FIRE PROTECTION USING FireCem

Professor Faris Ali, BEng (Hons), MSc, PhD, PGCUT, FICE
FireSERT, School of the Built Environment, University of Ulster, United Kingdom

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1. Assessment of FireCem Properties For Fire Protection

1.1. Introduction

Passive fire protection aims to control and reduce the effect of fire using protection elements that are integrated into the building structure. Passive fire protection materials can significantly increase the fire resistance of structures (see Figure 1). The main advantage of passive fire protection is that it does not require manual or automatic activation as is the case with active fire control systems. There are several forms of passive fire protection which are described in the following paragraphs[1,2]:

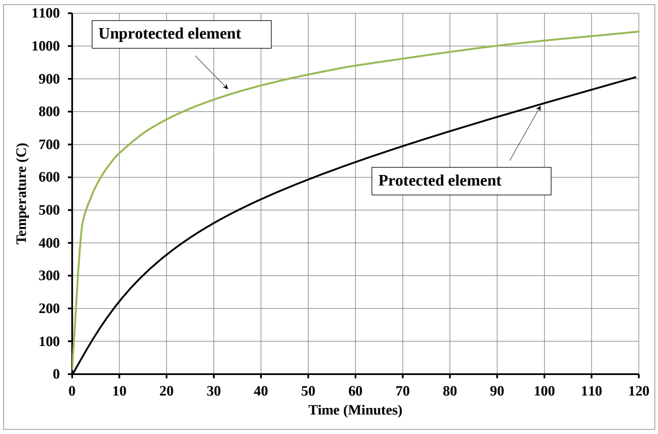

Figure 1. Effect of fire protection on reducing temperatures development[1]

Fire Insulation Boards

This is the most common type of passive fire protection where boards are manufactured mainly from Calcium Silicate (may include other ingredients). Fire insulation boards are manufactured in different dimensions, thicknesses and properties to provide the required level of fire resistance. Fire insulation boards can significantly reduce the fire impact on the protected element and keep the temperature low at the protected element particularly at the early stages of the fire as shown in Figure 1. However, the boards can be expensive and they take a relatively long time to fit using glue or fasteners. Flat fire insulation boards are problematic in curved concrete tunnels as they cannot be fitted to the linings of curved tunnels. However, a new type of flexible fire insulation board is now available for use on curved surfaces[2].

Spray-on insulation materials

This passive protection system involves spraying fire protection materials on the structural element. This system is cheaper than fire insulation boards and needs less time for application. However, it can be messy and in some cases its final look may not be suitable for conventional decoration. Therefore, it is mostly used in car parks or in industrial buildings. This type of protection is mainly used in steel structures and involves spraying a soft material on the element surface. The soft material dries out and forms an external solid protective layer. In recent years spray-on fire protection has been utilised for the protection of concrete tunnels using specially designed spray guns.

Intumescent material

This is one of the most recently developed passive protection systems where the fire protection is provided by painting the steel element with one or several coats of the intumescent paint to provide the required fire resistance. When exposed to fire, the intumescent paint converts into an insulating multi-cellular char. This char has low heat conductivity and forms an insulation layer. This method is expensive in comparison to other passive fire protection systems. However, it is easy to apply and provides a good decorative finish to the protected element.

1.2. Passive Fire Protection Using FireCem

A new type of passive fire protection material, FireCem has been developed recently by PowerCem Technologies. The FireCemX and FireCemY use materials which include RoadCem additives. They also contain Loam Clay (USCS classification: CL Lean Clay) and cement in their ingredients. Full details of the ingredients of the FireCemX and FireCemY (provided by PowerCem Technologies) are shown in Appendices A and B. Recent tests[3] have shown that FireCemX and FireCemY have unique fire resistance and fire protection properties.

This study represents an assessment of the fire protection properties of the FireCemX and FireCemY and compares them with other types of passive fire protection materials. The main criteria considered in the assessment are:

1. Thermal insulation
2. Strength under fire
3. Explosive spalling during fire

The robustness of FireCemX and FireCemY under the effects of other extreme environment conditions will also be discussed in this study.

1.2.1. Thermal insulation

In order for a fire protection material to perform efficiently it should provide sufficient thermal insulation. The thermal insulation requirements depend on the fire risk assessment and the type of building that needs to be protected. For example, in concrete tunnels the insulation material should be capable of maintaining a temperature less than 400°C on the unexposed side[4]. This is mainly to keep the temperature of the protected linings of the tunnel low enough to prevent strength loss and explosive spalling. The FireCemX and FireCemY have low thermal conductivity in comparison to other construction materials. The thermal conductivity of the FireCemX and FireCemY materials are 0.57 W/mK and 0.62 W/mK respectively[3]. These are lower than the thermal conductivity of concrete and cement mortar which is widely used in buildings. Table 1 shows the thermal conductivity of FireCemX and FireCemY compared to other construction materials.

Table 1. Thermal conductivity of FireCem and other construction materials[1,3,5,6]

Material	Thermal Conductivity W/mK
FireCemX	0.572
FireCemY	0.620
Gypsum plaster	0.48
Concrete	0.8 -1.4
Cement mortar	0.58 -1.16
Bricks	0.69

In recent tests performed at FireSERT Labs, FireCemX and FireCemY have shown excellent thermal insulation properties[3]. The 50mm thickness panels (exposed to fire from one side only), maintained sufficiently low temperatures on the unexposed side. Figure 2 shows the temperature development on the surface exposed to fire, at mid-depth of the panel and at the unexposed surface for 75 minutes of exposure to the ISO834 fire curve[7].

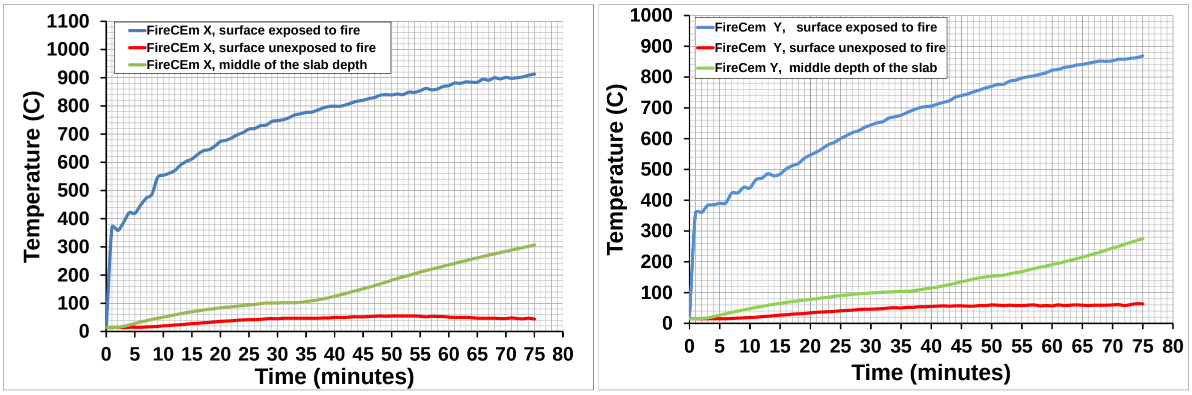

Figure 2. Development of temperatures with time in slabs FireCemX and FireCemY

Table 2 shows a summary of the test results[3] of the 50 mm thickness panels FireCemX and FireCemY subjected to the ISO834 fire curve.

Table 2. Recorded temperatures of FireCemX and FireCemY panels[3]

Slab	Minute 30		Minute 60		Minute 75	
	Exposed Side °C	Unexposed Side °C	Exposed Side °C	Unexposed Side °C	Exposed Side °C	Unexposed Side °C
FireCemX	748	45	872	51	913	44
FireCemY	644	46	822	57	869	63

The table shows that both slabs have maintained sufficiently low temperatures on the unexposed side of the panel, i.e. not exceeding 44ºC for FireCemX and 63ºC for FireCemY that is 4.8% and 7.2% of the temperature on the exposed side of the slabs.

1.2.2. Resistance to Explosive Spalling During Fire

Explosive spalling of building materials during fire is the most hazardous type of spalling which may cause partial or full collapse of the building and may significantly increase life loss[8,9,10,11,12,13,14].

In recent years a series of major fires have occurred in concrete tunnels around the world including Europe. Among those occurring in Europe were the fire catastrophe in Tauern Channel (May 1999)[15], the Channel Tunnel fire (1996)[16,17,18], the Mont Blanc fire (1999)[19,20], the Swiss Gotthard Tunnel fire (2001)[21,22], the Kapurn fire (2001)[23], and other incidents[24,25]. Some of these fires caused severe life loss and structural damage, including a structural collapse of some parts. In some cases restoration costs reached $16 million (Tauern fire)[15]. A hazardous scenario happens when the fire causes a structural failure in the tunnel. Whether the tunnel is built under water or under the ground surface, disastrous consequences can result. Under high temperatures, concrete containing high moisture can explode violently. Explosive spalling happens with high explosive energy causing concrete shrapnel to fly with high speed, causing further casualties and damage to the surrounding environment[13]. In addition, it can threaten the integrity of the whole structure and could lead to structural collapse of the tunnel. Figure 3 shows the destructive effect of explosive spalling.

Figure 3. Destructive effect of explosive spalling.

To explain why explosive spalling happens in concrete when subjected to fire it is important to know some facts about concrete. During concrete's exposure to fire, free (inside voids) and combined water within the concrete starts to evaporate. If the concrete has a low permeability, the pore pressure starts to build up and induces stresses on the internal structure of the concrete. The thermal gradient across the concrete element creates additional thermal stresses as shown in Figure 4. The combination of vapour and thermal stresses can reach high levels. If these exceed the tensile strength of the concrete, local failure occurs and high energy is released. This leads to a chain of concrete micro-structural failure in the adjacent parts and violent explosion of the concrete takes place. The best method to reduce explosive spalling is to mix polypropylene fibres with concrete or to mix a hybrid of polypropylene and steel fibres. During fire, the polypropylene fibres melt at 160°C and create a random matrix of micro hollow channels that allow the vapour to escape[2].

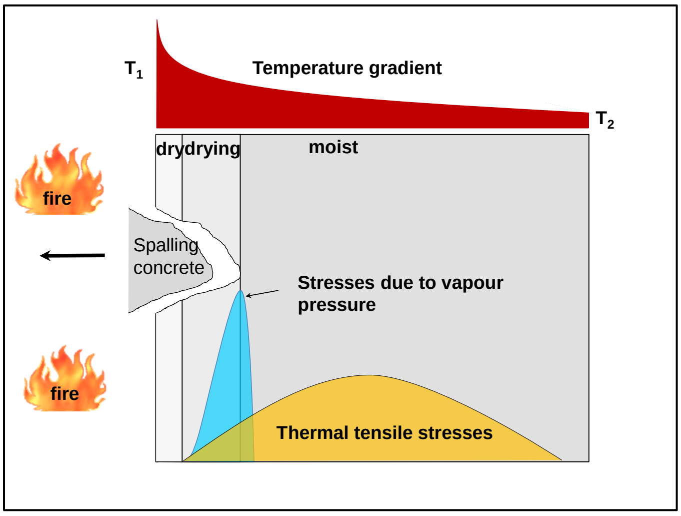

Figure 4 Vapour and thermal stresses and spalling mechanism during fire.

Recent tests[3] under extremely severe and high temperatures indicate that FireCemX and FireCemY have complete resistance to explosive spalling. It has an inherent property which eliminates explosive spalling and does not require the addition of polypropylene fibres. During the fire tests, FireCemX and FireCemY panels did not suffer from any explosive spalling in spite of the high moisture contents exceeding 16% in weight[3]. The tested panels have shown the ability to allow the vapour to escape and to defuse any possibility of explosive spalling. Figure 5 shows the FireCemX and FireCemY specimens after exposure to severe temperatures with no explosive spalling occurring[3].

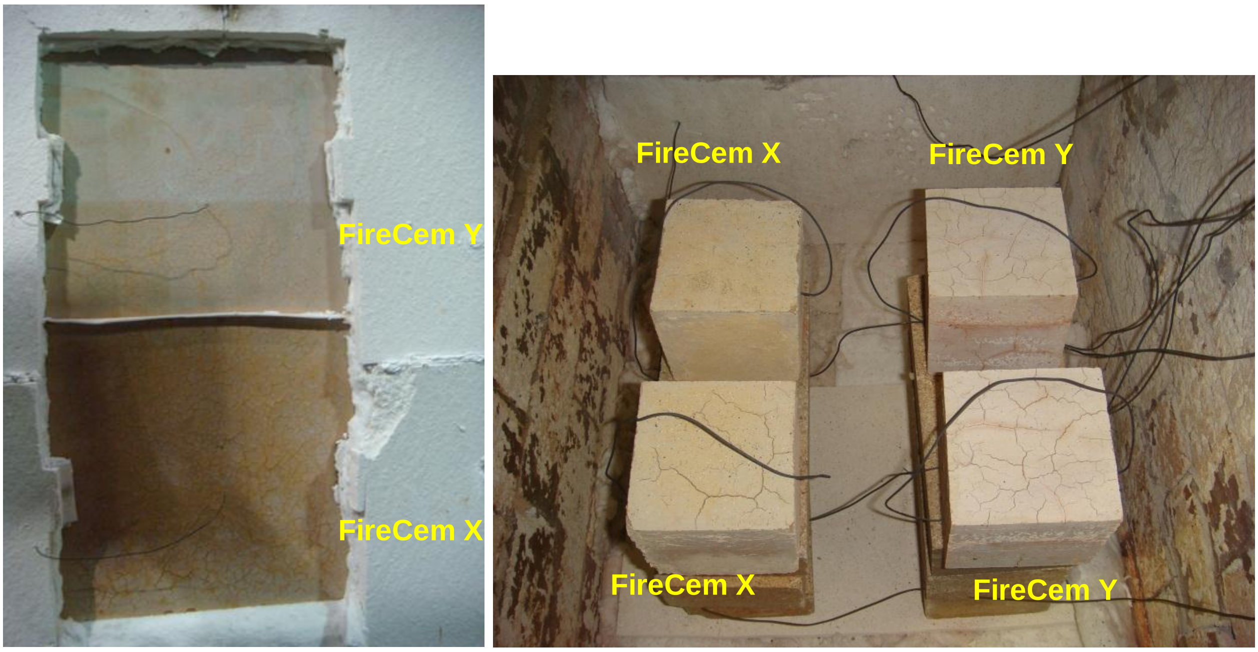

Figure 5. (left) FireCemX and FireCemY slabs after exposure to ISO834[7] fire, (right) FireCemX and FireCemY cubes after exposure to Hydrocarbon[26] fire.

1.2.3. Strength under fire

It is well known that building materials including steel and concrete lose their strength under fire[27,28]. For example, in temperatures of 1000°C the steel loses 96% of its yield strength[28]. The same behaviour occurs with concrete. Eurocode 2 indicates that normal weight concrete with siliceous aggregates loses 95% of its strength at 1000°C[27]. Contrary to expectations, the mechanical properties of FireCemX and FireCemY improve under fire. In a unique behaviour compared to other building materials, the strength of both FireCemX and FireCemY increases when exposed to fire. The increase in strength under fire gives FireCem clear superiority over any other fire protection materials. Recent tests[3] have shown that the strength of FireCemY increased by 12.72% under temperature of 1027°C as shown in Table 3.

Table 3 Strength gaining of FireCemX and FireCemY during Hydrocarbon fire exposure[3]

Sample	Max. surface temperature reached (°C)	Average compressive strength before fire N/mm^2	Average compressive strength after fire N/mm^2	Average strength gain due to fire exposure
FireCemX1	974	5.26	5.42	+%2.65
FireCemX2	1008			
FireCemY1	998	19.25	21.70	+%12.72
FireCemY2	1027			

The increase in the strength of FireCem when subjected to fire, the complete resistance to explosive spalling with extremely high moisture content exceeding 16% (in weight) without the need to add polypropylene fibres (or any additives), and the excellent thermal insulation, provide strong justification to classify FireCem as a new type of fire protection material.

2. Finite Element Study on the Thermal Behaviour of FireCem

To assess the thermal and fire performance of FireCemX and FireCemY a numerical study was performed using the Finite Element Method based on the software Diana 9.4.4[29]. A heat flow-stress 3D staggered model was adopted to perform a non-linear transient heat analysis. A 500mm x 500mm x 50mm slab was built using a 3D twenty node solid brick CHX60 element (see Figure 6). However, in order to allow for transient heat analysis to be performed, a quadrilateral boundary 4 nodes BHQ4HT element was used to model the external flow film surrounding the slab (Figure 6).

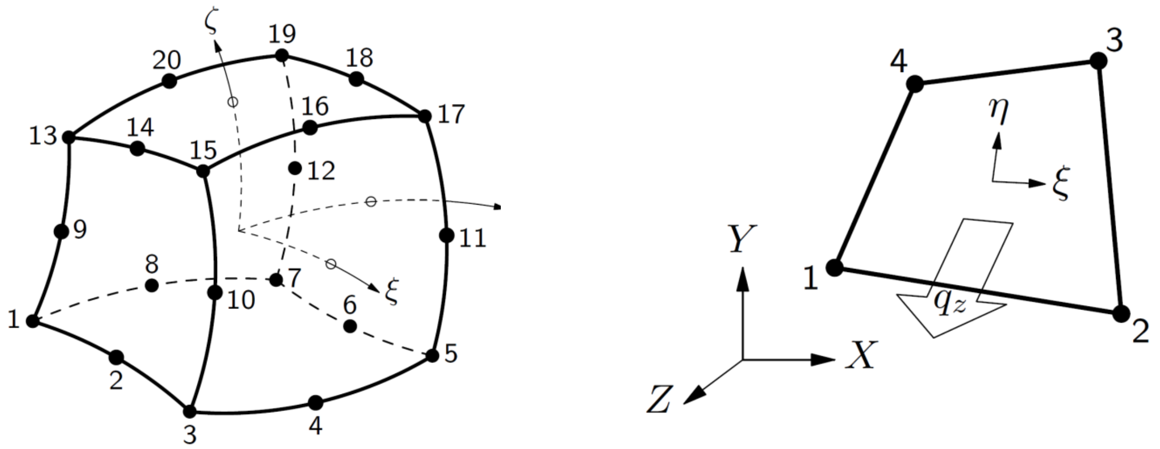

Figure 6. (left) Twenty node brick element CHX60, (right) 4 nodes flow elements BHQ4HT used in building the slab models[29]

A sensitivity analysis was performed to optimise the meshing process and the final meshed model consisted of 12500 elements and 55016 nodes and is shown in Figure 7. The Quasi-Newton method with line search algorithm was used in the iterative procedure to solve the equations and to obtain the required accuracy. Due to the complex nature of the moisture migration phenomenon and vapour pressure build up in concrete, these are not considered in the model.

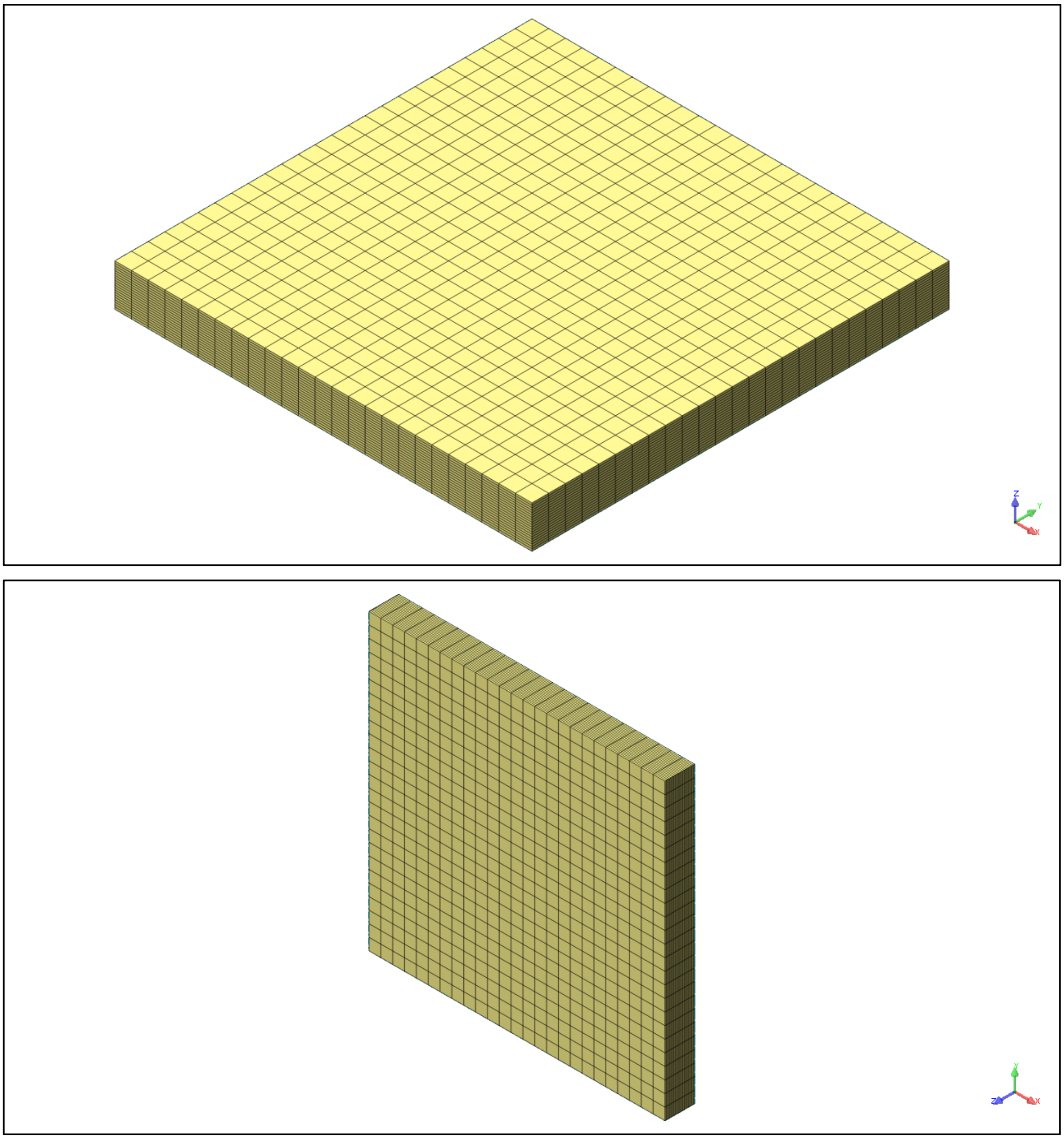

Figure 7. The meshed slab consisting of 12500 elements and 55016 nodes

2.1. Material Modelling

As the slabs are made from newly formed materials FireCemX and FireCemY, their mechanical and thermal properties were extracted from the series of the tests performed erlier[3]. The properties used in the analysis are shown in Table 4.

Table 4. Material properties used in the analysis

Material	Compressive strength N/mm^2	Thermal conductivity W/mK	Specific Heat J/kgK
FireCemX	5.26	0.572	756
FireCemY	19.5	0.62	806

2.2. Thermal Analysis

The thermal analysis was performed to determine the nodal temperature using a stepwise heat transfer time-history taking into account conduction, convection and radiation effects. The finite element formulation is based on the Galerkin method[29] by determining {*T*} as a function of time:

$$[k]\{T_n\}+[c]\{\dot{T}_n\}=\{F_n\} \qquad (1)$$

Where: [*k*]=element heat conduction/convection matrix, [*c*]=element heat capacity, $\{T_n\}$=element nodal Temperature Vector, {*F*}=element nodal heat input vector and is defined at boundary nodes using equation:

$$-k\left[\frac{\partial T}{\partial x}l_1+\frac{\partial T}{\partial y}m_1\right]=h\,[T_e-T_r]+\varepsilon_e\sigma\,[T_e^4-T_r^4] \qquad (2)$$

Where: T_e= temperature of emitting surface; T_r = temperature of surface; σ = Stefan-Boltzmann coefficient; l_1-direction cosine of n relative to x= cosθ; m_1=direction cosine of n relative to y = sinθ; ε_e = emissivity of the surface, *k* = coefficient of thermal conductivity; *h* = coefficient of heat transfer.

2.3. Calibration and Validation of the FE Models

The FE models of the FireCemX and FireCemY slabs were validated using the experimental results obtained during the fire tests performed on the 50mm thickness slabs [3]. The comparison with the experimental results showed sufficient accuracy of the built model in predicting the temperature of the exposed surface, middle depth and unexposed surface of the slabs. The results of the comparison are shown in Table 5.

Table 5. Validation of the Finite element models with experimental results

Slab	Location	Experimental (°C)	FE model calculations (°C)
FireCemX	Exposed	872	885
	Mid-depth	237	210
	Unexposed	51	55
FireCemY	Exposed	822	822
	Mid-depth	191	199
	Unexposed	57	55

Following the validation of the models, additional six 500mm x 500mm slabs models were built to enable a parametric assessment of their thermal performance. During the analysis the 20, 30, 40 and 50 mm slabs were subjected to fire from one side only that is the 500mmx500mm face. Three fire intensities were used in the analysis:- the ISO834, the Hydrocarbon fire, and the RWS[2] fire curves as shown in Figure 8 .

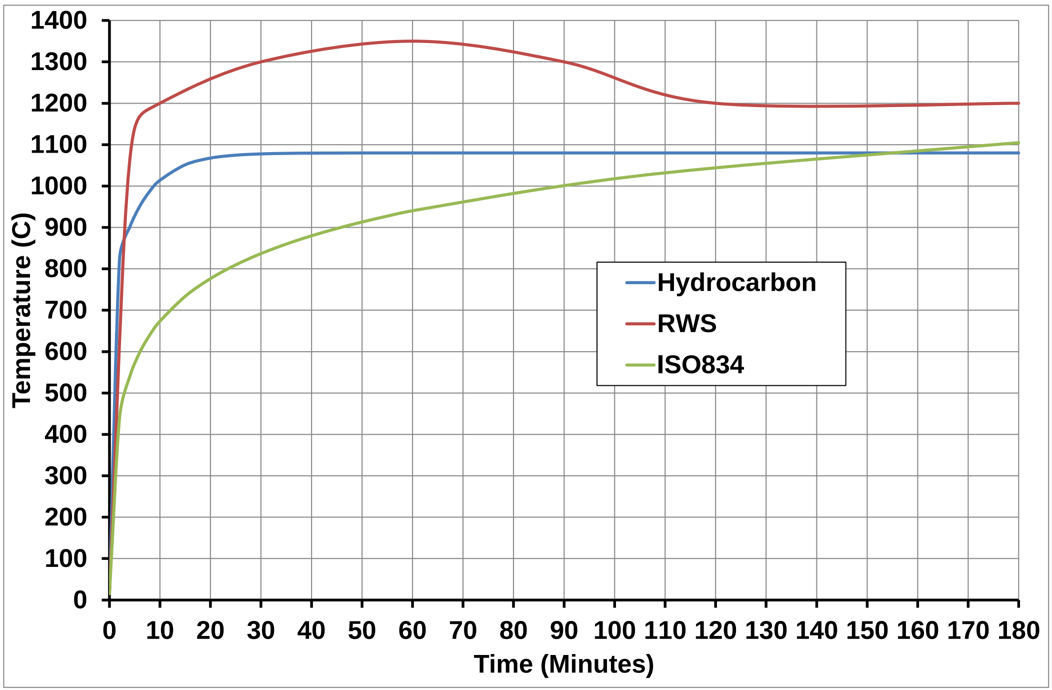

Figure 8. Fire curves used in the analysis

2.4. Analysis and Assessment

During the analysis, the iterative process was performed using 1 minute steps to ensure high accuracy in the obtained results. Figure 9 shows a typical contour distribution of temperatures in slabs FireCemX resulting from analysis under the severe RWS. The red top surface of the slab is the surface that is exposed to fire. The thermal gradient is noticeable by the changing colours towards the blue area at the bottom side of the slab that is unexposed to fire. An estimation of the temperature values can be performed using the legend shown on the right hand side of the figure.

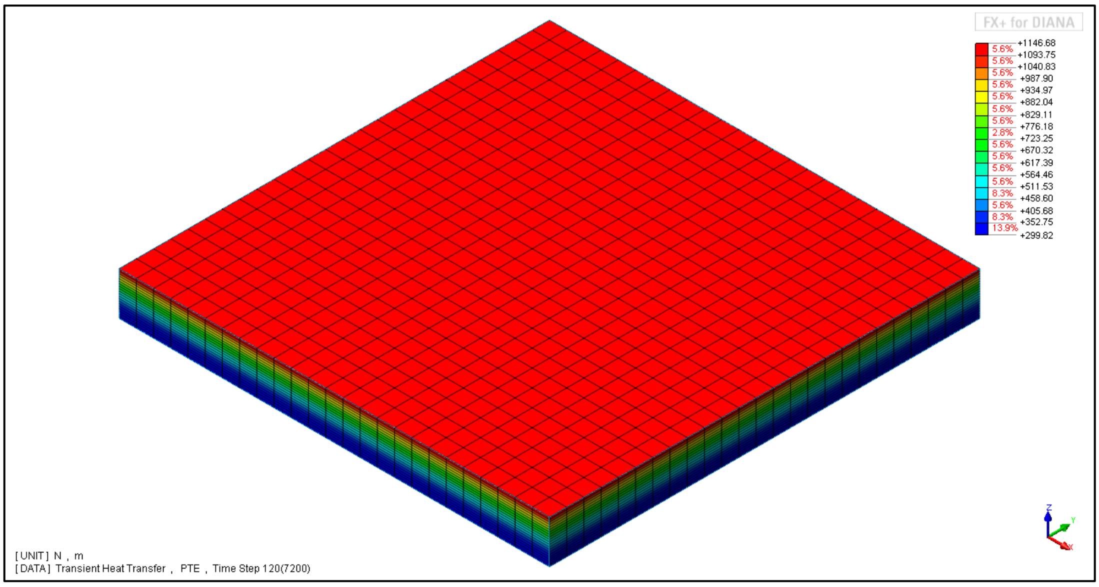

Figure 9. Thermal distribution in FireCemX at minute 120 of exposure to the severe RWS fire**.**

In order to achieve an efficient assessment, the Finite Element calculation results will be evaluated considering two parameters in the domain:- the material type being FireCemX and FireCemY; and the slab thickness being 20, 30, 40 and 50 mm.

2.4.1. <u>Assessment by Material Type</u>

2.4.1.1. <u>The FireCemY slabs</u>

Figure 10 shows the development of temperatures in panel FireCemY at 30, 60, 90 and 120 minutes respectively as obtained from the finite element analysis. The figure shows clearly the movement of the heat front across the slab depth with time. Figure 11 shows the thermal performance of the FireCemY slabs subjected to the moderate ISO834[7] and the severe hydrocarbon fire curve[26]. The figure shows the temperature development within time at the exposed to fire surface, at mid-depth of the slab and at the unexposed surface. The figure presents the behaviour of four thicknesses of FireCemY that is 20mm, 30mm, 40mm and 50mm. Figure 11 also shows that if considering 1 hr of fire exposure, slabs of thicknesses 30mm, 40mm and 50 mm are capable of maintaining low temperatures (less than 400°C[4]) on the unexposed surface for both fire intensities.

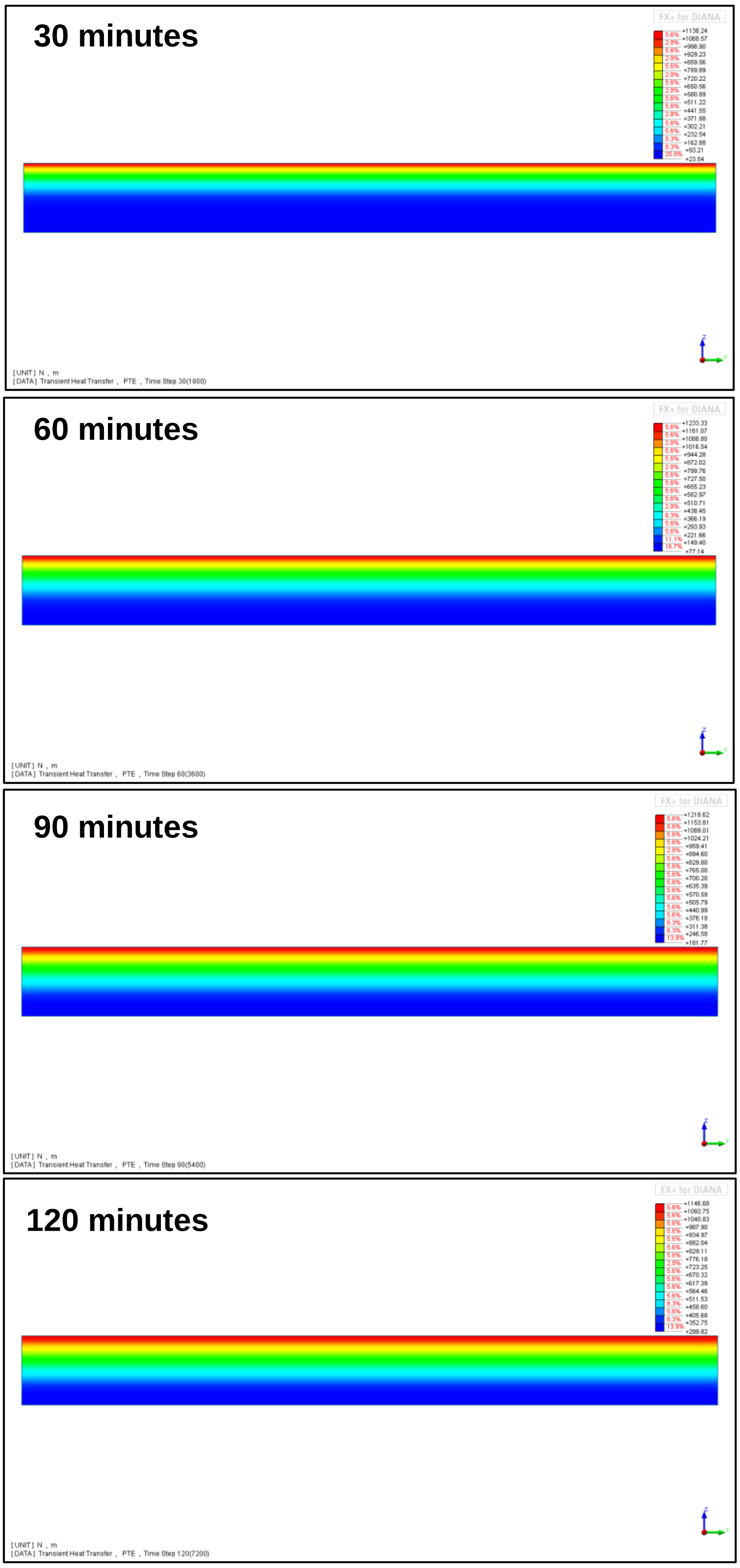

Figure 10. Development of temperatures of FireCemY slab under Hydrocarbon fire

However, if considering 2 hours of fire exposure, slabs of thicknesses 40 and 50 mm are capable of maintaining relatively low temperatures (less than 400°C[4]) on the exposed surface under ISO834. Under the severe Hydrocarbon fire curve only slab of 50mm thickness has the capacity to maintain the required temperatures for a 2 hour period. The figure also shows that the moisture at the mid depth of slabs of thickness of 40mm and 50 mm reaches the critical "boiling" temperature at around 24-36 minutes under the ISO834 and between 18-28 minutes under the hydrocarbon fire.

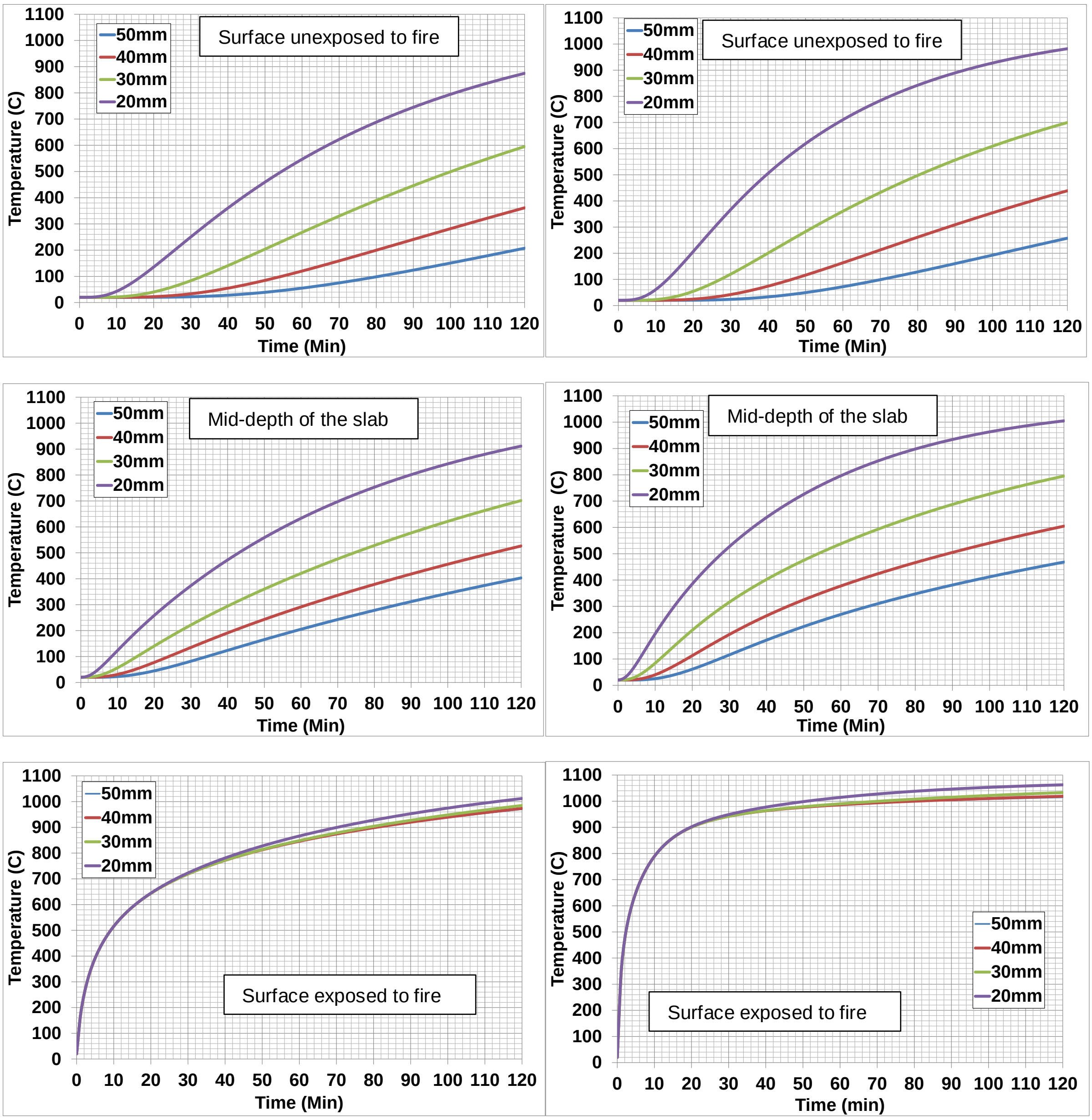

Figure 11. FireCemY (left) ISO 834 exposure (right) Hydrocarbon fire exposure

Figure 12 shows the pattern of the temperatures gradient across the thickness of the FireCemY slab subjected to ISO834 fire curve. The figure indicates a reasonable drop in the temperatures when moving away from the heated face.

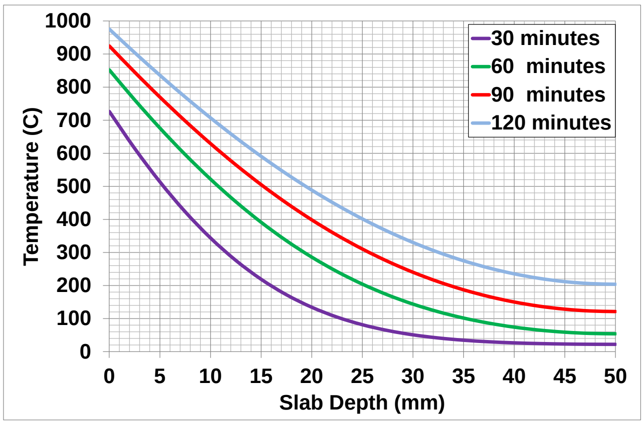

Figure 12. Temperature gradient in FireCemY slab at various stages of heating (0 depth presents the exposed surface, 50mm depth presents the unexposed surface)

2.4.1.2. <u>The FireCemX slabs</u>

Figure 13 shows the thermal performance of the FireCemX slabs subjected to the moderate ISO834 and the severe Hydrocarbon fire. The figure shows the temperature development within time at the exposed to fire surface, at the mid-depth of the slab and at the unexposed surface. The figure presents the behaviour of four thicknesses of FireCemY, i.e. 20mm, 30mm, 40mm and 50mm. The curves presented in Figure 13 indicate that slabs FireCemX slightly outperform the FireCemY slabs, particularly under the Hydrocarbon fire and demonstrate better thermal resistance during the two hrs period of fire exposure. However, the difference is minute (less than 1%) and negligible.

2.4.2. <u>Assessment by Slab Thickness</u>

In the previous paragraph the slabs were assessed based on the type of material. Using the data obtained from the Finite Element calculations the slabs have also been assessed by their thickness. As the difference in the thermal behaviour between the FireCemX and the FireCemY is negligible, only the performance of slabs FireCemX will be discussed in detail. Curves showing the behaviour of slab FireCemY are shown in Appendix E.

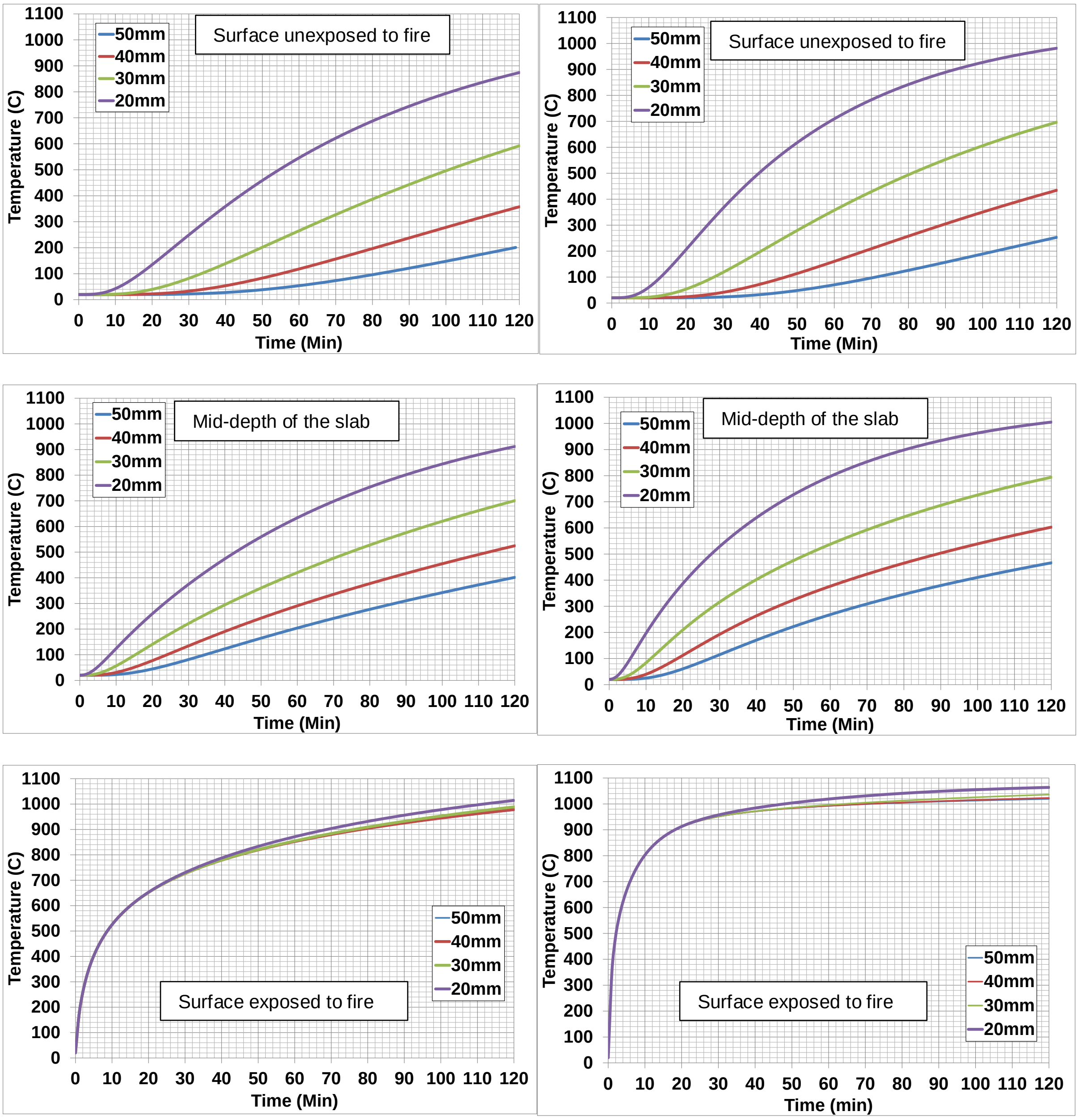

Figure 13. FireCemX (left) ISO 834 exposure (right) Hydrocarbon fire exposure

2.4.2.1. The 50mm slabs

Figure 14 shows that slabs of 50 mm thickness demonstrate an excellent capability of maintaining sufficiently low temperatures on the unexposed surface. If considering a period of 2 hrs it can be noticed that the 50mm slabs can maintain a temperature not exceeding 200°C when subjected to the ISO 834 and less than 250°C under the Hydrocarbon fire curve. The figure also shows that the 50mm slab can keep the temperature below the water "boiling" point at the mid depth of the slab for 34 minutes under the ISO834 and around 26 minutes under the hydrocarbon fire curve. This makes this thickness ideal for fire protection purposes.

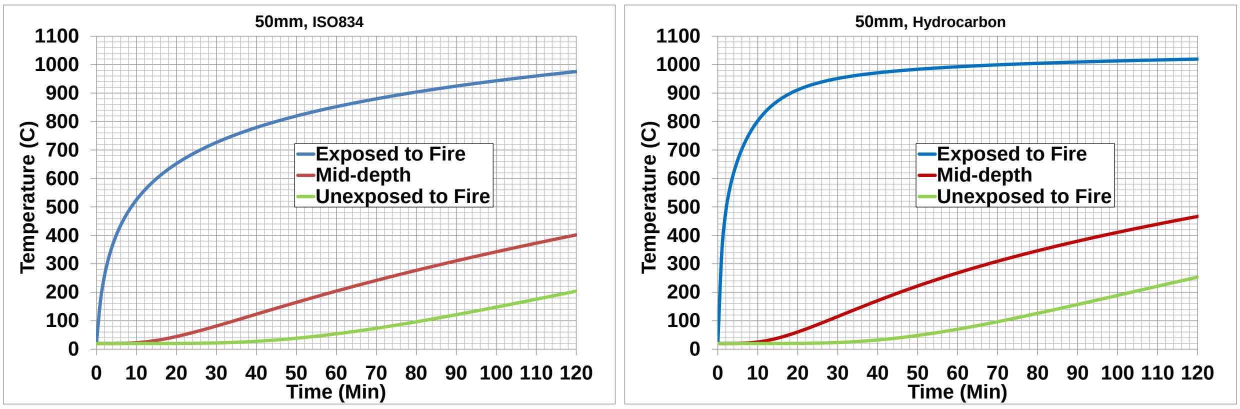

Figure 14. Temperatures development within time in slabs thickness 50mm under ISO834 and Hydrocarbon fire curves.

2.4.2.2. The 40mm slabs

The 40mm slabs also show reasonable fire protection properties under the ISO834 fire curve. Figure 15 shows that the 40mm slab maintains a temperature less than 400°C for 2 hours under ISO834 and for 1.5 hours under both of the ISO834 and the Hydrocarbon fire curves. The slab also shows the capability to keep the temperature lower than 100°C; the "boiling" point of water, for approximately 20 minutes under both fire intensities.

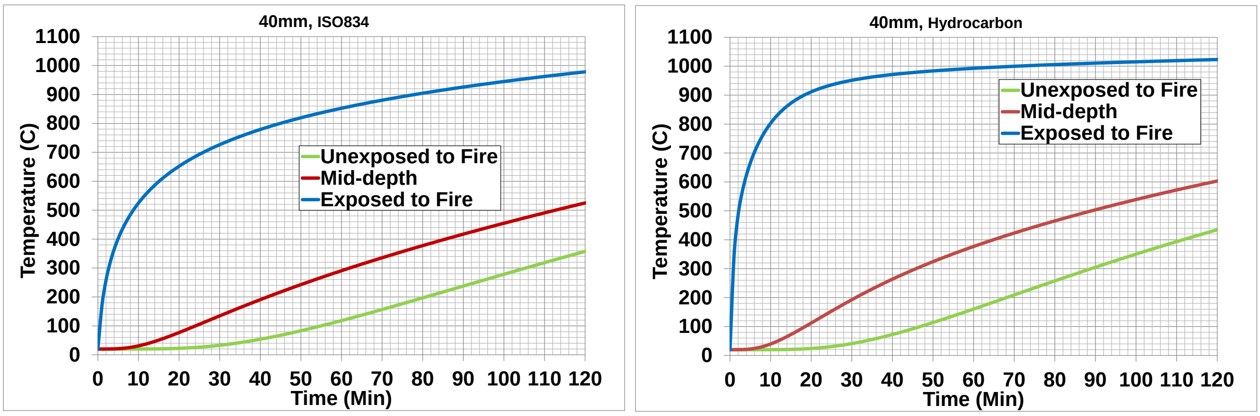

Figure 15. Temperature development within time in slabs thickness 40mm under ISO834 and hydrocarbon fire curves

2.4.2.3. <u>The 30mm slabs</u>

Figure 16 shows the thermal behaviour of slabs thickness 30mm subjected to ISO834 and the Hydrocarbon fire curve. The Figure shows that the 30mm slab can maintain temperatures less than 400°C[4] for 1 hour period of exposure for both of the ISO834 and the Hydrocarbon fire curves. The figure also shows that the temperature at the mid depth of the slabs is kept below 100°C for 15 minutes under the ISO 834 and 10 minutes under the hydrocarbon fire curve.

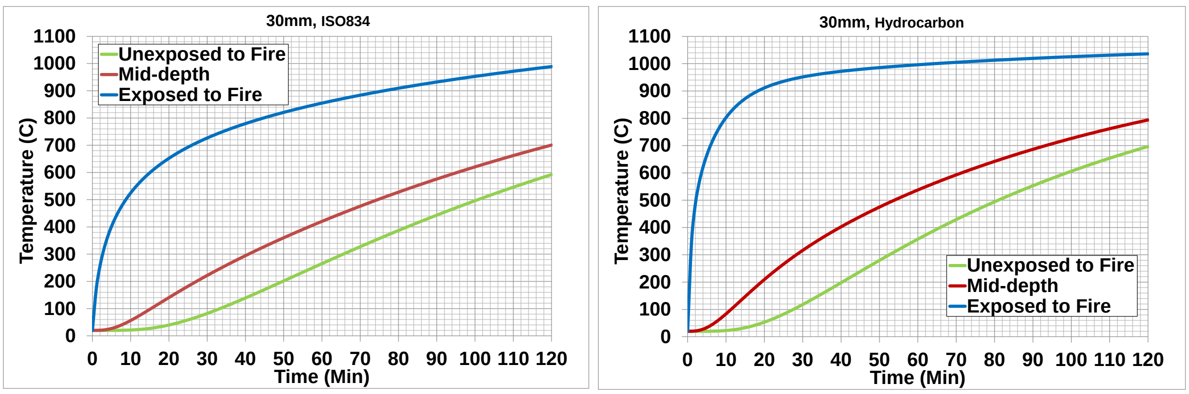

Figure 16. Temperature development within time in slabs thickness 30mm under ISO834 and hydrocarbon fire curves

2.4.2.4. The 20mm slabs

Due to the small thickness of these slabs they show a capability of maintaining the temperatures on the unexposed side at less than 400°C[5] for around 45 minutes under the ISO834 fire intensity. The thermal response of the slabs is shown in Figure 17.

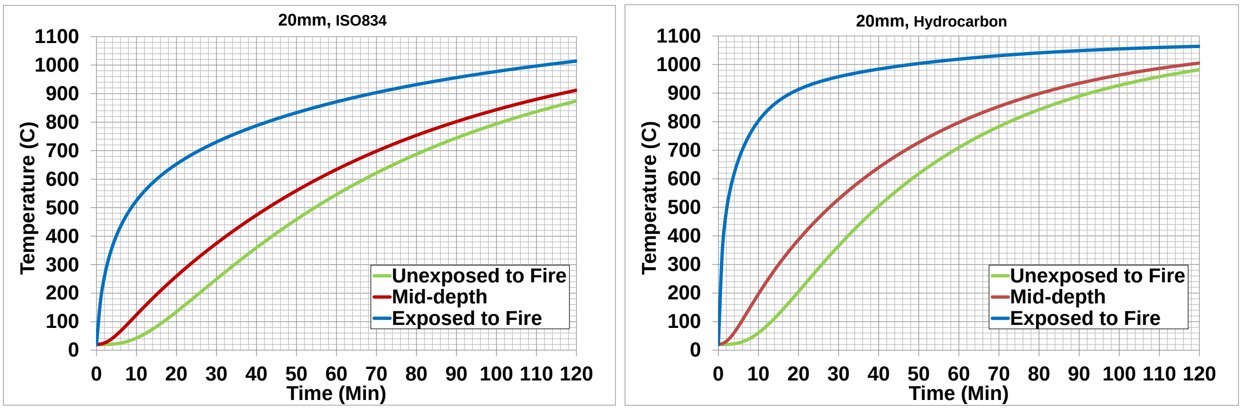

Figure 17. Temperatures in 20mm slabs under ISO834 and hydrocarbon fire curves

2.4.3. Overall assessment

Table 6 and Table 7 provide a summary of the Finite Element study and analysis of the slabs of different thicknesses under the two fire intensities. The tables show that the 50mm slabs have the capacity to provide fire protection for 2hrs under the severe hydrocarbon fire curve. The 40mm slabs provide fire protection for 2 hrs under ISO834 fire curve and for 1.5 hrs under the Hydrocarbon fire curve.

Table 6. Fire protection using FireCemX and FireCemY slabs under ISO834 fire

Panel thickness (mm)	Fire protection in minutes, ISO834 fire			
	30	60	90	120
50	yes	yes	yes	yes
40	yes	yes	yes	yes
30	yes	yes	No	No
20	yes	No	No	No

Table 7. Fire protection of FireCemX and FireCemY slabs under Hydrocarbon fire

Panel thickness (mm)	Fire protection in minutes, Hydrocarbon fire			
	30	60	90	120
50	yes	yes	yes	yes
40	yes	yes	yes	No
30	yes	yes	No	No
20	yes	No	No	No

2.5. Additional analysis under the extremely severe RWS fire curve.

The fire protection properties of the 40 and 50mm thickness slabs were analyzed further under more severe fire curve that is the RWS[2] shown in Figure 5. The two slabs were evaluated for fire exposure of 2 hrs period using the Finite Element models. The analysis has shown that the 50mm slabs can provide fire protection for 2 hours under the RWS fire, maintaining the required temperature. The 40mm achieved 1.5 hour of fire protection under the RWS curve. The development of temperatures of both slabs under the RWS fire curve is shown in Figure 18. The rating of the fire protection of the slabs is shown in Table 8.

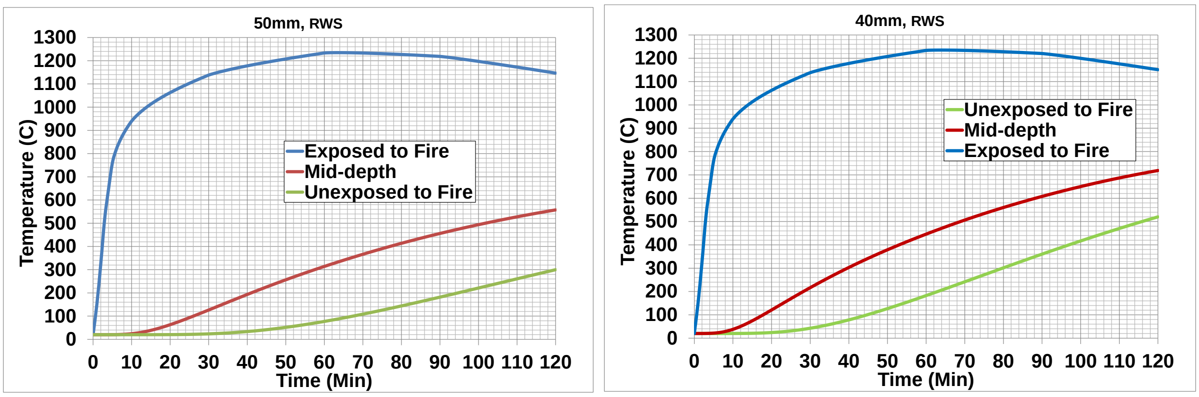

Figure 18. Temperature in 40mm and 50mm slabs under the RWS fire curve

Table 8. Fire protection of FireCemX and FireCemY slabs under RWS fire

Panel thickness (mm)	**Fire protection in minutes, RWS fire curve**			
	30	**60**	**90**	**120**
50	yes	yes	yes	yes
40	yes	yes	yes	No

3. Comparison Between FireCem and Other Fire Protection Materials

In this chapter, the performance of FireCemX and FireCemY as fire protection materials will be compared with other existing fire protection technologies. FireCem can be produced as insulation boards or as spray on materials. The comparison includes the MEYCO® Fireshield 1350, FireBarrier 135®, Fiberfrax® Duraboard® and plaster boards.

3.1. MEYCO® Fireshield 1350

The MEYCO® Fireshield 1350 is a passive fire protection material that aims to provide fire protection mainly in tunnels. The MEYCO® Fireshield 1350 is cementitous based mortar and can be applied in a spry form, cast in situ or as precast panels[30]. The information regarding the MEYCO® Fireshield 1350 from independent appraisers is very scarce or absent from the literature. From what is available in the public domain and published by the manufacturer BASF, the MEYCO® Fireshield 1350 has a compressive strength of 15-20 N/mm^2 at 28 days which is within the expectation of cement based materials[30]. However, the flexural strength of 2 N/mm^2 of the MEYCO® Fireshield 1350 is low[31]. This makes it fragile if provided in the form of panels and would require high thickness or reinforcement to maintain the required strength. The fire performance of the MEYCO® Fireshield 1350 is not clearly presented in the available literature. The information about its resistance to explosive spalling is also vague. It is very important that the assessment of the resistance of a material to explosive spalling is linked with the moisture content of the material. Naturally, concrete is not expected to suffer from any explosive spalling if the moisture content is low (less than 3 - 4%[13]). Therefore, considering a material to be resistant to explosive spalling without taking into account the level of moisture content is not reliable approach. Documents[30,31,32] issued by BASF indicate that a 50 mm thickness of the MEYCO® Fireshield 1350 is required to provide fire protection for 2 hrs under the RWS fire curve maintaining a temperature around 200°C on the unexposed to fire side. There is no information available about the thermal conductivity of the MEYCO® Fireshield 1350. If considered as a mortar it is expected[3,4] that the thermal conductivity of the MEYCO® Fireshield 1350 is between 0.58 and 1.16 W/mK.

However, the main expected drawback of the performance of the MEYCO® Fireshield 1350 is the change in its strength under high temperatures. There is no independent assessment of the strength of the MEYCO® Fireshield 1350 under fire in the public domain literature. However, as the MEYCO® Fireshield 1350 is a cement based mortar[30] it is expected that its strength decreases when exposed to high temperatures. The loss of strength of a mortar based material if exposed to temperatures up to 900°C is 92% of its strength at room temperature[33]. This may require the removal and the replacement of areas that affected by fire. It is expected that the decrease of the properties includes compressive strength, flexural strength and Young's modulus.

3.2. FireBarrier 135®

This fire protection material is mainly applied by spraying on, however it can also be provided in a precast form. The FireBarrier 135® is produced from mortar which is based on aluminous cement, kaolin, refractory brick powder and plaster[34]. There is no independent research available in the literature or in the public domain on the performance of FireBarrier 135®. However, a report[35] issued by Thermal Ceramics Europe indicates that several tests have been made on the FireBarrier 135® to evaluate its fire protection performance. It can be concluded from the report that these fire tests were not performed on the FireBarrier 135® on a standalone basis. Rather the tests were carried out on specimens where the FireBarrier 135® was cast on a concrete slab and formed a part of a multi-layer panel. Therefore, these tests cannot provide standard and accurate data about the fire performance of the FireBarrier 135® as it can be affected by the thermal properties of the concrete slab that it is attached to. Nevertheless, taking this into consideration, the report[35] indicates that a 38 mm of FireBarrier 135® maintained 334°C during 120 minutes of exposure to the RWS fire and that a 35 mm thickness layer maintained a 275°C for 2 hrs under the Hydrocarbon fire curve. On the other hand the mechanical properties of the FireBarrier 135® are not as high as the MEYCO® Fireshield 1350. The FireBarrier 135® has a relatively low compressive strength at 28 days = 10 MPa and a relatively weak flexural strength of 1.18 MPa. This can affect its application, particularly if used in the form of boards requiring increased thickness.

As was the case with the MEYCO® Fireshield 1350, the main expected drawback of the performance of the FireBarrier 135® is the change of its mechanical properties when subjected to fire. In the absence of an independent study, it is predictable that as the FireBarrier 135® is a mortar based material it will lose its strength when exposed to high temperatures. The loss of strength of a mortar based material if exposed to temperature of 900°C is 92% of its strength at room temperature[33]. It is expected that the decrease of the properties includes compressive strength, flexural strength and Young's modulus.

3.3. Plaster Boards.

Plaster boards are widely used as a passive fire protection material. Gypsum boards have been recognised for decades as a low cost construction and fire insulation materials. They are generally manufactured from aerated gypsum core with glass fibre, water repellent and other additives encased in, and firmly bonded to, strong paper liners[1]. Plaster Boards have a reasonably low thermal conductivity of 0.24-0.28 W/mK. In a study carried out at Empa[36] on 12 mm plaster boards the temperature on the unexposed to fire side reached approximately 220°C during 24 minutes of exposure to the mild ISO834. An important study[37] has shown that plaster boards lose strength sharply and rapidly under relatively low temperatures. The study[37] indicates that plaster boards lose around 86% of its strength at 400°C. This is twice as bad as any cement based material. Also plaster boards are very sensitive to humidity which may affect their properties.

3.4. Fiberfrax® Duraboard®

These are dedicated fire insulation boards usually manufactured in 3-75 mm thicknesses and have very low thermal conductivity 0.09 W/mK at 600°C as they are designed to work as a fire protection barrier[38]. However, these boards have very low strength. Their compressive strength is approximately 0.2 MPa and modulus of rupture 0.7 MPa[38]. This makes these boards not suitable for building or construction purposes. In addition, they need to be handled carefully due to health hazards related with its using as it can affect the respiratory tract, skin and eyes[39].

4. Robustness of FireCem under Extremely Severe Conditions

In addition to their fire protection and fire resistance properties, the FireCemX and FireCemY have inherent resistance to very extreme conditions. It is known that, materials used to protect tunnels or industrial buildings should have resistance to extreme environmental conditions. For example in tunnels, aggressive acid attacks and freezing temperatures are expected from the surrounding soil. The FireCemX and FireCemY have the ability to resist very aggressive attacks from acids. In recent tests[3] FireCemX and FireCemY have shown high stability to exposure of sulphuric H_2SO_4 acid of pH=1.04. In fact they neutralised the acidity and increased the pH of the acid as shown in Table 9. This makes the FireCem material ideal for tunnel or underground buildings including foundation or industrial transmission pipeline.

Table 9. FireCemX and FireCemY neutralising the acidity of H_2SO_4.

Sample Ref.	pH of the H_2SO_4 before exposure	pH of the supernatant liquid after exposure
FireCem X	1.04	6.44
FireCem Y	1.04	5.22

In addition, FireCemX and FireCemY have robust resistance and ability to remain stable under extremely low temperatures of -196°C which makes them ideal for harsh building environment. In recent tests[3] FireCemX and FireCemY maintained their stability and integrity after exposure to liquid nitrogen at boiling temperature = -196°C followed by 6 drop tests as shown in Figure 19. The capability to withstand extremely freezing and high temperature make them suitable for tough industrial applications.

Figure 19. FireCemY cube almost intact after exposure to liquid nitrogen & 6 drop tests

5. Conclusive Summary

The FireCemX and FireCemY are new type of fire protection materials that gains strength when subjected to fire. This unique property gives them superiority over available fire protection materials. FireCemX and FireCemY also have complete resistance to explosive spalling even when the moisture content exceeds 16% in weight. It is an inherent property of FireCemX and FireCemY that eliminates explosive spalling and does not require the addition of polypropylene fibres or any other additives. The FireCemX and FireCemY contain RoadCem additive mixed with Loam Clay, water and cement which make them very low cost material. The study has shown that a 50mm thickness panel of FireCemX can provide 2 hrs of fire protection under the extremely severe RWS fire curve. The FireCemX and FireCemY have high compressive and flexural strength which makes them suitable to provide additional stiffness as well fire protection to the structure. The sprayability of FireCemX and FireCemY and their resistance to severe environment including acids (sulphuric H_2SO_4 acid, pH≈1) and extremely low temperatures (-196°C) make them ideal for use in aggressive environments including tunnels' fire protection and for protection of industrial transmission pipelines where a wide temperature range needs to be maintained in and surrounding the pipelines. The superiority of FireCem material over other known fire protection materials is summarised in Table 10. It can be concluded from the table, that the FireCemY material fulfils all the criteria set in the comparison.

Table 10. Superiority of FireCem material over other fire protection materials

Material	Strength increase during fire	Resistance to explosive spalling with moisture content >16%	Flexural strength > 5 MPa	Compressive strength >15 MPa	Resistant to freezing temp. (-196°C)	Resistant to H_2SO_4 sulphuric acid pH≈1
FireCemY	Yes	Yes	Yes	Yes	Yes	Yes
FireCemX	Yes	Yes	No	No	Yes	Yes
MEYCO® Fireshield 1350	No**	No**	No	Yes	NDA*	NDA*
FireBarrier 135®	No**	No**	No	No	NDA*	NDA*
Plaster Boards	No	No**	No	No	NDA*	NDA*
Fiberfrax® Duraboard®	No**	N/A	No	No	NDA*	NDA*

**NDA-No data available, **based on predictions*

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Appendix A

(The data in this appendix was provided by PowerCem Technologies B.V.)

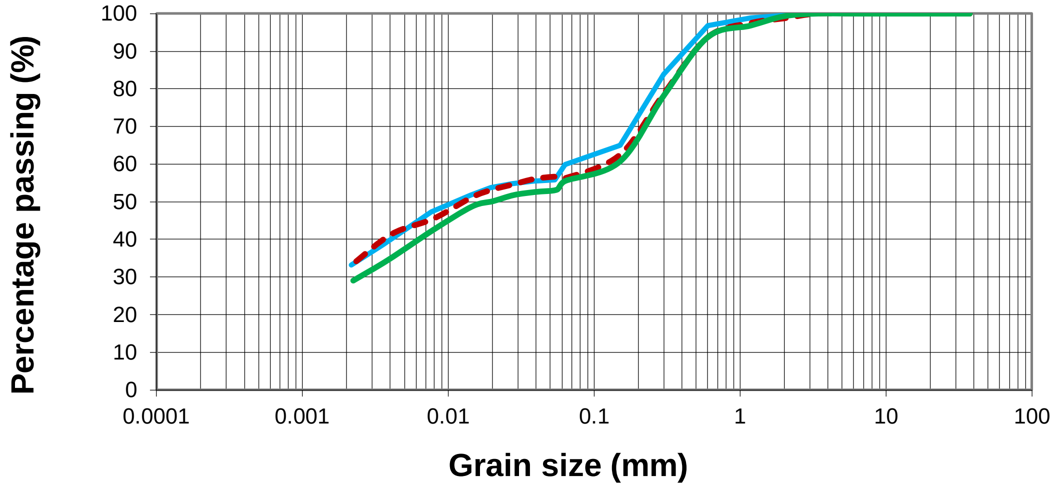
RC.RU.0668-Sample: XX

Preparation date: 22-08-2012, (18-09-2012 for thermal conductivity and Fire resistance tests)

Mix composition:

- Clay (dry) 983 kg/m^3
- Cement (CEM II/A-LL 42.5N) 228 kg/m^3
- RoadCem 2,3 kg/m^3
- Water 524 kg/m^3

Grain size distribution of the clay:



Physical Test results

	7 days curing		14 days curing		28 days curing	
	VM	Result	VM	Result	VM	Result
Flexural strength	1740 kg/m^3	1,0 N/mm^2	1592 kg/m^3	1,4 N/mm^2	1575 kg/m^3	1,6 N/mm^2
Compressive strength	1740 kg/m^3	3,8 N/mm^2	1592 kg/m^3	5,7 N/mm^2	1575 kg/m^3	6,6 N/mm^2

Appendix B

(The data in this appendix was provided by PowerCem Technologies B.V.)

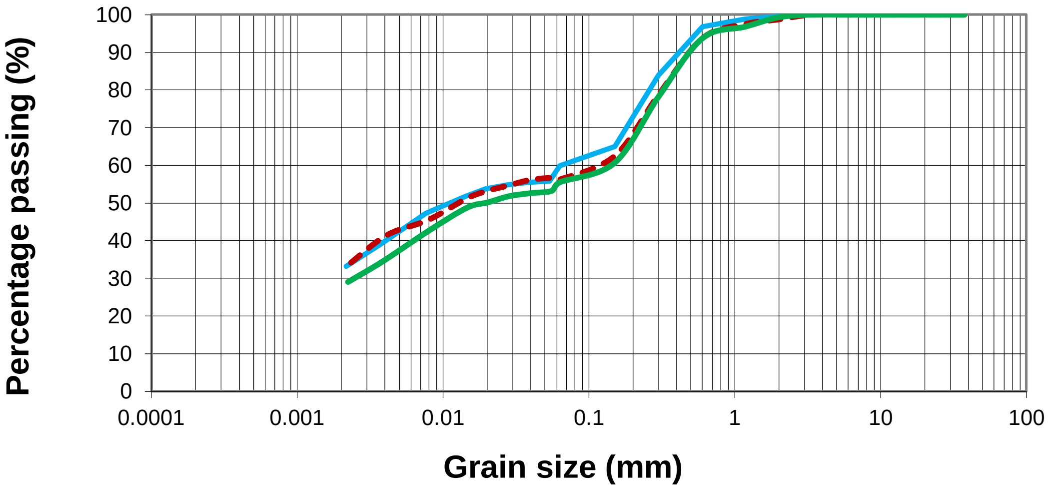
RC.RU.0668-Sample: Y

Preparation date: 18-9-2012

Mix composition:

- Clay (dry) 1.111 kg/m^3
- Cement (CEM II/A-LL 42.5N) 480 kg/m^3
- RoadCem 4,9 kg/m^3
- Water 366 kg/m^3

Grain size distribution of the clay:



Physical Test results

	3 days curing		37 days curing	
	VM	Result	VM	Result
Flexural strength	1867 kg/m^3	1,4 N/mm^2		5.8 N/mm^2
Compressive strength	1867 kg/m^3	5,2 N/mm^2		

Appendix C

Results of Finite Element Thermal Analysis of 500x500x20mm FireCemX Slabs

Fire curve: ISO834

Time	U*	MD*	E*
0	20	20	20
1	20	21	172
2	20	25	258
3	21	32	318
4	21	42	365
5	23	54	402
6	25	67	434
7	28	80	461
8	32	95	484
9	37	109	506
10	43	124	525
11	49	139	542
12	57	153	558
13	65	167	573
14	73	181	586
15	83	195	599
16	92	208	611
17	103	221	622
18	113	234	633
19	124	247	643
20	135	260	653
21	146	272	662
22	157	284	671
23	169	296	679
24	180	308	687
25	192	319	695
26	203	331	703
27	215	342	710
28	226	353	717
29	238	364	724
30	249	375	730
31	261	385	737
32	272	396	743
33	283	406	749
34	294	416	755
35	306	426	761
36	317	436	766
37	327	446	772
38	338	455	777
39	349	464	782
40	359	474	787
41	370	483	792
42	380	492	797
43	390	501	802
44	401	510	807
45	411	518	811
46	420	527	816
47	430	535	820
48	440	543	825
49	449	552	829
50	459	560	833
51	468	568	837
52	477	575	841
53	486	583	845
54	495	591	849
55	504	598	853
56	512	605	857
57	521	613	860
58	529	620	864

Fire curve: Hydrocarbon

Time	U*	MD*	E*
0	20	20	20
1	20	23	350
2	20	31	487
3	21	45	565
4	23	63	621
5	25	83	666
6	29	105	702
7	35	128	733
8	42	151	760
9	51	174	783
10	61	197	803
11	72	218	820
12	84	240	836
13	97	260	849
14	111	280	862
15	126	299	873
16	141	318	882
17	157	336	891
18	173	353	899
19	189	370	906
20	205	387	913
21	222	403	919
22	238	419	924
23	254	434	930
24	271	448	934
25	287	463	939
26	303	477	943
27	319	490	947
28	334	503	951
29	350	516	954
30	365	529	957
31	380	541	961
32	395	553	964
33	410	565	967
34	424	576	969
35	438	587	972
36	452	598	975
37	465	609	977
38	478	619	980
39	491	629	982
40	504	639	984
41	517	649	986
42	529	659	988
43	541	668	991
44	553	677	993
45	564	686	995
46	575	694	996
47	586	703	998
48	597	711	1000
49	608	719	1002
50	618	727	1004
51	628	735	1005
52	638	742	1007
53	647	750	1009
54	657	757	1010
55	666	764	1012
56	675	771	1013
57	684	778	1015
58	693	784	1016

Time	U*	MD*	E*
59	538	627	868
60	546	634	871
61	554	641	875
62	562	647	878
63	570	654	881
64	577	661	885
65	585	667	888
66	593	674	891
67	600	680	894
68	607	686	898
69	615	692	901
70	622	698	904
71	629	704	907
72	636	710	910
73	642	716	912
74	649	721	915
75	656	727	918
76	662	732	921
77	669	738	924
78	675	743	926
79	681	748	929
80	688	754	932
81	694	759	934
82	700	764	937
83	705	769	939
84	711	774	942
85	717	779	944
86	723	783	947
87	728	788	949
88	734	793	951
89	739	797	954
90	744	802	956
91	750	806	958
92	755	811	961
93	760	815	963
94	765	819	965
95	770	823	967
96	775	828	969
97	780	832	971
98	785	836	974
99	789	840	976
100	794	844	978
101	798	847	980
102	803	851	982
103	807	855	984
104	812	859	986
105	816	862	988
106	820	866	989
107	825	870	991
108	829	873	993
109	833	877	995
110	837	880	997
111	841	883	999
112	845	887	1000
113	848	890	1002
114	852	893	1004
115	856	896	1006
116	860	900	1007
117	863	903	1009
118	867	906	1011
119	871	909	1012
120	874	912	1014

Time	U*	MD*	E*
59	701	791	1018
60	710	797	1019
61	718	803	1020
62	726	809	1022
63	733	815	1023
64	741	821	1024
65	748	827	1025
66	756	832	1026
67	763	838	1028
68	770	843	1029
69	776	848	1030
70	783	853	1031
71	790	858	1032
72	796	863	1033
73	802	868	1034
74	808	873	1035
75	814	877	1036
76	820	882	1037
77	826	886	1038
78	831	890	1039
79	837	894	1040
80	842	898	1041
81	847	902	1042
82	852	906	1042
83	857	910	1043
84	862	914	1044
85	867	917	1045
86	872	921	1046
87	876	924	1046
88	881	928	1047
89	885	931	1048
90	889	934	1049
91	893	938	1049
92	898	941	1050
93	901	944	1051
94	905	947	1051
95	909	950	1052
96	913	953	1052
97	917	955	1053
98	920	958	1054
99	924	961	1054
100	927	963	1055
101	930	966	1055
102	934	968	1056
103	937	971	1056
104	940	973	1057
105	943	976	1057
106	946	978	1058
107	949	980	1058
108	952	982	1059
109	955	984	1059
110	957	986	1060
111	960	989	1060
112	963	991	1061
113	965	992	1061
114	968	994	1062
115	970	996	1062
116	973	998	1062
117	975	1000	1063
118	977	1002	1063
119	980	1003	1063
120	982	1005	1064

U=unexposed to fire surface, MD=Mid-depth of slab, E=Exposed to fire surface

Results of Finite Element Analysis of 500x500x30mm FireCemX Slabs

Fire curve: ISO834

Time	U*	MD*	E*
0	20	20	20
1	20	20	171
2	20	21	258
3	20	22	318
4	20	24	364
5	20	27	402
6	20	31	434
7	20	36	461
8	21	42	484
9	21	49	506
10	21	56	525
11	22	64	542
12	23	72	558
13	24	80	573
14	26	89	586
15	27	97	599
16	29	106	611
17	32	115	622
18	34	123	633
19	37	132	642
20	40	141	652
21	43	149	661
22	47	158	669
23	50	166	678
24	54	174	686
25	59	182	693
26	63	190	700
27	67	198	707
28	72	206	714
29	77	214	720
30	82	222	727
31	87	229	733
32	93	237	738
33	98	244	744
34	104	252	750
35	109	259	755
36	115	266	760
37	121	274	765
38	127	281	770
39	133	288	775
40	139	294	779
41	145	301	784
42	151	308	788
43	158	315	793
44	164	321	797
45	170	328	801
46	176	335	805
47	183	341	809
48	189	347	813
49	195	354	817
50	202	360	821
51	208	366	824
52	214	373	828
53	221	379	831
54	227	385	835
55	234	391	838
56	240	397	842
57	246	403	845
58	253	409	848
59	259	415	851
60	265	420	855
61	272	426	858

Fire curve: Hydrocarbon

Time	U*	MD*	E*
0	20	20	20
1	20	20	345
2	20	21	485
3	20	24	564
4	20	28	621
5	20	34	665
6	20	41	702
7	21	50	733
8	21	61	760
9	22	72	783
10	23	84	803
11	24	96	820
12	26	109	836
13	28	122	849
14	30	134	861
15	33	147	872
16	36	160	882
17	40	173	890
18	44	185	898
19	49	197	905
20	53	210	911
21	59	221	917
22	64	233	922
23	70	244	927
24	76	255	931
25	83	266	935
26	89	277	939
27	96	287	943
28	103	297	946
29	111	307	949
30	118	316	951
31	126	326	954
32	133	335	957
33	141	344	959
34	149	353	961
35	157	362	963
36	165	370	965
37	173	379	967
38	181	387	969
39	190	395	970
40	198	403	972
41	206	410	974
42	214	418	975
43	223	426	977
44	231	433	978
45	239	440	979
46	247	447	981
47	255	454	982
48	263	461	983
49	272	468	984
50	280	475	986
51	288	482	987
52	296	488	988
53	304	495	989
54	311	501	990
55	319	507	991
56	327	513	992
57	335	520	993
58	342	526	994
59	350	532	995
60	357	538	996
61	365	543	997

Time	U*	MD*	E*
62	278	432	861
63	284	438	864
64	290	443	867
65	297	449	870
66	303	454	873
67	309	460	875
68	315	465	878
69	321	471	881
70	327	476	884
71	333	481	886
72	340	487	889
73	346	492	892
74	352	497	894
75	357	502	897
76	363	508	899
77	369	513	902
78	375	518	904
79	381	523	907
80	387	528	909
81	393	533	912
82	398	538	914
83	404	543	916
84	410	547	919
85	415	552	921
86	421	557	923
87	427	562	926
88	432	566	928
89	438	571	930
90	443	576	932
91	449	580	934
92	454	585	936
93	459	590	939
94	465	594	941
95	470	599	943
96	475	603	945
97	481	607	947
98	486	612	949
99	491	616	951
100	496	620	953
101	501	625	955
102	506	629	957
103	511	633	959
104	516	637	960
105	521	642	962
106	526	646	964
107	531	650	966
108	536	654	968
109	541	658	970
110	546	662	972
111	551	666	973
112	555	670	975
113	560	674	977
114	565	678	979
115	569	682	980
116	574	685	982
117	579	689	984
118	583	693	985
119	588	697	987
120	592	701	989

Time	U*	MD*	E*
62	372	549	998
63	380	555	999
64	387	560	1000
65	394	566	1001
66	401	571	1002
67	408	577	1002
68	415	582	1003
69	422	588	1004
70	429	593	1005
71	436	598	1006
72	443	603	1007
73	449	608	1007
74	456	613	1008
75	462	618	1009
76	469	623	1010
77	475	628	1010
78	482	633	1011
79	488	637	1012
80	494	642	1013
81	500	647	1013
82	506	651	1014
83	512	656	1015
84	518	660	1015
85	524	665	1016
86	530	669	1017
87	536	674	1018
88	542	678	1018
89	547	682	1019
90	553	686	1019
91	559	691	1020
92	564	695	1021
93	570	699	1021
94	575	703	1022
95	580	707	1023
96	586	711	1023
97	591	715	1024
98	596	718	1024
99	601	722	1025
100	606	726	1026
101	611	730	1026
102	616	734	1027
103	621	737	1027
104	626	741	1028
105	631	744	1028
106	635	748	1029
107	640	751	1030
108	645	755	1030
109	649	758	1031
110	654	762	1031
111	658	765	1032
112	663	768	1032
113	667	772	1033
114	672	775	1033
115	676	778	1034
116	680	781	1034
117	684	785	1035
118	688	788	1035
119	693	791	1036
120	697	794	1036

U=unexposed to fire surface, MD=Mid-depth of slab, E=Exposed to fire surface

Results of Finite Element Analysis of 500x500x40mm FireCemX Slabs

Fire curve: ISO834

Time	U*	MD*	E*
0	20	20	20
1	20	20	170
2	20	20	257
3	20	20	318
4	20	21	364
5	20	21	402
6	20	22	433
7	20	24	461
8	20	26	484
9	20	28	506
10	20	31	525
11	20	34	542
12	20	38	558
13	20	42	573
14	20	46	586
15	21	51	599
16	21	56	611
17	21	61	622
18	21	66	633
19	22	72	642
20	22	77	652
21	23	83	661
22	24	88	669
23	24	94	678
24	25	100	685
25	26	106	693
26	27	111	700
27	29	117	707
28	30	123	714
29	31	129	720
30	33	135	726
31	35	140	732
32	36	146	738
33	38	152	744
34	40	157	749
35	42	163	755
36	44	169	760
37	47	174	765
38	49	180	770
39	51	185	774
40	54	191	779
41	56	196	783
42	59	201	788
43	62	207	792
44	65	212	796
45	68	217	800
46	71	222	804
47	74	228	808
48	77	233	812
49	80	238	816
50	83	243	819
51	86	248	823
52	90	253	827
53	93	257	830
54	97	262	833
55	100	267	837
56	104	272	840
57	107	277	843
58	111	281	846
59	114	286	849
60	118	291	852
61	122	295	855

Fire curve: Hydrocarbon

Time	U*	MD*	E*
0	20	20	20
1	20	20	346
2	20	20	486
3	20	20	565
4	20	21	621
5	20	22	666
6	20	24	702
7	20	27	733
8	20	31	760
9	20	35	783
10	20	40	803
11	20	45	820
12	20	51	836
13	21	58	849
14	21	65	861
15	21	72	872
16	21	80	882
17	22	88	890
18	23	96	898
19	23	104	905
20	24	112	911
21	25	120	917
22	26	129	922
23	28	137	927
24	29	145	931
25	31	153	935
26	33	161	939
27	34	169	943
28	37	177	946
29	39	185	949
30	41	193	951
31	44	200	954
32	46	208	956
33	49	215	959
34	52	222	961
35	55	230	963
36	58	237	965
37	62	244	966
38	65	250	968
39	69	257	970
40	72	264	971
41	76	270	973
42	80	277	974
43	84	283	976
44	88	289	977
45	92	295	978
46	96	301	979
47	101	307	980
48	105	313	982
49	109	319	983
50	114	324	984
51	118	330	985
52	123	335	986
53	127	341	987
54	132	346	988
55	137	351	989
56	141	357	989
57	146	362	990
58	151	367	991
59	156	372	992
60	161	377	993
61	165	382	994

Time	U*	MD*	E*
62	126	300	858
63	129	304	861
64	133	309	864
65	137	313	867
66	141	318	870
67	145	322	872
68	149	327	875
69	153	331	878
70	157	335	880
71	161	340	883
72	165	344	885
73	169	348	888
74	173	353	890
75	177	357	893
76	181	361	895
77	185	365	897
78	189	369	900
79	193	373	902
80	197	377	904
81	201	382	907
82	205	386	909
83	209	390	911
84	213	394	913
85	217	398	915
86	221	401	917
87	225	405	919
88	229	409	922
89	234	413	924
90	238	417	926
91	242	421	928
92	246	425	930
93	250	429	932
94	254	432	934
95	258	436	935
96	262	440	937
97	266	444	939
98	270	447	941
99	274	451	943
100	278	455	945
101	282	458	947
102	286	462	948
103	290	466	950
104	294	469	952
105	298	473	954
106	302	476	955
107	306	480	957
108	310	484	959
109	314	487	961
110	318	491	962
111	322	494	964
112	326	498	966
113	330	501	967
114	334	505	969
115	338	508	970
116	342	511	972
117	346	515	974
118	350	518	975
119	354	522	977
120	358	525	978

Time	U*	MD*	E*
62	170	386	994
63	175	391	995
64	180	396	996
65	185	401	996
66	190	405	997
67	195	410	998
68	199	414	998
69	204	419	999
70	209	423	1000
71	214	428	1000
72	219	432	1001
73	224	436	1002
74	229	440	1002
75	234	445	1003
76	238	449	1003
77	243	453	1004
78	248	457	1005
79	253	461	1005
80	258	465	1006
81	263	469	1006
82	267	473	1007
83	272	477	1007
84	277	481	1008
85	282	485	1008
86	286	489	1009
87	291	492	1009
88	296	496	1010
89	300	500	1010
90	305	504	1011
91	310	507	1011
92	314	511	1012
93	319	514	1012
94	323	518	1013
95	328	522	1013
96	332	525	1013
97	337	529	1014
98	341	532	1014
99	346	536	1015
100	350	539	1015
101	355	542	1016
102	359	546	1016
103	364	549	1016
104	368	553	1017
105	372	556	1017
106	377	559	1018
107	381	562	1018
108	385	566	1018
109	389	569	1019
110	394	572	1019
111	398	575	1020
112	402	578	1020
113	406	582	1020
114	410	585	1021
115	414	588	1021
116	418	591	1022
117	422	594	1022
118	426	597	1022
119	430	600	1023
120	434	603	1023

U=unexposed to fire surface, MD=Mid-depth of slab, E=Exposed to fire surface

Fire curve: RWS

Time	U	MD	E
0	20	20	20
1	20	20	154
2	20	20	327
3	20	20	519
4	20	21	646
5	20	22	760
6	20	23	817
7	20	25	857
8	20	29	889
9	20	33	916
10	20	38	940
11	20	44	958
12	20	51	974
13	20	58	988
14	21	66	1001
15	21	74	1013
16	21	83	1024
17	22	92	1034
18	22	102	1044
19	23	111	1054
20	24	121	1063
21	25	131	1071
22	26	140	1079
23	28	150	1087
24	29	160	1095
25	31	169	1103
26	33	179	1110
27	35	188	1117
28	37	198	1124
29	40	207	1131
30	43	216	1138
31	45	226	1143
32	48	235	1148
33	52	244	1152
34	55	252	1156
35	59	261	1160
36	62	270	1164
37	66	278	1168
38	70	287	1171
39	74	295	1175
40	78	303	1178
41	83	311	1181
42	87	319	1184
43	92	327	1187
44	97	335	1190
45	101	342	1193
46	106	350	1196
47	111	357	1199
48	116	365	1202
49	122	372	1205
50	127	379	1208
51	132	386	1210
52	137	393	1213
53	143	400	1216
54	148	407	1218
55	154	413	1221
56	160	420	1224
57	165	427	1226
58	171	433	1229
59	177	440	1231
60	183	446	1234
61	188	452	1234
62	194	459	1235

Time	U*	MD*	E*
63	200	465	1235
64	206	471	1235
65	212	477	1235
66	218	483	1235
67	224	489	1235
68	230	495	1234
69	236	501	1234
70	242	506	1234
71	248	512	1233
72	254	518	1233
73	260	523	1232
74	266	529	1232
75	272	534	1231
76	278	539	1231
77	284	545	1230
78	290	550	1229
79	295	555	1229
80	301	560	1228
81	307	565	1227
82	313	570	1227
83	319	575	1226
84	325	580	1225
85	331	585	1224
86	337	589	1224
87	343	594	1223
88	349	599	1222
89	354	603	1221
90	360	608	1220
91	366	612	1219
92	372	617	1217
93	378	621	1215
94	383	625	1213
95	389	629	1211
96	395	634	1209
97	400	638	1206
98	406	642	1204
99	411	646	1202
100	417	650	1200
101	422	654	1197
102	428	658	1195
103	433	662	1193
104	439	665	1190
105	444	669	1188
106	449	673	1186
107	455	676	1183
108	460	680	1181
109	465	683	1178
110	470	687	1176
111	475	690	1174
112	480	694	1171
113	486	697	1169
114	491	700	1166
115	496	703	1164
116	501	707	1161
117	506	710	1159
118	510	713	1156
119	515	716	1154
120	520	719	1151

U=unexposed to fire surface, MD=Mid-depth of slab, E=Exposed to fire surface

Results of Finite Element Analysis of 500x500x50mm FireCemX Slabs

Fire curve: ISO834

Time	U*	MD*	E*
0	20	20	20
1	20	20	169
2	20	20	257
3	20	20	318
4	20	20	364
5	20	20	402
6	20	20	433
7	20	21	461
8	20	21	484
9	20	22	506
10	20	23	525
11	20	24	542
12	20	25	558
13	20	27	573
14	20	29	586
15	20	31	599
16	20	33	611
17	20	36	622
18	20	38	633
19	20	41	643
20	20	44	652
21	20	48	661
22	20	51	670
23	20	55	678
24	21	58	686
25	21	62	693
26	21	66	700
27	21	69	707
28	21	73	714
29	22	77	720
30	22	81	726
31	22	85	732
32	23	90	738
33	23	94	744
34	24	98	749
35	24	102	755
36	25	106	760
37	26	110	765
38	26	115	770
39	27	119	774
40	28	123	779
41	29	127	783
42	29	131	788
43	30	136	792
44	31	140	796
45	32	144	800
46	34	148	804
47	35	152	808
48	36	156	812
49	37	160	816
50	38	165	819
51	40	169	823
52	41	173	826
53	43	177	830
54	44	181	833
55	46	185	837
56	47	189	840
57	49	193	843
58	50	196	846
59	52	200	849

Fire curve: Hydrocarbon

Time	U*	MD*	E*
0	20	20	20
1	20	20	343
2	20	20	485
3	20	20	565
4	20	20	621
5	20	20	666
6	20	21	702
7	20	21	733
8	20	22	760
9	20	24	783
10	20	25	803
11	20	27	820
12	20	30	836
13	20	32	849
14	20	35	861
15	20	39	872
16	20	43	882
17	20	47	890
18	20	51	898
19	20	56	905
20	20	61	911
21	21	66	917
22	21	71	922
23	21	76	927
24	21	81	931
25	21	87	935
26	22	92	939
27	22	98	943
28	22	103	946
29	23	109	949
30	23	115	951
31	24	120	954
32	25	126	956
33	25	132	959
34	26	137	961
35	27	143	963
36	28	149	965
37	29	154	966
38	30	160	968
39	31	165	970
40	32	171	971
41	34	176	973
42	35	181	974
43	36	187	976
44	38	192	977
45	40	197	978
46	41	202	979
47	43	207	980
48	45	212	982
49	46	217	983
50	48	222	984
51	50	227	985
52	52	232	986
53	54	237	987
54	56	241	988
55	59	246	988
56	61	250	989
57	63	255	990
58	65	259	991
59	68	264	992

Time	U*	MD*	E*
60	54	204	852
61	56	208	855
62	58	212	858
63	59	216	861
64	61	219	864
65	63	223	867
66	65	227	869
67	67	231	872
68	69	234	875
69	71	238	877
70	73	242	880
71	76	245	882
72	78	249	885
73	80	252	887
74	82	256	890
75	84	260	892
76	87	263	894
77	89	267	897
78	91	270	899
79	94	274	901
80	96	277	904
81	99	280	906
82	101	284	908
83	103	287	910
84	106	291	912
85	108	294	914
86	111	297	916
87	114	301	919
88	116	304	921
89	119	307	923
90	121	310	925
91	124	314	926
92	126	317	928
93	129	320	930
94	132	323	932
95	134	326	934
96	137	330	936
97	140	333	938
98	142	336	940
99	145	339	941
100	148	342	943
101	151	345	945
102	153	348	947
103	156	351	948
104	159	354	950
105	162	358	952
106	164	361	954
107	167	364	955
108	170	367	957
109	173	370	958
110	176	372	960
111	178	375	962
112	181	378	963
113	184	381	965
114	187	384	966
115	190	387	968
116	192	390	969
117	195	393	971
118	198	396	973
119	201	399	974
120	204	402	976

Time	U*	MD*	E*
60	70	268	992
61	73	272	993
62	75	277	994
63	78	281	995
64	80	285	995
65	83	289	996
66	86	293	997
67	88	297	997
68	91	301	998
69	94	305	999
70	97	309	999
71	99	313	1000
72	102	317	1000
73	105	321	1001
74	108	324	1002
75	111	328	1002
76	114	332	1003
77	117	335	1003
78	120	339	1004
79	123	342	1004
80	126	346	1005
81	129	349	1005
82	132	353	1006
83	135	356	1006
84	138	360	1007
85	141	363	1007
86	145	367	1007
87	148	370	1008
88	151	373	1008
89	154	376	1009
90	157	380	1009
91	160	383	1010
92	164	386	1010
93	167	389	1010
94	170	392	1011
95	173	395	1011
96	176	398	1012
97	179	402	1012
98	183	405	1012
99	186	408	1013
100	189	411	1013
101	192	414	1013
102	196	416	1014
103	199	419	1014
104	202	422	1014
105	205	425	1015
106	208	428	1015
107	212	431	1015
108	215	434	1016
109	218	437	1016
110	221	439	1016
111	224	442	1017
112	228	445	1017
113	231	448	1017
114	234	450	1018
115	237	453	1018
116	240	456	1018
117	244	458	1019
118	247	461	1019
119	250	464	1019
120	253	466	1019

U=unexposed to fire surface, MD=Mid-depth of slab, E=Exposed to fire surface

Fire curve: RWS

Time	U*	MD*	E*
0	20	20	20
1	20	20	153
2	20	20	326
3	20	20	518
4	20	20	646
5	20	20	759
6	20	20	817
7	20	21	857
8	20	22	889
9	20	23	916
10	20	24	940
11	20	26	958
12	20	29	974
13	20	32	988
14	20	35	1001
15	20	39	1013
16	20	43	1024
17	20	47	1034
18	20	52	1044
19	20	58	1054
20	20	63	1063
21	20	69	1071
22	21	75	1079
23	21	81	1087
24	21	87	1095
25	21	93	1103
26	22	100	1110
27	22	106	1117
28	22	113	1124
29	23	120	1131
30	24	126	1138
31	24	133	1143
32	25	140	1148
33	26	147	1152
34	27	153	1156
35	27	160	1160
36	29	167	1164
37	30	173	1168
38	31	180	1171
39	32	187	1175
40	33	193	1178
41	35	200	1181
42	36	206	1184
43	38	213	1187
44	40	219	1190
45	42	225	1193
46	43	232	1196
47	45	238	1199
48	47	244	1202
49	49	250	1205
50	52	256	1208
51	54	262	1210
52	56	268	1213
53	59	274	1216
54	61	280	1218
55	64	286	1221
56	66	292	1223
57	69	297	1226
58	72	303	1228
59	74	308	1231

Time	U*	MD*	E*
60	77	314	1233
61	80	319	1234
62	83	325	1235
63	86	330	1235
64	89	336	1235
65	92	341	1235
66	95	346	1235
67	99	351	1234
68	102	356	1234
69	105	361	1234
70	108	366	1233
71	112	371	1233
72	115	376	1232
73	119	381	1232
74	122	386	1231
75	126	391	1230
76	129	395	1230
77	133	400	1229
78	137	405	1228
79	140	409	1228
80	144	414	1227
81	148	418	1226
82	151	423	1225
83	155	427	1225
84	159	431	1224
85	163	435	1223
86	166	440	1222
87	170	444	1221
88	174	448	1220
89	178	452	1220
90	182	456	1219
91	186	460	1217
92	190	464	1215
93	193	468	1213
94	197	472	1211
95	201	475	1209
96	205	479	1206
97	209	483	1204
98	213	487	1202
99	217	490	1200
100	221	494	1197
101	225	497	1195
102	229	501	1192
103	233	504	1190
104	237	508	1188
105	241	511	1185
106	245	515	1183
107	249	518	1180
108	253	521	1178
109	257	524	1175
110	261	528	1173
111	265	531	1170
112	269	534	1167
113	272	537	1165
114	276	540	1162
115	280	543	1160
116	284	546	1157
117	288	549	1155
118	292	552	1152
119	296	555	1149
120	300	557	1147

U=unexposed to fire surface, MD=Mid-depth of slab, E=Exposed to fire surface

Appendix D

Results of Finite Element Analysis of 500x500x20mm FireCemY Slabs

Fire curve: ISO834				Fire curve: Hydrocarbon			
Time	U*	MD*	E*	Time	U*	MD*	E*
0	20	20	20	0	20	20	20
1	20	21	166	1	20	23	338
2	20	25	250	2	20	31	472
3	21	32	310	3	21	45	550
4	21	42	355	4	23	62	606
5	23	53	393	5	26	83	650
6	25	66	424	6	30	105	687
7	28	80	451	7	35	128	719
8	32	94	475	8	43	151	745
9	37	109	496	9	51	173	769
10	43	123	516	10	61	195	789
11	50	138	533	11	73	217	807
12	57	152	549	12	85	238	823
13	65	166	564	13	98	259	837
14	74	180	578	14	112	278	849
15	83	194	590	15	127	298	860
16	93	207	602	16	142	316	870
17	103	220	614	17	158	334	880
18	114	233	625	18	174	352	888
19	125	246	635	19	190	369	895
20	136	259	645	20	207	385	902
21	147	271	654	21	223	401	908
22	158	283	663	22	239	417	914
23	170	295	671	23	256	432	920
24	181	307	679	24	272	447	925
25	193	318	687	25	288	461	929
26	204	330	695	26	304	475	934
27	216	341	702	27	320	489	938
28	227	352	709	28	336	502	942
29	239	363	716	29	351	515	945
30	250	373	723	30	367	527	949
31	262	384	729	31	382	540	952
32	273	394	736	32	396	552	955
33	284	405	742	33	411	563	959
34	295	415	748	34	425	575	962
35	307	425	754	35	439	586	964
36	318	435	759	36	453	597	967
37	328	444	765	37	466	608	970
38	339	454	770	38	480	618	972
39	350	463	776	39	493	628	975
40	360	473	781	40	505	638	977
41	371	482	786	41	518	648	980
42	381	491	791	42	530	657	982
43	391	500	796	43	542	667	984
44	402	509	801	44	554	676	986
45	412	517	805	45	565	685	988
46	421	526	810	46	576	693	990
47	431	534	815	47	587	702	992
48	441	542	819	48	598	710	994
49	450	551	823	49	609	718	996
50	460	559	828	50	619	726	998
51	469	567	832	51	629	734	1000
52	478	574	836	52	639	741	1002
53	487	582	840	53	649	749	1003
54	496	590	844	54	658	756	1005
55	505	597	848	55	667	763	1007
56	513	605	852	56	676	770	1008
57	522	612	855	57	685	777	1010
58	530	619	859	58	694	784	1012
59	538	626	863	59	702	790	1013

Time	U*	MD*	E*
60	547	633	866
61	555	640	870
62	563	647	873
63	571	653	877
64	578	660	880
65	586	666	884
66	593	673	887
67	601	679	890
68	608	685	893
69	615	691	896
70	622	697	899
71	629	703	903
72	636	709	906
73	643	715	908
74	650	721	911
75	657	726	914
76	663	732	917
77	669	737	920
78	676	743	923
79	682	748	925
80	688	753	928
81	694	758	931
82	700	763	933
83	706	768	936
84	712	773	938
85	718	778	941
86	723	783	943
87	729	788	946
88	734	792	948
89	740	797	951
90	745	801	953
91	750	806	955
92	756	810	958
93	761	815	960
94	766	819	962
95	771	823	964
96	776	827	966
97	780	831	969
98	785	835	971
99	790	839	973
100	794	843	975
101	799	847	977
102	803	851	979
103	808	855	981
104	812	858	983
105	817	862	985
106	821	866	987
107	825	869	989
108	829	873	991
109	833	876	993
110	837	880	995
111	841	883	996
112	845	886	998
113	849	890	1000
114	853	893	1002
115	857	896	1004
116	860	899	1005
117	864	902	1007
118	867	905	1009
119	871	909	1010
120	875	912	1012

Time	U*	MD*	E*
60	710	796	1015
61	718	803	1016
62	726	809	1017
63	734	815	1019
64	742	820	1020
65	749	826	1021
66	756	832	1023
67	763	837	1024
68	770	842	1025
69	777	848	1026
70	784	853	1028
71	790	858	1029
72	797	863	1030
73	803	867	1031
74	809	872	1032
75	815	877	1033
76	821	881	1034
77	826	885	1035
78	832	890	1036
79	837	894	1037
80	843	898	1038
81	848	902	1039
82	853	906	1040
83	858	910	1041
84	863	913	1042
85	868	917	1042
86	872	921	1043
87	877	924	1044
88	881	927	1045
89	886	931	1046
90	890	934	1046
91	894	937	1047
92	898	940	1048
93	902	943	1048
94	906	946	1049
95	910	949	1050
96	913	952	1051
97	917	955	1051
98	921	958	1052
99	924	960	1052
100	928	963	1053
101	931	966	1054
102	934	968	1054
103	937	971	1055
104	940	973	1055
105	944	975	1056
106	947	978	1056
107	949	980	1057
108	952	982	1057
109	955	984	1058
110	958	986	1058
111	961	988	1059
112	963	990	1059
113	966	992	1060
114	968	994	1060
115	971	996	1061
116	973	998	1061
117	975	1000	1061
118	978	1002	1062
119	980	1003	1062
120	982	1005	1063

U=unexposed to fire surface, MD=Mid-depth of slab, E=Exposed to fire surface

Results of Finite Element Analysis of 500x500x30mm FireCemY Slabs

Fire curve: ISO834

Time	U*	MD*	E*
0	20	20	20
1	20	20	166
2	20	21	250
3	20	22	309
4	20	24	355
5	20	27	393
6	20	31	424
7	20	37	451
8	21	43	475
9	21	49	496
10	22	57	516
11	22	64	533
12	23	72	549
13	24	81	564
14	26	89	577
15	28	97	590
16	30	106	602
17	32	115	613
18	34	123	624
19	37	132	634
20	40	141	644
21	44	149	653
22	47	157	661
23	51	166	670
24	55	174	677
25	59	182	685
26	64	190	692
27	69	198	699
28	73	206	706
29	78	214	713
30	83	222	719
31	89	229	725
32	94	237	731
33	100	244	737
34	105	252	742
35	111	259	748
36	117	266	753
37	123	273	758
38	129	280	763
39	135	287	768
40	141	294	772
41	147	301	777
42	153	308	781
43	159	315	786
44	166	321	790
45	172	328	794
46	178	335	798
47	185	341	802
48	191	348	806
49	197	354	810
50	204	360	814
51	210	366	818
52	217	373	821
53	223	379	825
54	229	385	829
55	236	391	832
56	242	397	835
57	249	403	839
58	255	409	842
59	261	415	845
60	268	421	849
61	274	426	852

Fire curve: Hydrocarbon

Time	U*	MD*	E*
0	20	20	20
1	20	20	332
2	20	21	470
3	20	24	549
4	20	28	605
5	20	34	650
6	20	41	687
7	21	51	718
8	21	61	745
9	22	72	769
10	23	84	789
11	24	96	807
12	26	109	823
13	28	122	836
14	31	135	849
15	34	147	860
16	37	160	870
17	41	173	879
18	45	185	887
19	49	197	894
20	54	209	900
21	60	221	906
22	65	233	912
23	71	244	917
24	78	255	921
25	84	266	926
26	91	276	929
27	98	287	933
28	105	297	936
29	112	307	939
30	120	316	942
31	128	326	945
32	135	335	948
33	143	344	950
34	151	353	952
35	159	361	955
36	167	370	957
37	176	378	959
38	184	387	961
39	192	395	962
40	200	403	964
41	209	410	966
42	217	418	967
43	225	425	969
44	234	433	971
45	242	440	972
46	250	447	973
47	258	454	975
48	266	461	976
49	274	468	977
50	283	475	979
51	291	482	980
52	299	488	981
53	307	495	982
54	314	501	983
55	322	507	985
56	330	514	986
57	338	520	987
58	345	526	988
59	353	532	989
60	361	538	990
61	368	544	991

Time	U*	MD*	E*
62	280	432	855
63	287	438	858
64	293	443	861
65	299	449	864
66	305	455	867
67	312	460	870
68	318	466	873
69	324	471	875
70	330	476	878
71	336	482	881
72	342	487	884
73	348	492	886
74	354	498	889
75	360	503	892
76	366	508	894
77	372	513	897
78	378	518	899
79	384	523	902
80	390	528	904
81	395	533	907
82	401	538	909
83	407	543	911
84	413	548	914
85	418	553	916
86	424	558	918
87	430	562	921
88	435	567	923
89	441	572	925
90	446	577	927
91	452	581	930
92	457	586	932
93	462	590	934
94	468	595	936
95	473	599	938
96	478	604	940
97	484	608	942
98	489	613	944
99	494	617	946
100	499	621	948
101	504	626	950
102	509	630	952
103	514	634	954
104	519	638	956
105	524	642	958
106	529	647	960
107	534	651	962
108	539	655	964
109	544	659	966
110	549	663	967
111	554	667	969
112	558	671	971
113	563	675	973
114	568	679	975
115	572	683	976
116	577	686	978
117	582	690	980
118	586	694	982
119	591	698	983
120	595	702	985

Time	U*	MD*	E*
62	375	550	992
63	383	555	993
64	390	561	994
65	397	566	995
66	404	572	996
67	412	577	997
68	419	583	998
69	425	588	999
70	432	593	1000
71	439	599	1000
72	446	604	1001
73	453	609	1002
74	459	614	1003
75	466	619	1004
76	472	624	1005
77	479	629	1005
78	485	633	1006
79	491	638	1007
80	498	643	1008
81	504	648	1009
82	510	652	1009
83	516	657	1010
84	522	661	1011
85	528	666	1012
86	534	670	1012
87	539	675	1013
88	545	679	1014
89	551	683	1014
90	556	687	1015
91	562	692	1016
92	567	696	1017
93	573	700	1017
94	578	704	1018
95	584	708	1019
96	589	712	1019
97	594	716	1020
98	599	720	1021
99	604	723	1021
100	609	727	1022
101	614	731	1022
102	619	735	1023
103	624	738	1024
104	629	742	1024
105	634	746	1025
106	639	749	1025
107	643	753	1026
108	648	756	1027
109	652	760	1027
110	657	763	1028
111	662	766	1028
112	666	770	1029
113	670	773	1029
114	675	776	1030
115	679	779	1030
116	683	783	1031
117	687	786	1031
118	692	789	1032
119	696	792	1032
120	700	795	1033

U=unexposed to fire surface, MD=Mid-depth of slab, E=Exposed to fire surface

Results of Finite Element Analysis of 500x500x40mm FireCemY Slabs

Fire curve: ISO834

Time	U*	MD*	E*
0	20	20	20
1	20	20	164
2	20	20	250
3	20	20	309
4	20	21	355
5	20	21	393
6	20	22	424
7	20	24	451
8	20	26	475
9	20	28	496
10	20	31	516
11	20	34	533
12	20	38	549
13	20	42	564
14	20	47	577
15	21	51	590
16	21	56	602
17	21	61	613
18	22	67	624
19	22	72	634
20	23	77	644
21	23	83	653
22	24	89	661
23	25	94	670
24	26	100	677
25	27	106	685
26	28	112	692
27	29	118	699
28	30	124	706
29	32	129	713
30	33	135	719
31	35	141	725
32	37	147	731
33	39	152	736
34	41	158	742
35	43	164	747
36	45	169	752
37	47	175	758
38	50	180	762
39	52	186	767
40	55	191	772
41	58	197	776
42	60	202	781
43	63	207	785
44	66	213	789
45	69	218	793
46	72	223	798
47	75	228	801
48	78	233	805
49	81	238	809
50	85	243	813
51	88	248	816
52	91	253	820
53	95	258	823
54	98	263	827
55	102	268	830
56	106	273	833
57	109	277	837
58	113	282	840
59	117	287	843
60	120	291	846

Fire curve: Hydrocarbon

Time	U*	MD*	E*
0	20	20	20
1	20	20	333
2	20	20	471
3	20	20	550
4	20	21	606
5	20	23	651
6	20	25	687
7	20	27	719
8	20	31	746
9	20	35	769
10	20	40	789
11	20	46	807
12	20	52	823
13	21	59	837
14	21	66	849
15	21	73	860
16	22	81	870
17	22	88	879
18	23	97	887
19	24	105	894
20	24	113	900
21	26	121	906
22	27	129	912
23	28	138	917
24	30	146	921
25	31	154	926
26	33	162	929
27	35	170	933
28	37	178	936
29	40	186	939
30	42	193	942
31	45	201	945
32	47	209	947
33	50	216	950
34	53	223	952
35	56	230	954
36	60	237	956
37	63	244	958
38	67	251	960
39	70	258	962
40	74	264	963
41	78	271	965
42	82	277	966
43	86	284	968
44	90	290	969
45	94	296	971
46	98	302	972
47	103	308	973
48	107	314	974
49	112	319	976
50	116	325	977
51	121	331	978
52	125	336	979
53	130	342	980
54	135	347	981
55	139	352	982
56	144	357	983
57	149	363	984
58	154	368	985
59	159	373	985
60	163	378	986

Time	U*	MD*	E*
61	124	296	849
62	128	301	852
63	132	305	855
64	136	310	858
65	139	314	861
66	143	319	863
67	147	323	866
68	151	328	869
69	155	332	872
70	159	336	874
71	163	341	877
72	167	345	879
73	171	349	882
74	175	353	884
75	179	358	887
76	183	362	889
77	187	366	892
78	192	370	894
79	196	374	896
80	200	378	899
81	204	382	901
82	208	387	903
83	212	391	905
84	216	395	908
85	220	399	910
86	224	403	912
87	229	406	914
88	233	410	916
89	237	414	918
90	241	418	920
91	245	422	922
92	249	426	924
93	253	430	926
94	257	434	928
95	261	437	930
96	266	441	932
97	270	445	934
98	274	449	936
99	278	452	938
100	282	456	940
101	286	460	941
102	290	463	943
103	294	467	945
104	298	471	947
105	302	474	949
106	306	478	950
107	310	481	952
108	314	485	954
109	318	489	956
110	322	492	957
111	326	496	959
112	330	499	961
113	334	503	962
114	338	506	964
115	342	509	966
116	346	513	967
117	350	516	969
118	354	520	970
119	358	523	972
120	362	526	974

Time	U*	MD*	E*
61	168	383	987
62	173	387	988
63	178	392	989
64	183	397	989
65	188	402	990
66	193	406	991
67	198	411	992
68	203	415	992
69	208	420	993
70	213	424	994
71	217	429	995
72	222	433	995
73	227	437	996
74	232	442	996
75	237	446	997
76	242	450	998
77	247	454	998
78	252	458	999
79	257	462	1000
80	261	466	1000
81	266	470	1001
82	271	474	1001
83	276	478	1002
84	281	482	1002
85	285	486	1003
86	290	490	1003
87	295	494	1004
88	300	497	1005
89	304	501	1005
90	309	505	1006
91	314	509	1006
92	318	512	1007
93	323	516	1007
94	327	520	1008
95	332	523	1008
96	337	527	1009
97	341	530	1009
98	346	534	1010
99	350	537	1010
100	355	541	1010
101	359	544	1011
102	363	547	1011
103	368	551	1012
104	372	554	1012
105	377	557	1013
106	381	561	1013
107	385	564	1014
108	389	567	1014
109	394	571	1014
110	398	574	1015
111	402	577	1015
112	406	580	1016
113	410	583	1016
114	415	586	1017
115	419	590	1017
116	423	593	1017
117	427	596	1018
118	431	599	1018
119	435	602	1019
120	439	605	1019

U=unexposed to fire surface, MD=Mid-depth of slab, E=Exposed to fire surface

Results of Finite Element Analysis of 500x500x50mm FireCemY Slabs

Fire curve: ISO834				Fire curve: Hydrocarbon			
Time	**U***	**MD***	**E***	**Time**	**U***	**MD***	**E***
0	20	20	20	**0**	20	20	20
1	20	20	163	**1**	20	20	330
2	20	20	249	**2**	20	20	470
3	20	20	309	**3**	20	20	549
4	20	20	355	**4**	20	20	606
5	20	20	393	**5**	20	20	651
6	20	20	424	**6**	20	21	688
7	20	21	451	**7**	20	21	719
8	20	21	475	**8**	20	22	746
9	20	22	496	**9**	20	24	769
10	20	23	516	**10**	20	25	789
11	20	24	533	**11**	20	27	807
12	20	25	549	**12**	20	30	823
13	20	27	564	**13**	20	33	837
14	20	29	577	**14**	20	36	849
15	20	31	590	**15**	20	39	860
16	20	34	602	**16**	20	43	870
17	20	36	613	**17**	20	47	879
18	20	39	624	**18**	20	52	887
19	20	42	634	**19**	20	56	894
20	20	45	644	**20**	20	61	901
21	20	48	653	**21**	21	66	906
22	20	52	661	**22**	21	71	912
23	21	55	670	**23**	21	77	917
24	21	59	677	**24**	21	82	921
25	21	62	685	**25**	21	88	926
26	21	66	692	**26**	22	93	929
27	21	70	699	**27**	22	99	933
28	22	74	706	**28**	23	104	936
29	22	78	713	**29**	23	110	939
30	22	82	719	**30**	24	116	942
31	23	86	725	**31**	24	122	945
32	23	90	731	**32**	25	127	948
33	23	94	736	**33**	26	133	950
34	24	99	742	**34**	27	139	952
35	25	103	747	**35**	28	144	954
36	25	107	752	**36**	28	150	956
37	26	111	758	**37**	30	155	958
38	27	115	762	**38**	31	161	960
39	27	120	767	**39**	32	166	962
40	28	124	772	**40**	33	172	963
41	29	128	776	**41**	34	177	965
42	30	132	781	**42**	36	183	966
43	31	137	785	**43**	37	188	968
44	32	141	789	**44**	39	193	969
45	33	145	793	**45**	40	198	971
46	34	149	797	**46**	42	204	972
47	35	153	801	**47**	44	209	973
48	37	157	805	**48**	46	214	974
49	38	161	809	**49**	48	219	975
50	39	166	813	**50**	49	223	977
51	41	170	816	**51**	51	228	978
52	42	174	820	**52**	54	233	979
53	43	178	823	**53**	56	238	980
54	45	182	827	**54**	58	243	981
55	47	186	830	**55**	60	247	982
56	48	190	833	**56**	62	252	983
57	50	194	837	**57**	65	256	983
58	52	197	840	**58**	67	261	984
59	53	201	843	**59**	69	265	985
60	55	205	846	**60**	72	269	986
61	57	209	849	**61**	75	274	987

Time	U*	MD*	E*
62	59	213	852
63	61	217	855
64	63	221	858
65	65	224	860
66	67	228	863
67	69	232	866
68	71	235	869
69	73	239	871
70	75	243	874
71	77	246	876
72	80	250	879
73	82	254	881
74	84	257	884
75	86	261	886
76	89	264	889
77	91	268	891
78	93	271	893
79	96	275	896
80	98	278	898
81	101	282	900
82	103	285	902
83	106	288	904
84	108	292	907
85	111	295	909
86	113	299	911
87	116	302	913
88	118	305	915
89	121	308	917
90	124	312	919
91	126	315	921
92	129	318	923
93	132	321	925
94	134	325	927
95	137	328	929
96	140	331	931
97	143	334	932
98	145	337	934
99	148	341	936
100	151	344	938
101	154	347	940
102	156	350	941
103	159	353	943
104	162	356	945
105	165	359	947
106	167	362	948
107	170	365	950
108	173	368	952
109	176	371	953
110	179	374	955
111	182	377	957
112	184	380	958
113	187	383	960
114	190	386	961
115	193	389	963
116	196	392	964
117	199	395	966
118	202	397	967
119	204	400	969
120	207	403	971

Time	U*	MD*	E*
62	77	278	988
63	80	282	988
64	82	286	989
65	85	291	990
66	88	295	991
67	90	299	991
68	93	303	992
69	96	307	993
70	99	311	993
71	102	314	994
72	105	318	994
73	108	322	995
74	111	326	996
75	114	329	996
76	117	333	997
77	120	337	997
78	123	340	998
79	126	344	998
80	129	347	999
81	132	351	1000
82	135	354	1000
83	138	358	1001
84	141	361	1001
85	144	365	1002
86	148	368	1002
87	151	371	1002
88	154	375	1003
89	157	378	1003
90	160	381	1004
91	164	384	1004
92	167	388	1005
93	170	391	1005
94	173	394	1006
95	177	397	1006
96	180	400	1006
97	183	403	1007
98	186	406	1007
99	190	409	1008
100	193	412	1008
101	196	415	1008
102	199	418	1009
103	203	421	1009
104	206	424	1010
105	209	427	1010
106	212	430	1010
107	216	433	1011
108	219	436	1011
109	222	438	1011
110	225	441	1012
111	228	444	1012
112	232	447	1012
113	235	450	1013
114	238	452	1013
115	241	455	1013
116	245	458	1014
117	248	460	1014
118	251	463	1014
119	254	466	1015
120	257	468	1015

U=unexposed to fire surface, MD=Mid-depth of slab, E=Exposed to fire surface

Appendix E

Finite Element Thermal Analysis of FireCemY slabs thickness 50,40,30 and 20 mm under ISO834 and Hydrocarbon fire curves