0	240.0
SIC7	HEA 220	140.0	100.0
SIC11	IPE 200	220.0	100.0

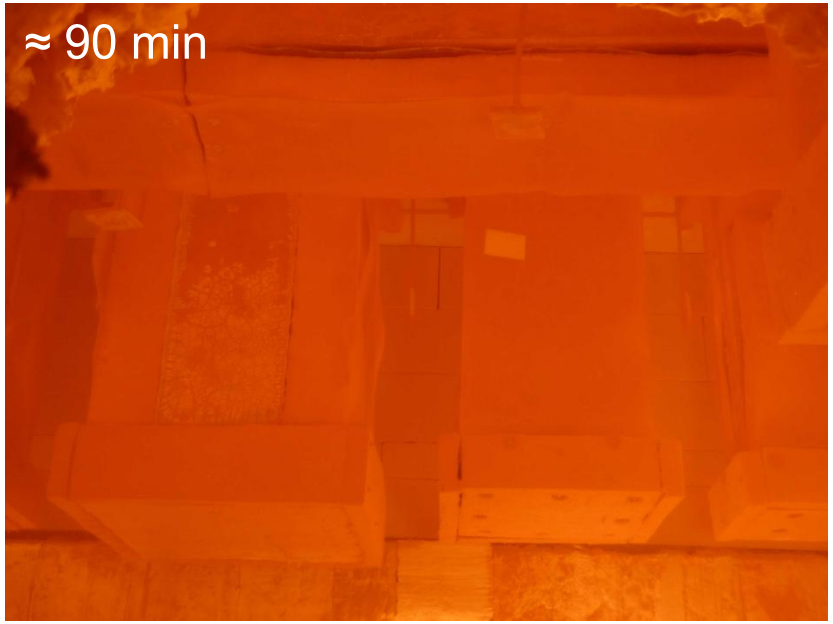
Tests results

- **Fire resistance test #2:**
  - This test included:

Specimen	Cross-section size	Section factor A_p/V (m^{-1})	Panel thickness d_p (mm)
LBmin	IPE 400	121.0	100.0
RBmin	IPE 400	121.0	100.0
SIC1	HEM 280	51.0	100.0
SIC2	HEM 280	51.0	175.0
SIC3	HEM 280	51.0	240.0
SIC4	HEA 300	110.0	100.0
SIC5	HEA 300	110.0	240.0
SIC7	HEA 220	140.0	100.0
SIC11	IPE 200	220.0	100.0

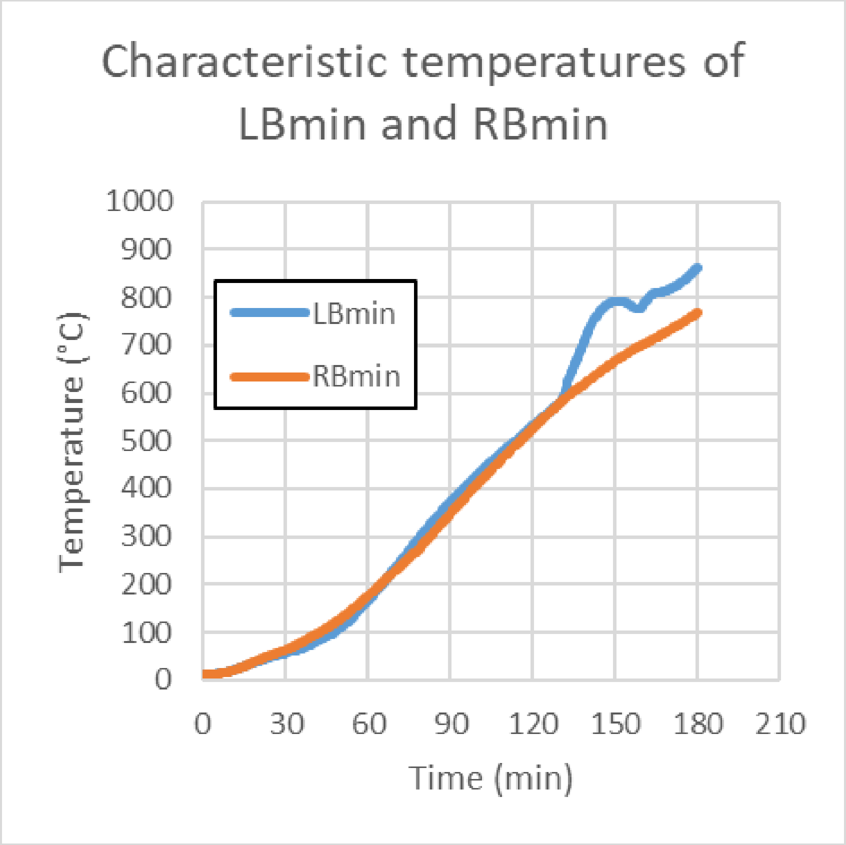
  - During the test:

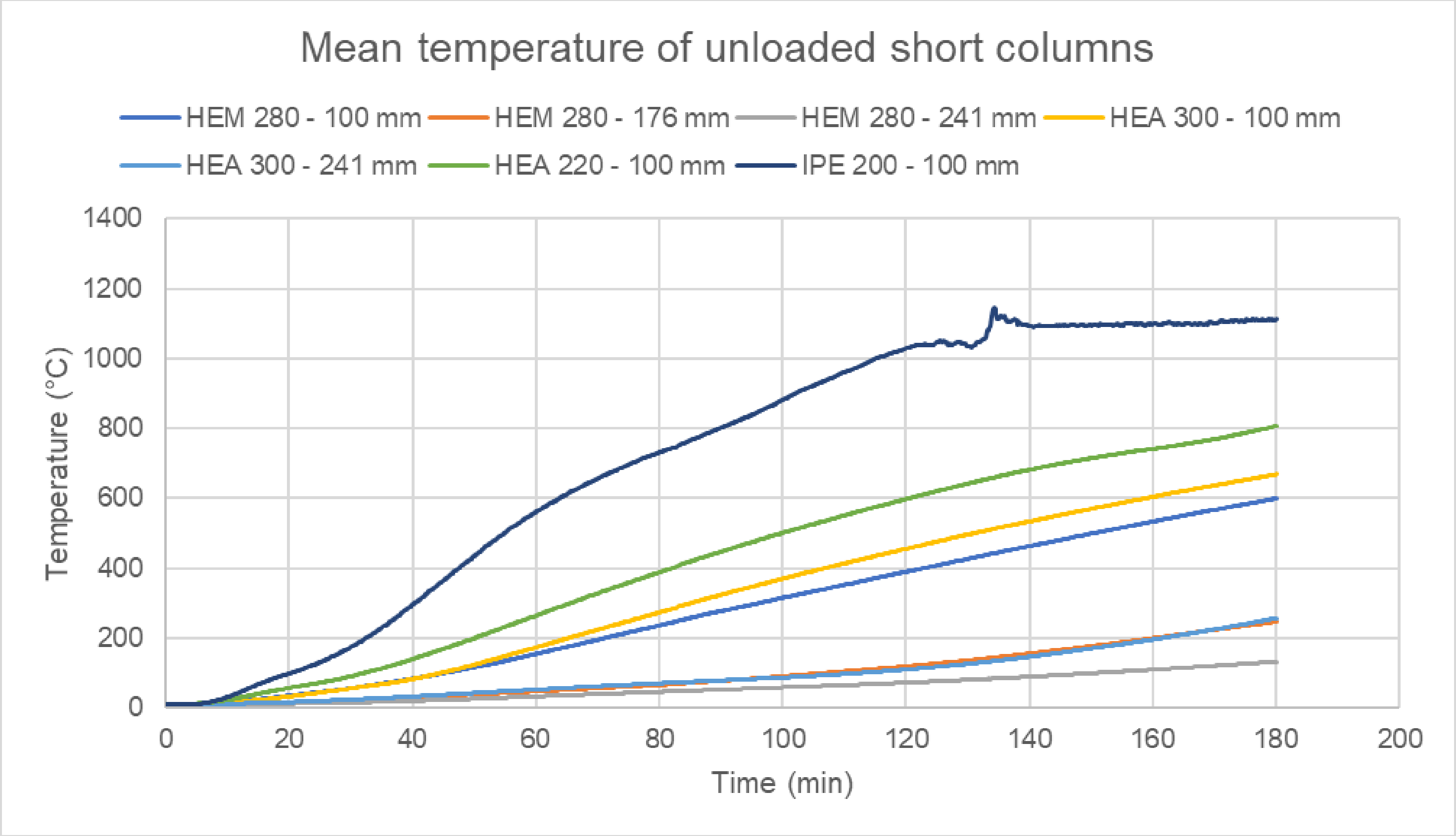




Tests results

- **Fire resistance test #2:**
  - Steel temperatures





Assessment according to EN 13381-4

- **An assessment or thermal analysis is performed in 3 steps:**
  1. A correction of the data based on the comparison between results of the loaded beam and results of the unloaded beam tested which gives the correction factor to correct the time to reach a steel temperature of the short specimens,
  2. A thermal analysis using the thermal data, corrected or uncorrected depending on the analysis method used, coming from the short sections. All partners agreed that linear regression and variable thermal conductivity approaches should be used and compared in order to select the final one.
  3. The result of the thermal analysis from step 2 are compared to the corrected data coming from step 1 and have to fit some acceptability criteria. If the criteria are not fitted, modification of the analysis should be made until the criteria of acceptability are met.

Assessment according to EN 13381-4

➢ Specimens used for the analysis

Specimen	Cross-section size	Section factor A_p/V (m^{-1})	Section range factor k_s	Range of k_s	Panel thickness d_p (mm)	Thickness range factor k_d	Range of k_d
LBmin	IPE 400	121.0	0.414	0.2 to 0.8	100.0	-	-
RBmin	IPE 400	121.0	0.414	0.2 to 0.8	100.0	-	-
SIC1	HEM 280	51.0	0.000	0.0	100.0	0	0
SIC4	HEA 300	110.0	0.349	0.2 to 0.5	100.0	0.000	0.0
SIC7	HEA 220	140.0	0.527	0.5 to 0.8	100.0	0.000	0.0
SIC11	IPE 200	220.0	1.000	1.0	100.0*	0.375	0.2 to 0.5

LB : loaded beam – RB : Reference unloaded beam – SIC : Short unloaded I column

k_s and k_d are defined in the test method EN 13381-4

* Thickness changed in fire test #2 with all partners agreement

Assessment according to EN 13381-4

- **Step 1 – Correction of data**
  - Calculation of correction factor

  Sometimes called « Stickability » factor

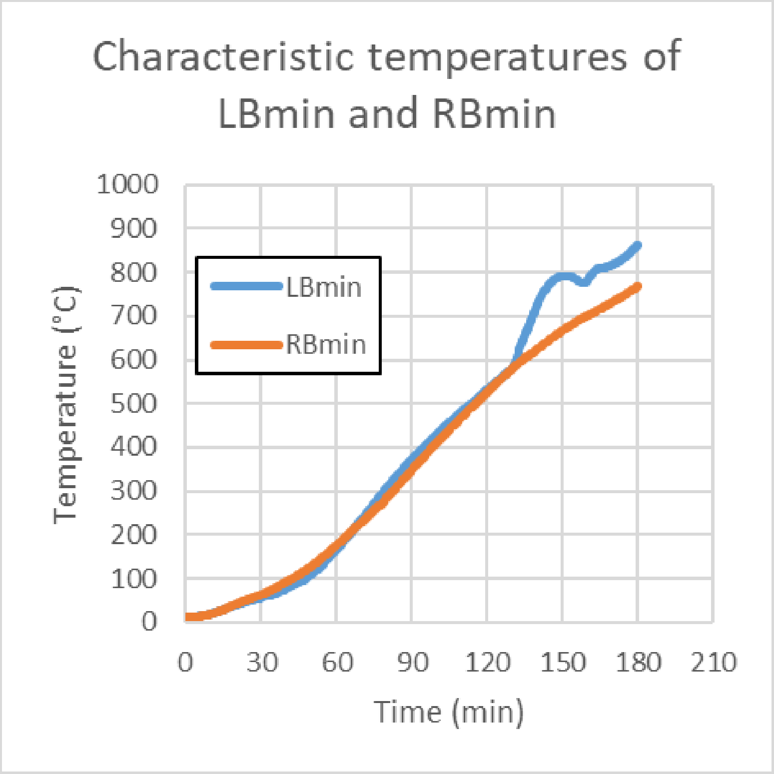
According to the standard EN 13381-4, the stickability factor is calculated using the formula:

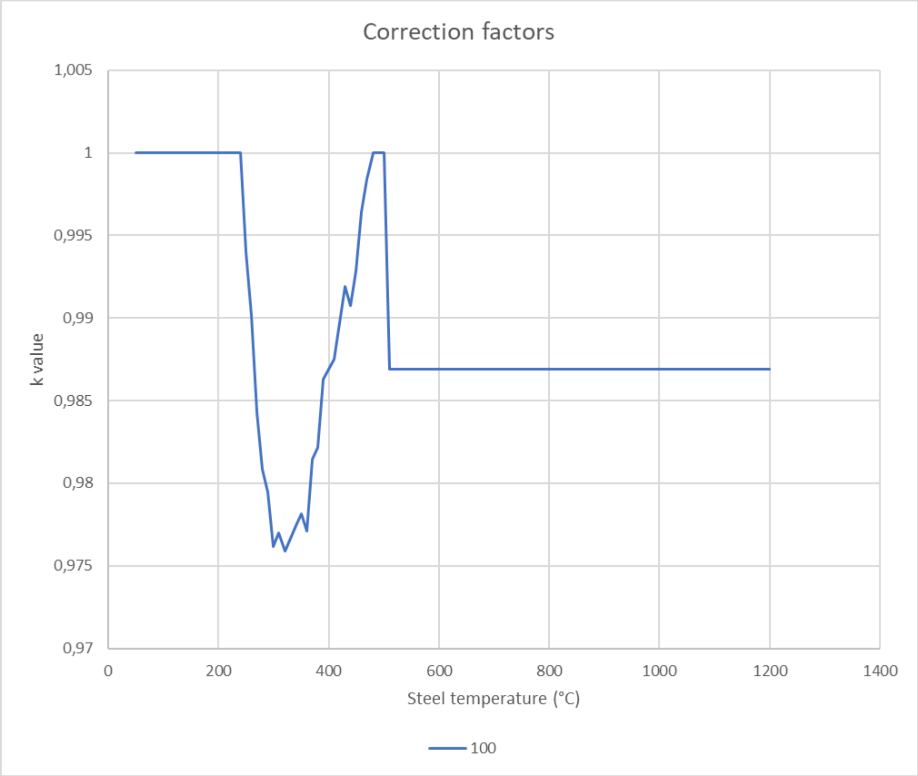
$$k = \frac{t_l}{t_1 \times \frac{S_1}{S} \times \frac{D}{D_1}}$$

where

t_l	is the time for the loaded section to reach the design temperature.
t_1	is the time for the reference section to reach the design temperature;
S	is the section factor of the loaded section;
S_1	is the section factor of the reference section;
D	is the protection thickness for the loaded section;
D_1	is the protection thickness for the reference section.

Where the stickability factor is greater than one, a stickability factor of one is used.





Assessment according to EN 13381-4

➢ Step 1 – Correction of data

- Calculation of corrected time to reach a steel temperature

Nr	Profile	Section factor (m^{-1})	Th (mm)	Uncorrected time (min) to reach the steel design temperature (°C)								
				350	400	450	500	550	600	650	700	750
SIC 11	IPE 200	224,7	100	43,8	47,5	51	54,8	59	63,7	69,3	75,3	83
SIC 7	HEA 220	143,3	100	73,5	82	90,5	99,7	109,8	120,5	132	145,2	163,3
SIC 4	HEA 300	115,1	100	95,5	106,8	118,8	131	144,5	158,8	174		
SIC 1	HEM 280	52,2	100	109,3	122,8	136,3	150,3	165				

Application of the correction factor corresponding to each temperature

Nr	Profile	Section factor (m^{-1})	Th (mm)	Corrected time (min) to reach the steel design temperature (°C)								
				350	400	450	500	550	600	650	700	750
SIC 11	IPE 200	224,7	100	42,9	46,9	50,6	54,8	58,2	62,8	68,4	74,3	81,9
SIC 7	HEA 220	143,3	100	71,9	80,9	89,9	99,7	108,4	118,9	130,3	143,3	161,2
SIC 4	HEA 300	115,1	100	93,4	105,4	118	131	142,6	156,8	171,7		
SIC 1	HEM 280	52,2	100	106,9	121,2	135,4	150,3	162,8				

Assessment according to EN 13381-4

➢ Step 2 & 3 – Thermal analysis – Linear regression

- Find the factors a_0 to a_7 of the formula $t = a_0 + a_1 d_p + a_2 \frac{d_p}{A_m/V} + a_3 \theta_a + a_4 d_p \theta_a + a_5 d_p \frac{\theta_a}{A_m/V} + a_6 \frac{\theta_a}{A_m/V} + a_7 \frac{1}{A_m/V}$

A7	A6	A5	A4	A3	A2	A1	A0
0	0	0,2260034	-0,000219	0	-60,49541	0	48,659009

- Calculate the predicted time to reach the steel temperature

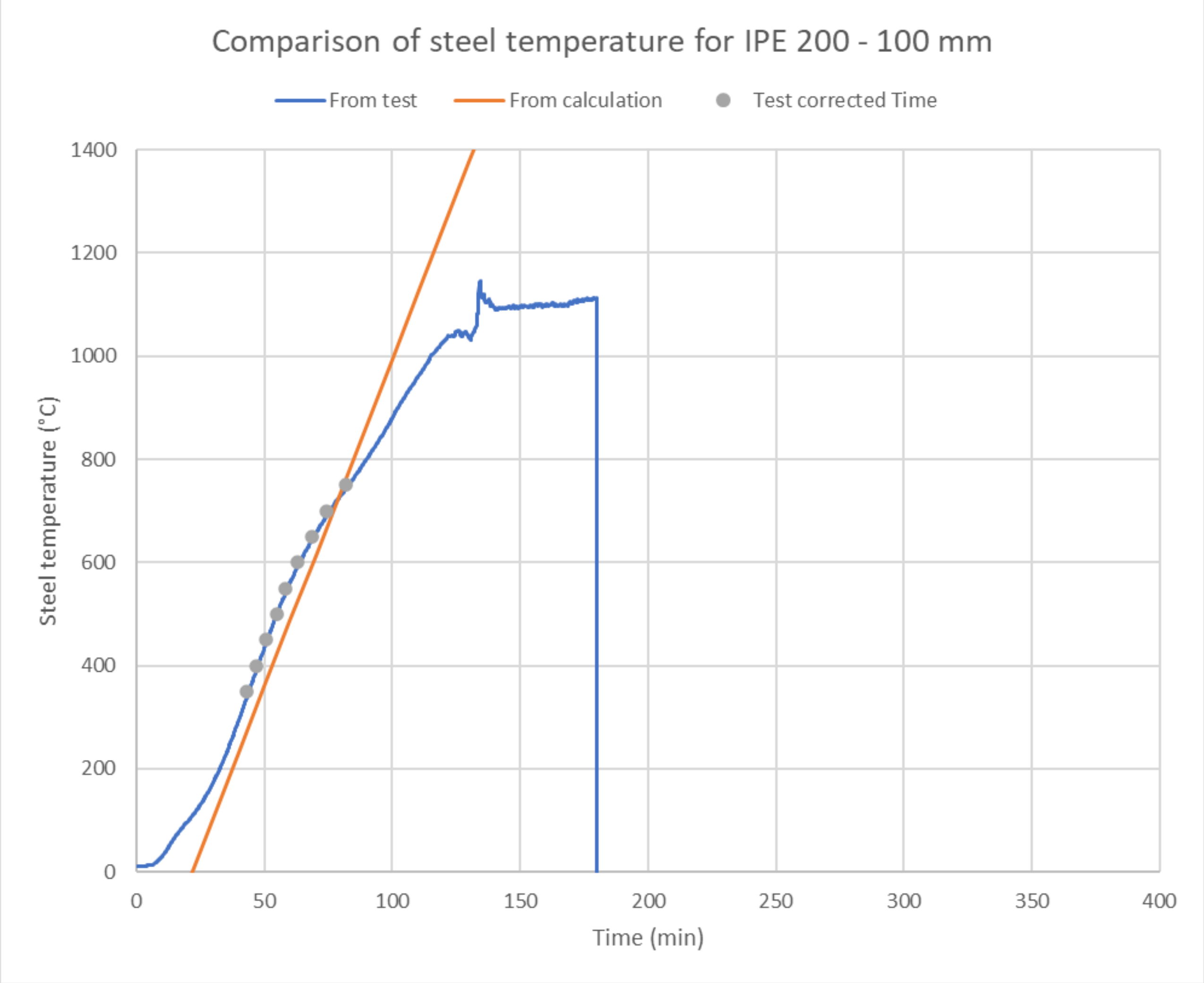
				Steel temperature (°C)								
Specimen	Profile	Section factor (m^{-1})	Protection thickness (mm)	Calculated time to reach the steel temperature (min)								
SIC 11	IPE 200	224,7	100	49,280843	53,215783	57,150723	61,085663	65,020603	68,955543	72,890484	76,825424	80,760364
SIC 7	HEA 220	143,3	100	53,984364	60,775975	67,567586	74,359196	81,150807	87,942418	94,734029	101,52564	108,31725
SIC 4	HEA 300	115,1	100	57,165451	65,889087	74,612722	83,336357	92,059992	100,78363	109,50726	118,2309	126,95453
SIC 1	HEM 280	52,2	100	76,64383	97,197604	117,75138	138,30515	158,85893	179,4127	199,96647	220,52025	241,07402

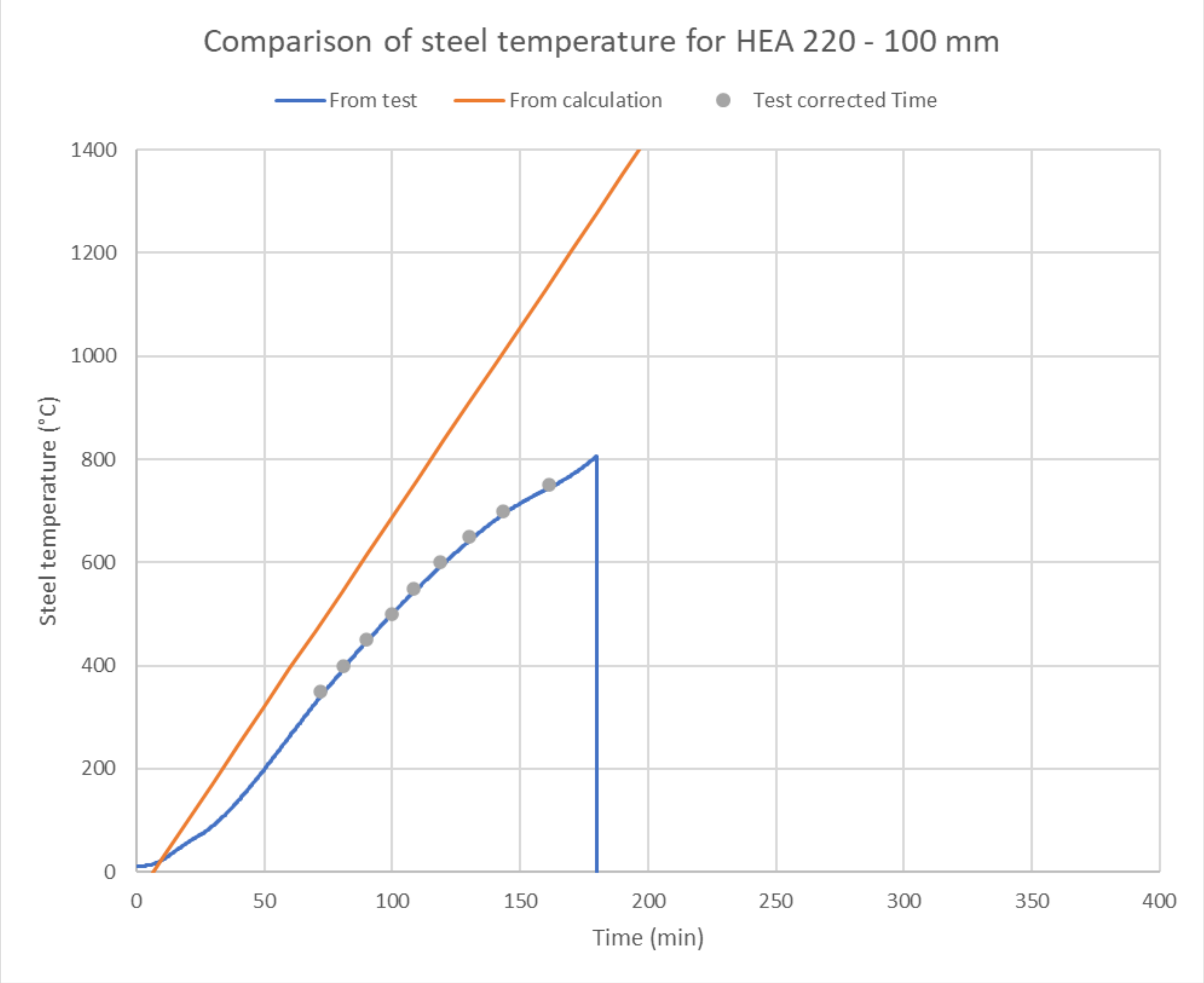
- Respect of the acceptability criteria

ACCEPTABILITY OF ANALYSIS			
Criterion	Description	Value	Result
13.5 a)	Predicted time for each element ≤ 15% larger than corrected time	14,94 %	PASSED
13.5 b)	Mean value of all percentage differences < 0%	-16,21 %	PASSED
13.5 c)	Maximum of 30% of values > 0%	26,7 %	PASSED

Assessment according to EN 13381-4

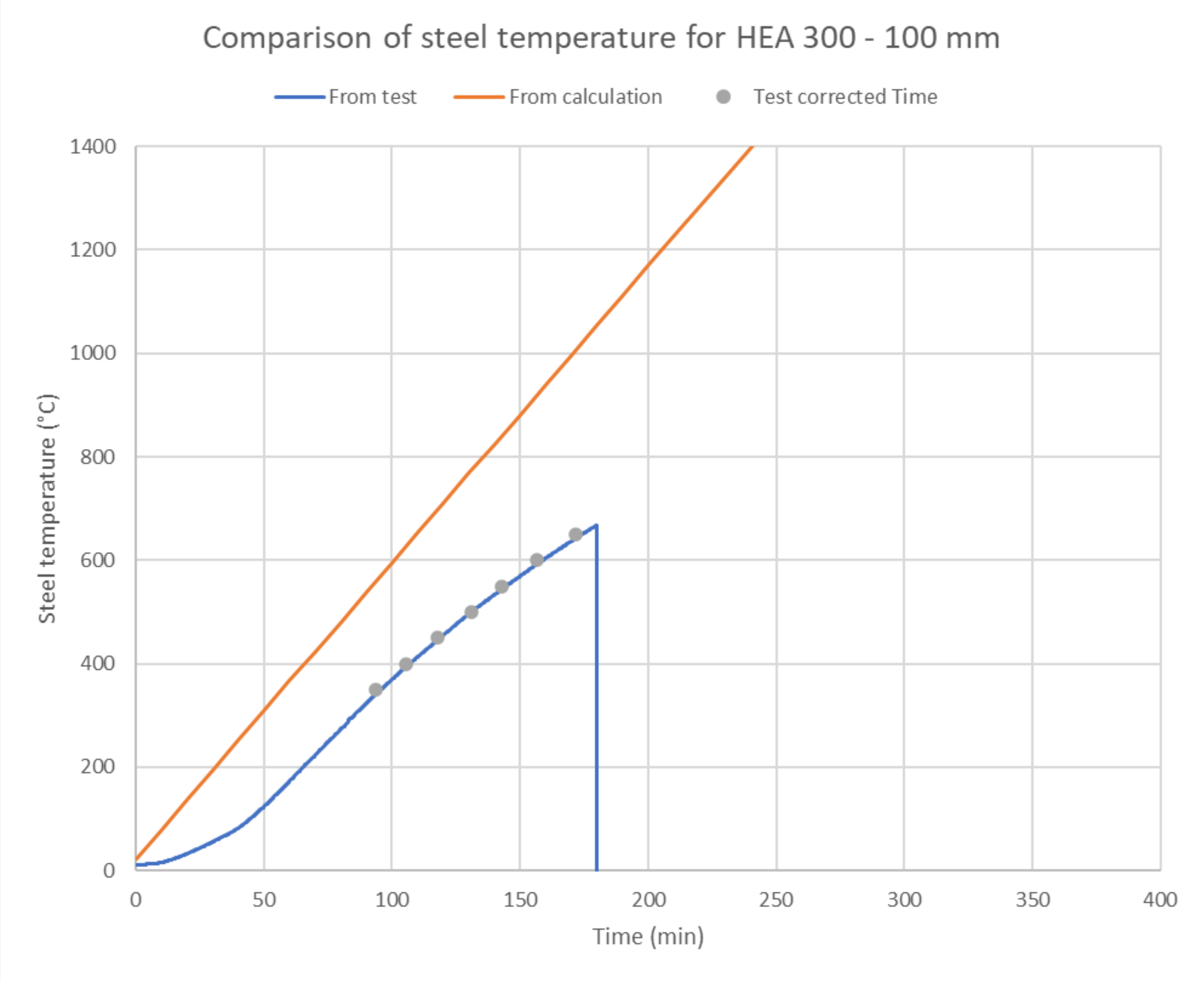
➢ Step 2 – Thermal analysis – Linear regression

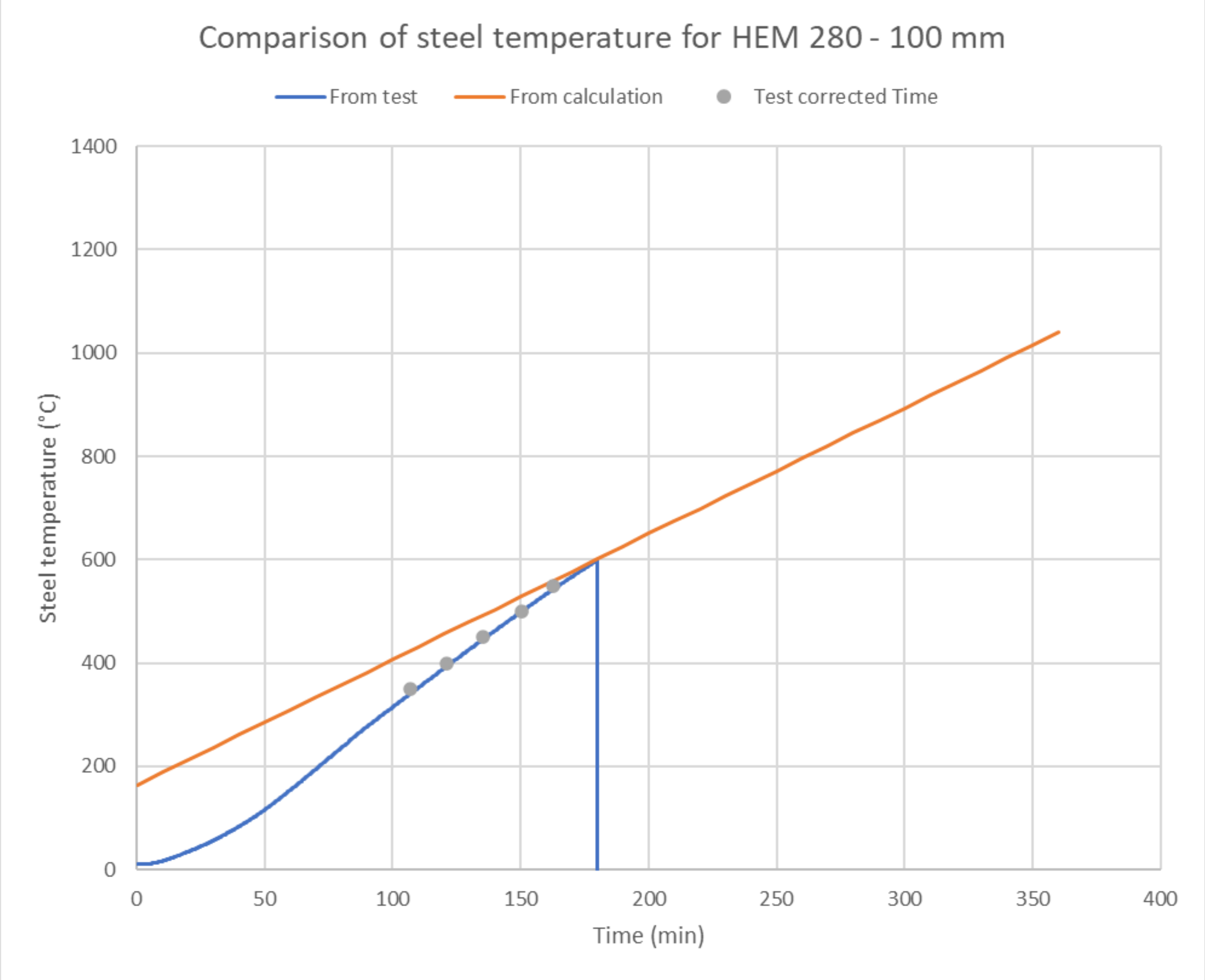




Assessment according to EN 13381-4

➢ Step 2 – Thermal analysis – Linear regression





Assessment according to EN 13381-4

➢ Step 2 & 3 – Thermal analysis – Variable thermal conductivities

- Find the lambdas values based on formula $\Delta\theta_{a,t}=\left[\frac{\lambda_{p,t}/d_p}{c_a\rho_a}\times\frac{A_m}{V}\times\left(\frac{1}{1+\phi/3}\right)\times(\theta_t-\theta_{a,t})\Delta t\right]-\left[\left(e^{\phi/10}-1\right)\Delta\theta_t\right]$

Temperature range	from	0	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
	to	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000	1050
λ		102,8	9,461	5,458	3,527	2,186	0,325	0,331	0,422	0,375	0,455	0,628	0,822	0,949	1,061	1,145	1,216	1,354	2,057	2,107	3,135	3,135

- Calculate the predicted time to reach the steel temperature

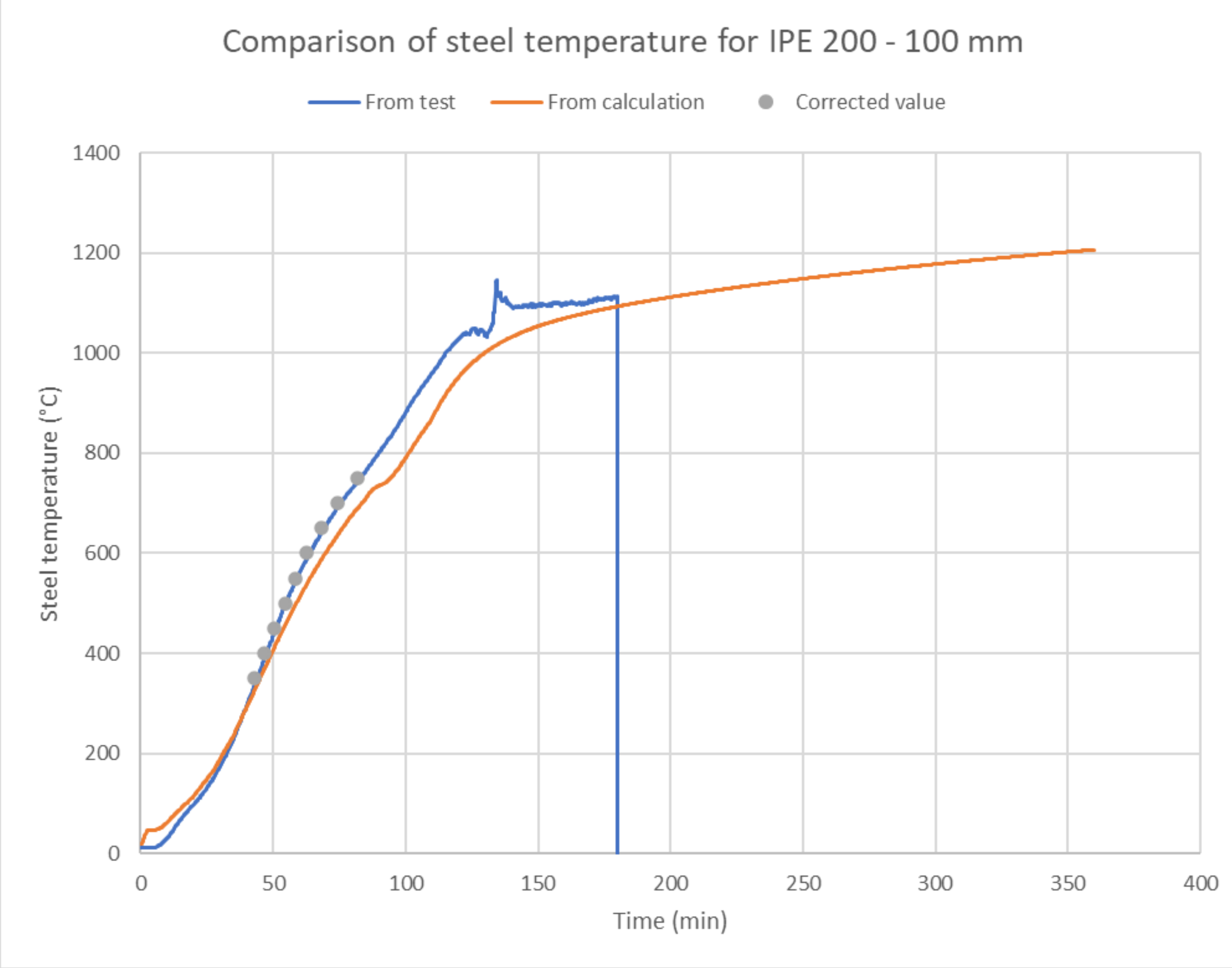
				Steel temperature (°C)								
Specimen	Profile	Shape factor (m^{-1})	Protection thickness (mm)	Calculated time to reach the steel temperature (min)								
SIC 11	IPE 200	224,7	100	45	49,3333	53,8333	58,6667	64	69,6667	76	83,5	94,1667
SIC 7	HEA 220	143,3	100	55,5	61,1667	67,1667	73,3333	80,1667	87,8333	95,8333	104	118,167
SIC 4	HEA 300	115,1	100	62,1667	68,6667	75,3333	82,6667	90,5	99	108,167	116,667	133
SIC 1	HEM 280	52,2	100	98,8333	109,833	121,667	133,833	147	161	172,333	185,333	213,667

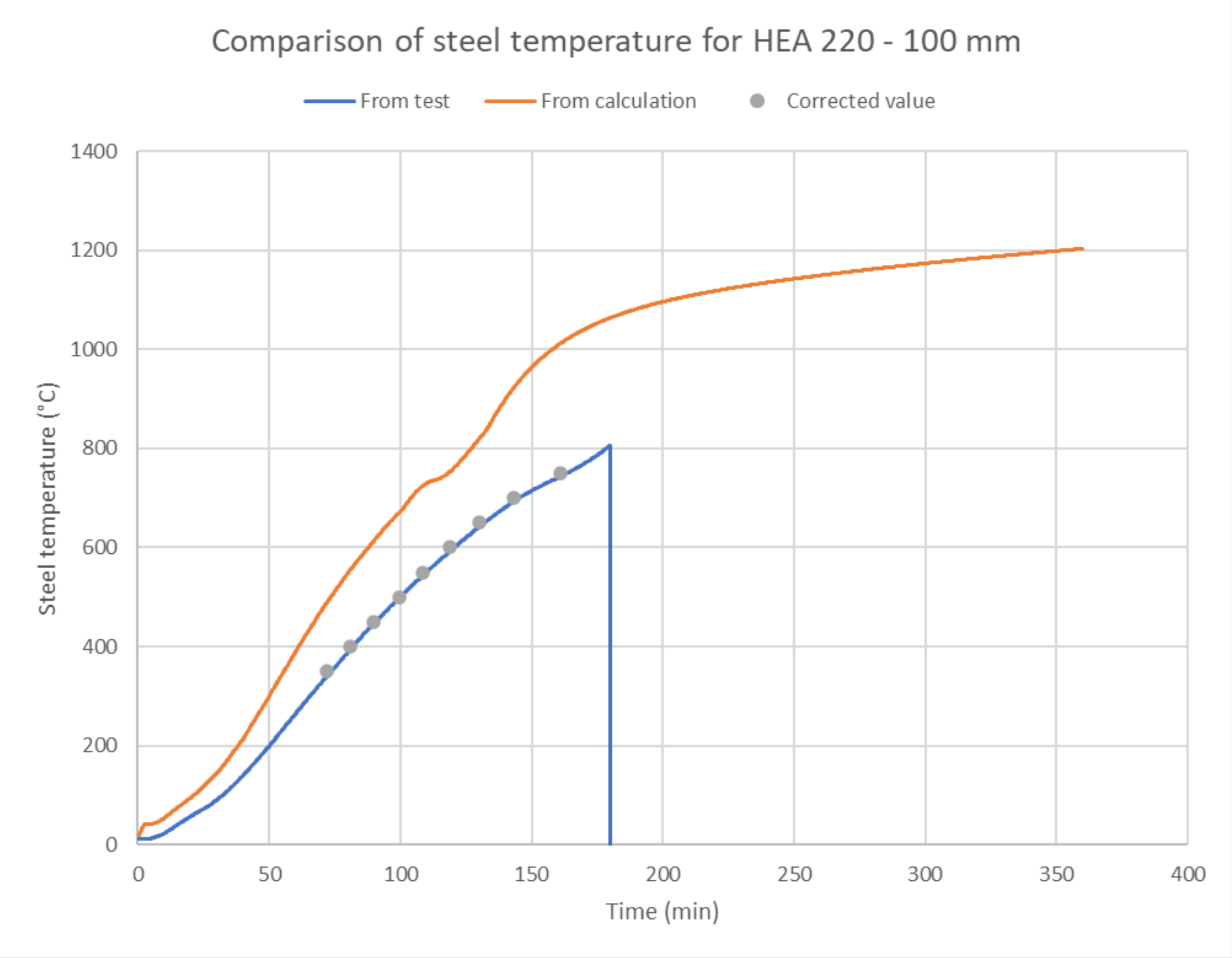
- Respect of the acceptability criteria

ACCEPTABILITY OF ANALYSIS			
Criterion	Description	Value	Result
13.5 a)	Predicted time for each element ≤ 15% larger than corrected time	14,96 %	PASSED
13.5 b)	Mean value of all percentage differences < 0%	-14,95 %	PASSED
13.5 c)	Maximum of 30% of values > 0%	30,0 %	PASSED

Assessment according to EN 13381-4

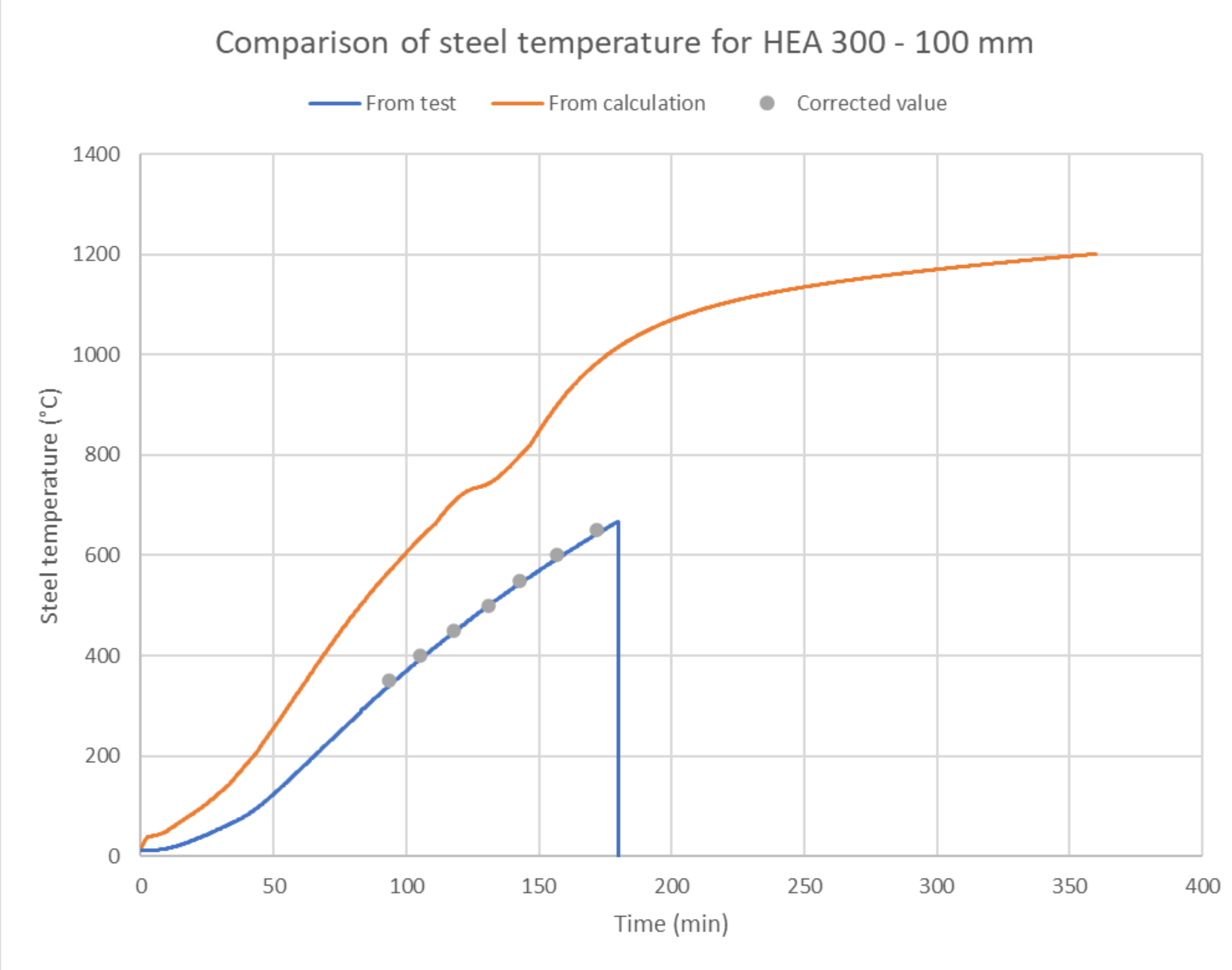
➢ Step 2 – Thermal analysis – Variable thermal conductivities

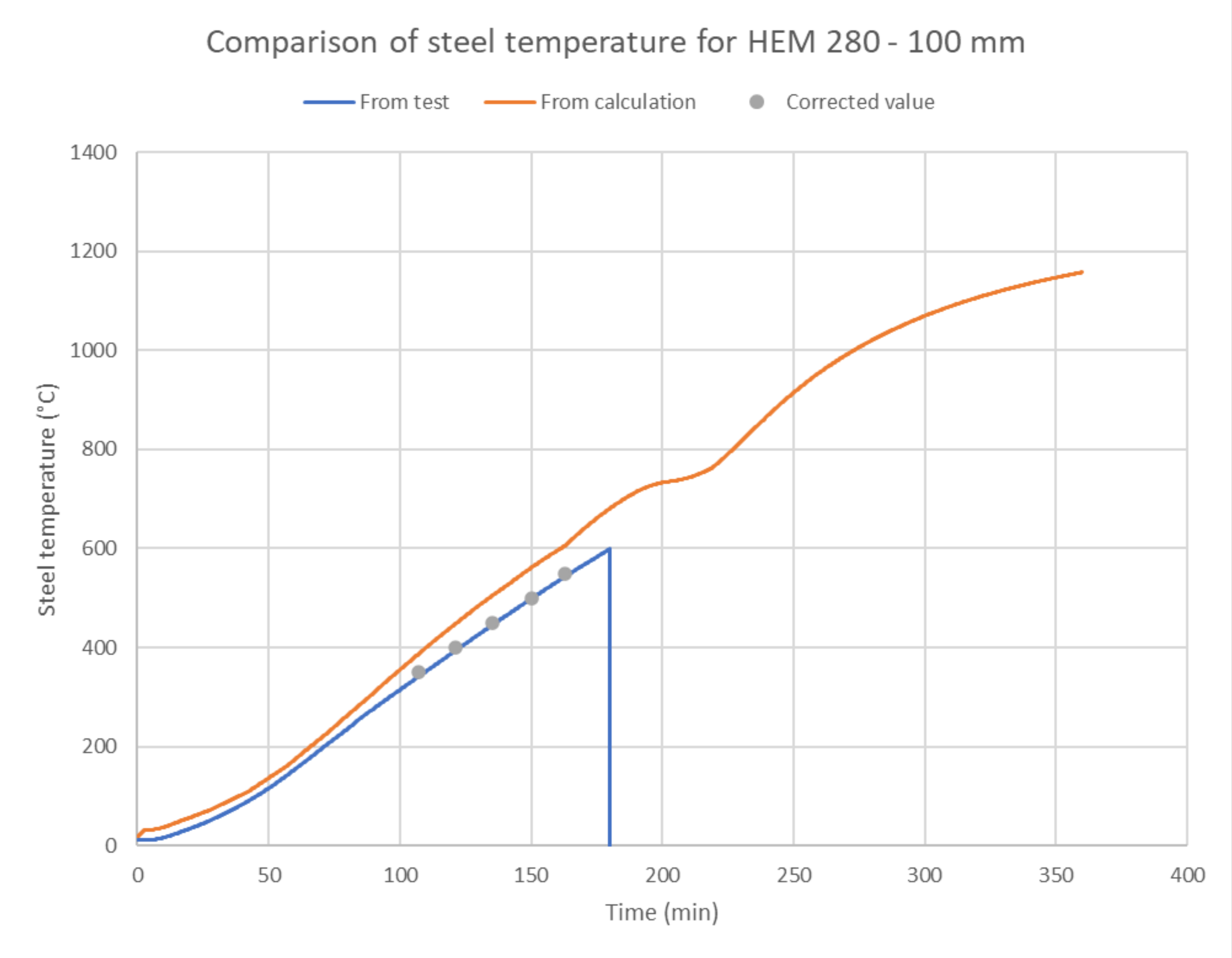




Assessment according to EN 13381-4

➢ Step 2 – Thermal analysis – Variable thermal conductivities





Assessment according to EN 13381-4

- **The linear regression approach was selected:**
  - The results of each method were not so different
  - This method seems to be the most used in all fire laboratories in Europe
  - Despite the variable thermal conductivity approach has more common points with the Eurocode 3 part 2, EN 1993-1-2

- **Requirement thickness of protection to apply, depending on the fire duration, the section factor and the steel critical temperature, can be calculated:**

$$t = a_0 + a_1 d_p + a_2 \frac{d_p}{A_m/V} + a_3\theta_a + a_4 d_p \theta_a + a_5 d_p \frac{\theta_a}{A_m/V} + a_6 \frac{\theta_a}{A_m/V} + a_7 \frac{1}{A_m/V}$$

→

$$d_p = \frac{t - a_0 - a_3\theta_a - \left(\frac{a_6\theta_a}{A_m/V}\right) - \left(\frac{a_7}{A_m/V}\right)}{a_1 + a_4\theta_a + \left(\frac{a_2}{A_m/V}\right) + \left(\frac{a_5\theta_a}{A_m/V}\right)}$$

Assessment according to EN 13381-4

➢ R15 & R30

With linear regression method									
Section factor (m^{-1})	Minimum required thickness to reach R15 & R30 (mm)								
	Standard steel temperature (°C)								
	350	400	450	500	550	600	650	700	750
≤ 47	100	100	100	100	100	100	100	100	100
50	100	100	100	100	100	100	100	100	100
60	100	100	100	100	100	100	100	100	100
70	100	100	100	100	100	100	100	100	100
80	100	100	100	100	100	100	100	100	100
90	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
110	100	100	100	100	100	100	100	100	100
120	100	100	100	100	100	100	100	100	100
130	100	100	100	100	100	100	100	100	100
140	100	100	100	100	100	100	100	100	100
150	100	100	100	100	100	100	100	100	100
160	100	100	100	100	100	100	100	100	100
170	100	100	100	100	100	100	100	100	100
180	100	100	100	100	100	100	100	100	100
190	100	100	100	100	100	100	100	100	100
200	100	100	100	100	100	100	100	100	100
210	100	100	100	100	100	100	100	100	100
220	100	100	100	100	100	100	100	100	100
230	100	100	100	100	100	100	100	100	100
240	100	100	100	100	100	100	100	100	100
247	100	100	100	100	100	100	100	100	100

➢ R45

With linear regression method									
Section factor (m^{-1})	Minimum required thickness to reach R45 (mm)								
	Standard steel temperature (°C)								
	350	400	450	500	550	600	650	700	750
≤ 47	100	100	100	100	100	100	100	100	100
50	100	100	100	100	100	100	100	100	100
60	100	100	100	100	100	100	100	100	100
70	100	100	100	100	100	100	100	100	100
80	100	100	100	100	100	100	100	100	100
90	100	100	100	100	100	100	100	100	100
100	100	100	100	100	100	100	100	100	100
110	100	100	100	100	100	100	100	100	100
120	100	100	100	100	100	100	100	100	100
130	100	100	100	100	100	100	100	100	100
140	100	100	100	100	100	100	100	100	100
150	100	100	100	100	100	100	100	100	100
160	100	100	100	100	100	100	100	100	100
170	100	100	100	100	100	100	100	100	100
180	100	100	100	100	100	100	100	100	100
190	100	100	100	100	100	100	100	100	100
200	100	100	100	100	100	100	100	100	100
210	100	100	100	100	100	100	100	100	100
220	100	100	100	100	100	100	100	100	100
230	100	100	100	100	100	100	100	100	100
240	100	100	100	100	100	100	100	100	100
247	100	100	100	100	100	100	100	100	100

Assessment according to EN 13381-4

➢ R60

With linear regression method

Section factor (m^{-1})	Minimum required thickness to reach R60 (mm) – Standard steel temperature (°C)								
	350	400	450	500	550	600	650	700	750
≤ 47	100	100	100	100	100	100	100	100	100
50	100	100	100	100	100	100	100	100	100
60	100	100	100	100	100	100	100	100	100
70	100	100	100	100	100	100	100	100	100
80	100	100	100	100	100	100	100	100	100
90	100	100	100	100	100	100	100	100	100
100	-	100	100	100	100	100	100	100	100
110	-	100	100	100	100	100	100	100	100
120	-	100	100	100	100	100	100	100	100
130	-	100	100	100	100	100	100	100	100
140	-	100	100	100	100	100	100	100	100
150	-	-	100	100	100	100	100	100	100
160	-	-	100	100	100	100	100	100	100
170	-	-	100	100	100	100	100	100	100
180	-	-	100	100	100	100	100	100	100
190	-	-	100	100	100	100	100	100	100
200	-	-	-	100	100	100	100	100	100
210	-	-	-	100	100	100	100	100	100
220	-	-	-	100	100	100	100	100	100
230	-	-	-	100	100	100	100	100	100
240	-	-	-	-	100	100	100	100	100
247	-	-	-	-	100	100	100	100	100

➢ R90

With linear regression method

Section factor (m^{-1})	Minimum required thickness to reach R90 (mm) – Standard steel temperature (°C)								
	350	400	450	500	550	600	650	700	750
≤ 47	-	100	100	100	100	100	100	100	100
50	-	100	100	100	100	100	100	100	100
60	-	-	100	100	100	100	100	100	100
70	-	-	100	100	100	100	100	100	100
80	-	-	100	100	100	100	100	100	100
90	-	-	-	100	100	100	100	100	100
100	-	-	-	100	100	100	100	100	100
110	-	-	-	-	100	100	100	100	100
120	-	-	-	-	-	100	100	100	100
130	-	-	-	-	-	100	100	100	100
140	-	-	-	-	-	-	100	100	100
150	-	-	-	-	-	-	100	100	100
160	-	-	-	-	-	-	-	100	100
170	-	-	-	-	-	-	-	100	100
180	-	-	-	-	-	-	-	-	100
190	-	-	-	-	-	-	-	-	-
200	-	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-	-
220	-	-	-	-	-	-	-	-	-
230	-	-	-	-	-	-	-	-	-
240	-	-	-	-	-	-	-	-	-
247	-	-	-	-	-	-	-	-	-

Assessment according to EN 13381-4

- **R120**

With linear regression method									
Section factor (m^{-1})	Minimum required thickness to reach R90 (mm)								
	Standard steel temperature (°C)								
	350	400	450	500	550	600	650	700	750
≤ 47	-	100	100	100	100	100	100	100	100
50	-	100	100	100	100	100	100	100	100
60	-	-	100	100	100	100	100	100	100
70	-	-	100	100	100	100	100	100	100
80	-	-	100	100	100	100	100	100	100
90	-	-	-	100	100	100	100	100	100
100	-	-	-	100	100	100	100	100	100
110	-	-	-	-	100	100	100	100	100
120	-	-	-	-	-	100	100	100	100
130	-	-	-	-	-	100	100	100	100
140	-	-	-	-	-	-	100	100	100
150	-	-	-	-	-	-	100	100	100
160	-	-	-	-	-	-	-	100	100
170	-	-	-	-	-	-	-	100	100
180	-	-	-	-	-	-	-	-	100
190	-	-	-	-	-	-	-	-	-
200	-	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-	-
220	-	-	-	-	-	-	-	-	-
230	-	-	-	-	-	-	-	-	-
240	-	-	-	-	-	-	-	-	-
247	-	-	-	-	-	-	-	-	-

Conclusion

- **The thermal analysis confirmed that the encasement system with sandwich panels tested provides an efficient fire protection of steel members.**
  - However, it is limited to the protection encasement system with 100 mm thick panels, because of suspicions that unforeseen shadow effects may have happened during the fire test on thicker panels.

- **Results of the undertaken assessment are valid for the following conditions:**
  - both three or four sided protections;
  - Steel section factor until 247 m-1;
  - Steel temperature ranging between 350 to 750°C;
  - Fire resistance rating ranging from R15 to R120;

- **For this protection system, a wider scope including thicker protection panels could be possible by performing additional fire resistance tests.**

L'ENVELOPPE MÉTALLIQUE DU BÂTIMENT
ASSOCIATION DES FABRICANTS DE PANNEAUX, PROFILS ET SYSTÈMES

JORISIDE
THE STEEL FUTURE

PAVUS
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