SIGGMA

Job title: **Chemfix CH+ with post-installed rebars**
Report title: **Evaluation of Fire Resistance**
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chemfix
TOTAL SERVICE

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1. INTRODUCTION

Chemfix Products LTD distributes the injection system Chemfix CH+ (Vinylester type), holding the ETA number ETA-14/0057 for post installed rebar.

Chemfix performed additional tests to high temperature at the Testing Material Laboratory of the Politecnico di Milano (Italy), as detailed in Chapter 4. No test was carried out by the Manufacturer.

In Europe no specific provision (nor standard or guideline) exists so far for the evaluation of the fire resistance of post-installed rebars.
Therefore, the scope of this expert report is the evaluation of the fire resistance according to a procedure agreed with the manufacturer, that is responsible for the declared performances.

Under no circumstances this report can be assumed as equivalent to a Product Specification or to a Design Report. The conformity of the suggested approach to each specific design situation shall be verified by the designer, under his sole responsibility.

2. REFERENCES AND SYMBOLS

2.1. References

[1] EOTA TR 023, Assessment of post-installed rebar connections (Edition November 2006)

[2] ETA-14/0057, European Technical Approval for Injection System Chemfix CH+

[3] EN 1992- 1-2, Eurocode 2 - Design of concrete structures, Part 1-2: General rules - Structural fire design

[4] UNI 9502, Analytical fire resistance assessment of reinforced concrete and prestressed concrete structural elements

[R1] Test report “Tensile load tests on Chemfix post-installed rebar subject to high temperature exposure”, by the Laboratory of Material Testing (Laboratorio Prove Materiali) of Politecnico di Milano (Italy)

3. DESCRIPTION OF THE BONDED ANCHORS

A detailed description of the anchor, its installation procedure, its factory production control its and manufacturing process is the documents provided by the manufacturer [2,R1].

4.TESTS

4.1 Miscellaneous

The test procedure is described in [R1].

The test programme was drawn up jointly with the manufacturer. Temperature tests were performed in two phases: ten stabilized temperature tests and ten constant load tests. In addition five reference tests were carried out at ambient temperature during the first testing phase.

The test program is summarized in table 4.1.

Table 4.1 - Temperature tests on CH+

Description	Concrete	Temperature	Φ12
Reference test	C20/25	normal	5
Stabilized temperature test	C20/25	60 °C	5
	C20/25	150 °C	5
Constant load test	C20/25	variable	10

The rebar used in the tests is a ribbed bar made of B450C carbon steel with a diameter equal to 12 mm.

5. DETERMINATION OF THE CHARACTERISTIC RESISTANCE

5.1 Assessment principle

The fire resistance of post-installed rebars is initially evaluated in terms of bond strength vs. temperature. It is assumed that the decay in the bond resistance is a function only of the maximum temperature reached in a given position of a reinforced concrete element, that is only indirectly a function of the fire duration.

From the results of the tension tests the average bond resistance is calculated according to [1], Equation (5.1).

$$f_{bm}^{t} = \frac{N_{u,m}}{\pi \cdot d \cdot l_v} \left(\frac{0.08}{f_R}\right)^{0,4} \tag{5.1}$$

with:

f^{t}_{bm} = average bond resistance in the test series;
$N_{u,m}$ = average value of the failure loads in the test series;
d = rebar diameter;
l_v = embedment length of the bar in the concrete.

A relative rib area of the rebar f_R = 0,08 is assumed.

If the average bond resistance f^{t}_{bm} determined according to Equation (5.1) reaches at least the required bond resistance $f_{req,bm}$ (10 N/mm²) then the post-installed rebar may be designed using the design value of the ultimate bond stress, f_{bd} = 2.3 N/mm² for ribbed bars according to Eurocode 2 for concrete strength class C20/25.

If the required bond resistance in C20/25 and/or C50/60 is not fulfilled, then the design bond strength f_{bd} shall be calculated accounting for a temperature reduction factor at increased temperatures.

The values of f^{t}_{bm} from tests are fitted by a power trend function according to the following equation:

$$f_{b,m}(\theta) = a \cdot \theta^{-b} \tag{5.2}$$

Where:

$f_{b,m}$ = average bond resistance at the temperature θ
θ = temperature of the bond
a, b = power fitting curve constants

Temperature reduction factor *K(θ)* is then determined as it follows:

$$k(\theta) = 1 \qquad for \quad 20°C \leq \theta \leq \theta_k \tag{5.3}$$

$$k(\theta) = \frac{f_{b,m}(\theta)}{(\frac{1,5}{k})\cdot \min(f_{b,m}(20\,°C); f_{bm}^{req})} \qquad for \quad \theta_k \leq \theta \leq \theta_{max} \tag{5.4}$$

Where:

$k(\theta)$ = temperature reduction factor;

k = factor for cracked concrete (1,0; 1,5);

$f_{b,m}(\theta)$ = average bond resistance at the temperature θ, calculated with Equation (5.2);

$f_{b,m}(20\,°C)$ = value of the fitting curve at 20°C;

f_{bm}^{req} = required bond strength in cold state (10 N/mm² for C20/25);

θ = temperature of the bond;

θ_k = temperature for which $f_{b,m}(\theta_k)$=10 N/mm^2;

θ_{max} = maximal temperature measured during the tests.

The factor *K(θ)* is a function of the temperature related to a specific fire duration and it is used to reduce the design reference value of the ultimate bond stress at 20°C temperature.

$$f_{bd}(\theta) = k(\theta) \cdot f_{bd(20°C)} \tag{5.5}$$

Where:

$f_{bd(20°C)}$ = 2,3 N/mm^2 for Φ12, Φ14 and Φ16 diameters (according to [2]);
= 1,6 N/mm^2 for Φ8 and Φ10 diameters (according to [2]).

5.2 Evaluation of the design bond strength

Based on the test results reported in [R1], Figure 5.1 reports the scattered average bond strengths as a function of the temperature. The values of test bond resistance f^{t}_{bm} are fitted with the power trend function (Equation 5.2) plotted in orange. The fitting curve is then cut-off at the maximal temperature measured during the tests and at bond resistance equal to 10 N/mm^2.

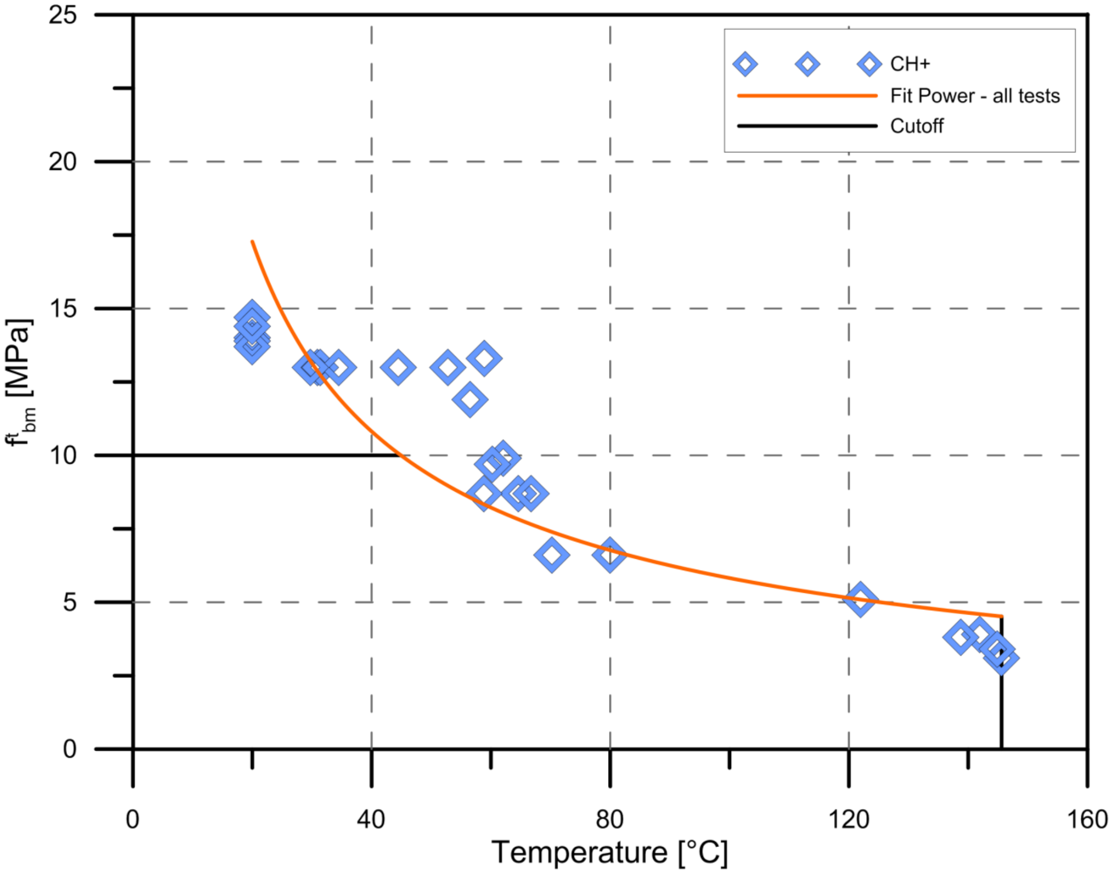


Figure 5.1 - CH+ average bond strength against temperature, fitted with power function

The fit returns the following values:
a = 130,828
b = -0,6758

As it can be noticed, the trend function overestimates the values of bond resistance measured during tests at high temperature.

For this reason a new trend function is calculated forcing the curve to pass through two significant points:

1. the bond strength value from a test result at high temperature:

$$\theta = 138.8\,°C\ ;\ f^{t}_{bm} = 3.8\ N/mm^2$$

2. the interpolated value of bond strengths at glass transition temperature:

$$\theta = 45.7\,°C\quad ;\ f^{t}_{bm} = 9.9\ N/mm^2$$

Figure 5.2 reports the new power trend function plotted in green. As it can be noticed this curve fits the test results at high temperature and so it allows a more realistic assessment of CH+ performance at high temperature.

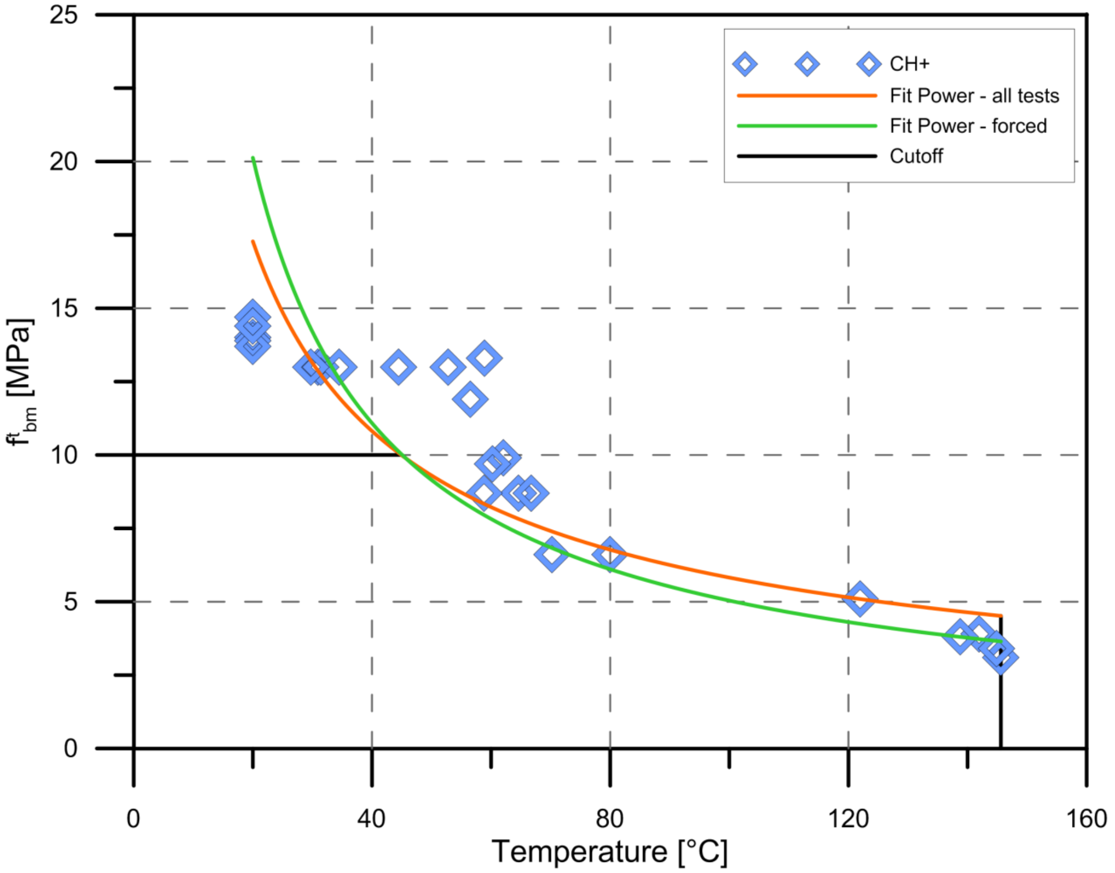


Figure 5.2 - CH+ average bond strength against temperature, fitted with new power function

The new fit returns the following values:
a = 265,0416
b = -0,8605

Figure 5.3 reports the plotted values of the temperature reduction factor $K(\theta)$ evaluated according to Equation (5.4) and to the assumed power law. The design values of the ultimate bond stress as a function of the temperature are finally reported.

ϑ [°C]	K(ϑ) [-]	$f_{bd}(\vartheta)$ Φ12,Φ14,Φ16 [Mpa]	$f_{bd}(\vartheta)$ Φ8,Φ10 [Mpa]
20,00	1,00	2,30	1,60
25,00	1,00	2,30	1,60
30,00	1,00	2,30	1,60
35,00	1,00	2,30	1,60
40,00	1,00	2,30	1,60
45,00	1,00	2,30	1,60
50,00	0,91	2,10	1,46
55,00	0,84	1,94	1,35
60,00	0,78	1,80	1,25
65,00	0,73	1,68	1,17
70,00	0,68	1,58	1,10
75,00	0,65	1,48	1,03
80,00	0,61	1,40	0,98
85,00	0,58	1,33	0,93
90,00	0,55	1,27	0,88
95,00	0,53	1,21	0,84
100,00	0,50	1,16	0,81
105,00	0,48	1,11	0,77
110,00	0,46	1,07	0,74
115,00	0,45	1,03	0,71
120,00	0,43	0,99	0,69
125,00	0,42	0,96	0,67
130,00	0,40	0,92	0,64
135,00	0,39	0,90	0,62
140,00	0,38	0,87	0,60
145,00	0,37	0,84	0,59
145,60	0,36	0,84	0,58

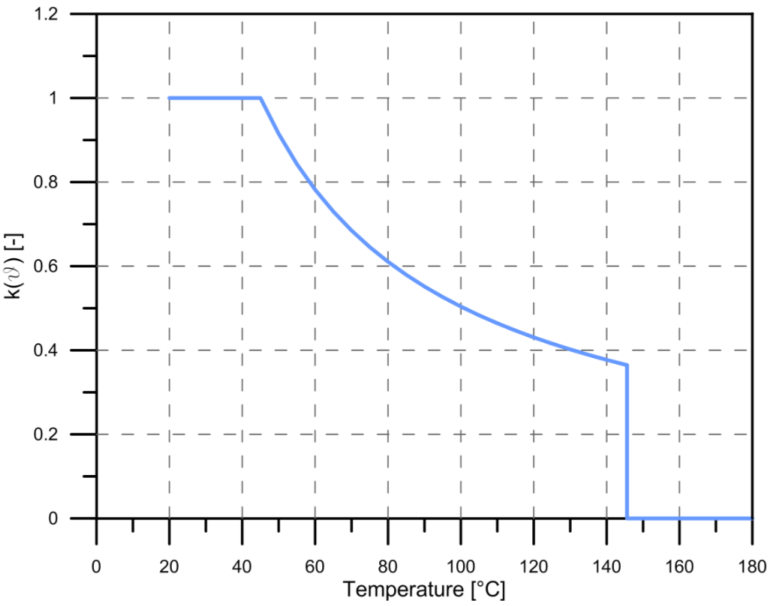


Figure 5.3 - Temperature reduction factor k(θ) and ultimate bond strength design values of CH+

The reduction factor k(θ) and consequently the bond strength are set equal to zero for temperatures higher than the maximal measured temperature during the tests ($\theta_{max} = 145.6\,°C$), as no extrapolation on test temperature is possible.

6. RESISTANCE TO FIRE FOR WALL TO SLAB CONNECTION

6.1 Temperature profiles

Table 6.1 reports the temperature profiles that can be assumed for a concrete slab according to [4] for different fire durations (from 30’ to 240’) as a function of the distance ‘e’ (in *cm*) from the exposed surfaces for calcareous aggregate.

Table 6.1 – Temperature profiles for a slab for different fire duration (according to [4])

e	30	60	90	120	180	240
0	661	824	907	963	1039	1092
1	482	661	758	824	914	977
2	326	490	595	669	770	840
3	222	370	466	541	648	723
3,5	191	325	415	486	594	671
4	161	286	372	439	544	622
4,5	135	252	334	398	498	577
5	114	223	301	362	458	534
6	82	175	246	302	390	460
7	60	138	202	254	335	399
8	45	109	166	213	289	350
9	35	86	136	180	251	308
10	29	69	112	152	218	271

The value reported in Table 6.1 are subsequently fitted by an exponential law and extrapolated to account for a distance from the surface greater than 10 cm.

Figure 6.1 reports the obtained temperature profiles.

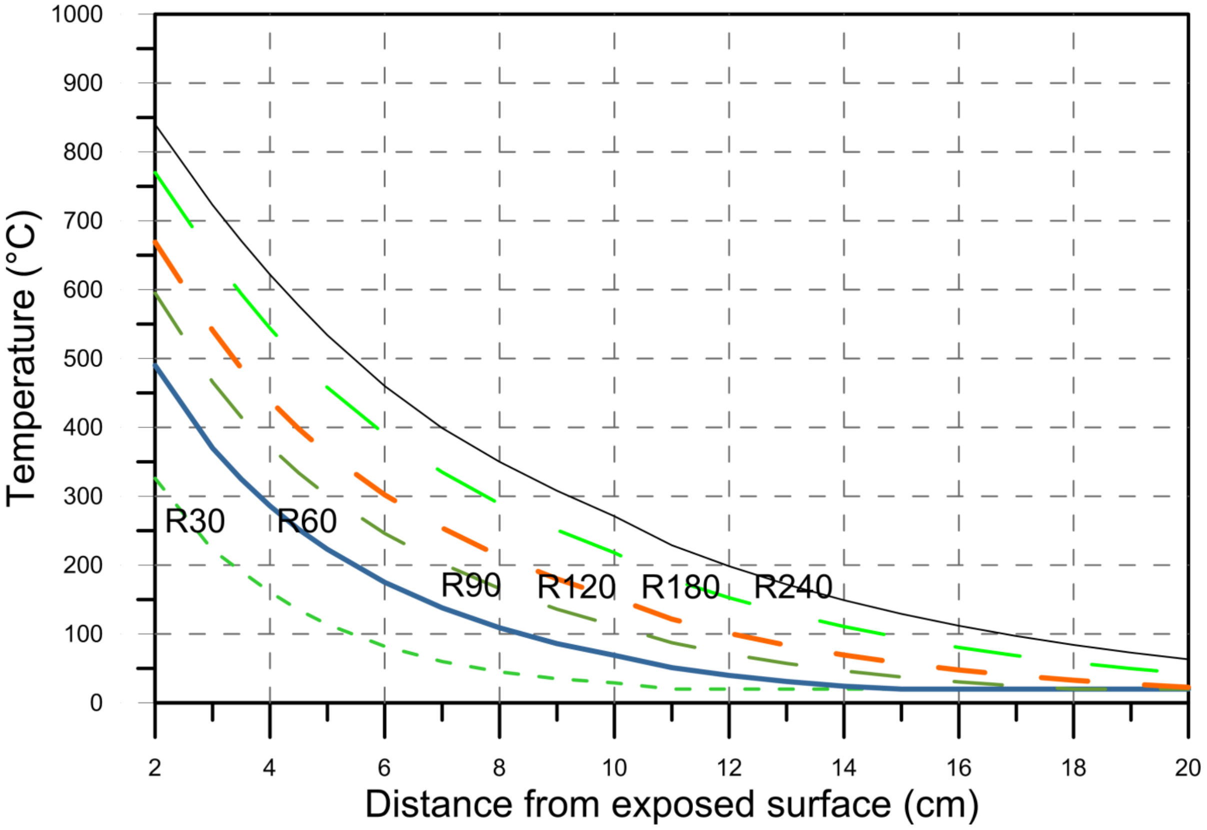


Figure 6.1 – Extrapolated temperature profiles for a slab for different fire durations

The conformity of the reported profiles to each specific design situation shall be verified by the designer.

6.2 Evaluation of design bond resistance

The values of design bond resistance are evaluated for CH+ as a function of the fire duration and of the distance of the rebar from the exposed surface. The results are reported in Table 6.2 for rebar diameters Φ8 and Φ10 and in Table 6.3 for rebar diameters Φ12, Φ14 and Φ16.

Table 6.2 – Design bond resistance for a slab for different fire duration – Φ8 and Φ10

Fire duration						**Distance drom the edge e**
R30	**R60**	**R90**	**R120**	**R180**	**R240**	
N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	mm
0,6						45
0,7						50
0,7						55
1,0						60
1,0						65
1,3	0,6					70
1,3	0,6					75
1,6	0,8					80
	0,8					85
	0,9	0,6				90
	0,9	0,6				95
	1,2	0,7				100
	1,2	0,7				105
	1,5	0,9	0,7			110
	1,5	0,9	0,7			115
	1,6	1,1	0,8			120
		1,1	0,8			125
		1,3	1,0	0,6		130
		1,3	1,0	0,6		135
		1,6	1,2	0,7		140
			1,2	0,7		145
			1,3	0,9	0,7	150
			1,3	0,9	0,7	155
			1,6	1,0	0,7	160
				1,0	0,7	165
				1,2	0,8	170
				1,2	0,8	175
				1,3	1,0	180
				1,3	1,0	185
				1,6	1,1	190
					1,1	195
					1,3	200
					1,3	205
					1,5	210
					1,5	215
					1,6	220

Table 6.3 – Design bond resistance for a slab for different fire duration – Φ12, Φ14 and Φ16

Fire duration						**Distance drom the edge e**
R30	**R60**	**R90**	**R120**	**R180**	**R240**	
N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	N/mm^2	mm
0,9						45
1,1						50
1,1						55
1,4						60
1,4						65
1,8	0,9					70
1,8	0,9					75
2,3	1,1					80
	1,1					85
	1,3	0,9				90
	1,3	0,9				95
	1,7	1,1				100
	1,7	1,1				105
	2,1	1,3	1,0			110
	2,1	1,3	1,0			115
	2,3	1,6	1,2			120
		1,6	1,2			125
		1,9	1,4	0,9		130
		1,9	1,4	0,9		135
		2,3	1,7	1,1		140
			1,7	1,1		145
			1,9	1,3	1,0	150
			1,9	1,3	1,0	155
			2,3	1,4	1,1	160
				1,4	1,1	165
				1,7	1,2	170
				1,7	1,2	175
				1,9	1,4	180
				1,9	1,4	185
				2,3	1,6	190
					1,6	195
					1,8	200
					1,8	205
					2,1	210
					2,1	215
					2,3	220

6.3 Evaluation of basic anchorage length

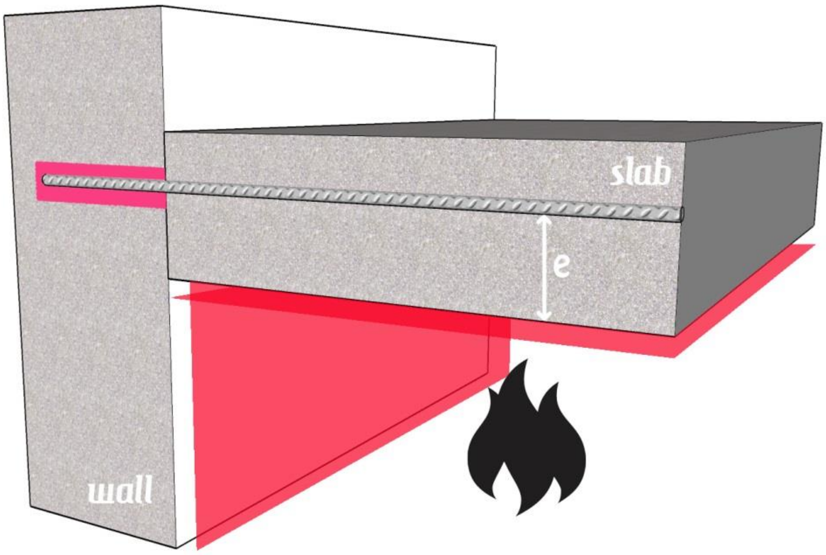
Finally, as a function of the fire duration and of the distance of the rebar from the exposed surface, the basic anchorage length l_b [3] is evaluated for CH+.

The results are reported in Annex 1. The following information are reported:

- Φ: diameter of the rebar;
- F_{Rd}: maximum force that can be transmitted by the rebar at ambient temperature, assuming a steel class B450C;
- e: distance from the exposed surface;
- l_b: basic anchorage length as a function of the fire durations F30, F60, F90, F120, F180 and F240. The basic anchorage length at ambient temperature F0 is also reported.

For values of the force to be transferred lower than the reported one, the basic anchorage lengths can be linearly reduced.

ANNEX 1



Wall to slab connection – CH+ (all the distances are in mm)

Rebar	**F_{Rd}**	**Distance**	**R0**	**R30**	**R60**	**R90**	**R120**	**R180**	**R240**
ϕ (mm)	**(kN)**	**e (mm)**	**basic anchorage length l_b**						
8	19,7	45	489	1257					
		70		625	1257				
		90		489	844	1257			
		110		489	535	844	1136		
		130		489	489	580	801	1217	
		150		489	489	489	580	887	1176
		170		489	489	489	489	670	929
		190		489	489	489	489	489	714
		210		489	489	489	489	489	535
		220		489	489	489	489	489	489

Rebar	**F_{Rd}**	**Distance**	**R0**	**R30**	**R60**	**R90**	**R120**	**R180**	**R240**
ϕ (mm)	**(kN)**	**e (mm)**	**basic anchorage length l_b**						
10	30,7	45	611	1571					
		70		782	1571				
		90		611	1055	1571			
		110		611	668	1055	1420		
		130		611	611	725	1001	1521	
		150		611	611	611	725	1108	1470
		170		611	611	611	611	838	1161
		190		611	611	611	611	611	893
		210		611	611	611	611	611	668
		220		611	611	611	611	611	611

Rebar	**F_{Rd}**	**Distance**	**R0**	**R30**	**R60**	**R90**	**R120**	**R180**	**R240**
ϕ (mm)	**(kN)**	**e (mm)**	**basic anchorage length l_b**						
12	44,2	45	510	1311					
		70		653	1311				
		90		510	881	1311			
		110		510	558	881	1185		
		130		510	510	606	836	1270	
		150		510	510	510	606	925	1227
		170		510	510	510	510	699	969
		190		510	510	510	510	510	745
		210		510	510	510	510	510	558
		220		510	510	510	510	510	510

Rebar	**F_{Rd}**	**Distance**	**R0**	**R30**	**R60**	**R90**	**R120**	**R180**	**R240**
ϕ (mm)	**(kN)**	**e (mm)**	**basic anchorage length l_b**						
14	60,2	45	595	1530					
		70		761	1530				
		90		595	1028	1530			
		110		595	651	1028	1383		
		130		595	595	707	975	1481	
		150		595	595	595	707	1079	1432
		170		595	595	595	595	816	1131
		190		595	595	595	595	595	869
		210		595	595	595	595	595	651
		220		595	595	595	595	595	595

Rebar	**F_{Rd}**	**Distance**	**R0**	**R30**	**R60**	**R90**	**R120**	**R180**	**R240**
ϕ (mm)	**(kN)**	**e (mm)**	**basic anchorage length l_b**						
16	78,6	45	681	1749					
		70		870	1749				
		90		681	1174	1749			
		110		681	744	1174	1580		
		130		681	681	807	1115	1693	
		150		681	681	681	807	1234	1637
		170		681	681	681	681	932	1292
		190		681	681	681	681	681	994
		210		681	681	681	681	681	744
		220		681	681	681	681	681	681