Durability of Self-Compacting Concrete with polypropylene fibres

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ABSTRACT

This paper outlines studies on the durability of Self-Compacting Concrete with polypropylene fibres and an estimation of the amount of ppf to mitigate fire spalling. Both Self-Compacting Concrete and normal concrete were studied. Frost resistance of concrete with fibres suffered a decrease as compared to concrete without fibres. Chloride migration was not affected by ppf. Lower coefficient of thermal expansion and creep was observed with ppf in SCC than without polypropylene fibres. To estimate the required amount of ppf 360 tests were evaluated. The polypropylene fibre diameter had a dominating effect (diameter ≤18 μm to be selected). The amount of polypropylene fibres may be 0.7 kg/m³ for indoor concrete and 1.4 kg/m³ for tunnel applications.

Key-words: Chloride migration, Durability, Explosive spalling, Fire resistance, Frost resistance, Polypropylene fibres, Self-Compacting Concrete.

1. BACKGROUND AND OBJECTIVE

1. Background and objective

Self-Compacting Concrete, SCC, with polypropylene fibres, ppf, have proven to be efficient to avoid fire spalling [1–6]. The hypothesis of the effect of ppf in concrete is that ppf lower the permeability at temperature less than the melting point of ppf, i.e. 160 °C [4]. At lower temperature, i.e. inward the concrete at fire, the moisture at fire will move out of the concrete instead of inward. Normally, without ppf, the moisture move inward the concrete building up high pressure, the basis for explosive spalling. With evaporating ppf at the surface of the concrete, i.e. above the melting point of ppf, the moisture more easily move towards the surface and then out of the concrete instead of inward [4]. The performance of ppf in concrete at high temperature has thus been explained with lower permeability at temperature lower than the melting point of the ppf, i.e. 160 °C, than that of concrete without ppf, and larger permeability at temperature above the melting point of the ppf, i.e. 160 °C, than that of concrete without ppf [4,7]. SCC is defined by its high fluidity, i.e. slump flow of about 700 mm, and no segregation [4,5]. For this purpose either high content of filler is required in SCC or viscosity agent. Examples of 21 SCC, testing age and so forth are given in the Appendices. The efficiency of ppf for this purpose was first shown for High-Performance Concrete, HPC, during the construction of the Frankfurt sky line [8]. Ppf thus are required in order to obtain explosive fire spalling resistance of SCC in severe condition, i.e. SCC with low w/c. In severe conditions a durability exploration in turn is essential. According to the present recommendations 2 kg/m³ of 18 μm ppf has to be introduced in tunnel concrete in order to prevent fire spalling [9]. As regards the effect of ppf fibres in SCC one major report exists, dealing with plastic shrinkage, which seems to be increased as compared with normal concrete, NC, mainly due the high filler content of SCC [10]. The filler in SCC absorbs the surface water of SCC, in turn leading to rapid evaporation at early age, the main reason for plastic shrinkage [10]. Previously it has been shown that shrinkage and creep of SCC without ppf were within the same order as for NC [11]. The alternative to using ppf additive in SCC is to cover all concrete with fire insulation which is more costly and also requires an increase of space, for a tunnel an increase of excavation. The purpose of the project was to investigate durability aspects of SCC with ppf and of comparable NC, and give recommendations on the required ppf amount in SCC to prevent explosive spalling, for indoor and outdoor concrete.

2. DURABILITY OF NC AND SCC WITH AND WITHOUT PPF

2.1 General

Before ppf may be used in concrete under severe conditions it must be ensured that durability effects other than fire resistance are not affected. Therefore some durability effects were briefly investigated, such as:

1. Chloride migration
2. Transient strain at high temperatures
3. Frost resistance, internal and salt frost scaling
4. Thermal expansion and shrinkage at high temperatures
5. Sulphate resistance

2.2 Chloride migration and sulphate resistance

The chloride migration coefficient, D, of NC and SCC, with and without ppf, did not differ significantly. Probably the chloride migration coefficient was somewhat smaller for SCC with ppf than for SCC without ppf, Figure 1 [12]. The measurement of D was performed with the Tang method, NT BUILD 492 [13,14]. Estimations of D were done with the following equation defined for D of SCC without ppf, Figure 2 [15] (x10 ^{12} m²/s), Appendices 1-2:

$$D = [(0.0055\cdot\ln(t)-0.2122)\cdot c-3.5\cdot\ln(t)+104]\cdot(4\cdot w/c-1.2)/0.4 \quad (1)$$

c denotes the cement content ($375 < c < 450$ kg/m³)
ln(t) denotes the natural logarithm of concrete age at the start of testing ($1 < t < 36$ months)
w/c denotes the water-cement ratio ($0.35 < w/c < 0.50$)
D denotes the chloride migration coefficient ($x10^{-12}$ m²/s)

Equation (1) shows the dominating parameters that affect D, i.e. age, which in turn affect the permeability, cement content due to its chloride binding ability, mainly of the aluminates, and w/c, which has an influence on the permeability [14]. D estimated for SCC with ppf coincided well with D for SCC without ppf, i.e. no significant difference due to the compaction method was observed, Appendix 3. However, D was somewhat larger for SCC with viscosity agent (without filler) than foreseen with the equation (1). Sulphate resistance was observed for five years at 5 °C with a solution of 18 g/l sodium sulphate in distilled water. The research on the sulphate resistance showed extensive deterioration for all SCC with limestone powder after 5 years due to Thaumasite Sulphate Attack, TSA, Appendix 2, Figure 3 [12]. SCC itself exhibited much lower permeability than NC, but lower permeability was inconsistent since TSA deteriorates the cement paste. The permeability is inconsistent in this respect, Figure 4 [16].

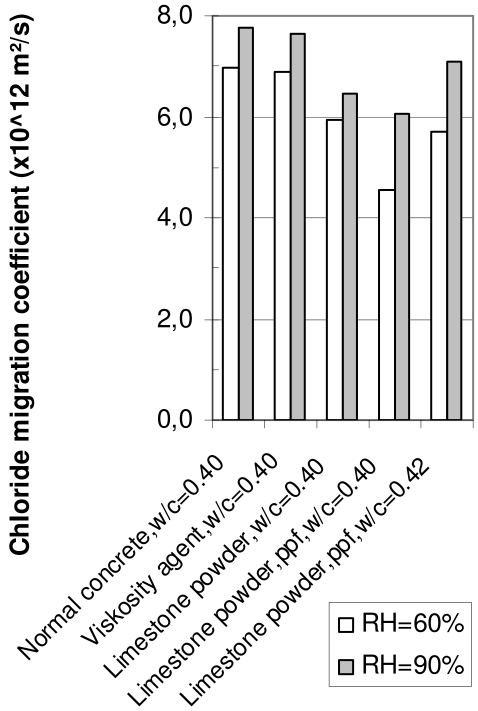

Figure 1 – Chloride migration coefficient of NC and SCC, 1.4 kg/m³ 18 µm ppf.

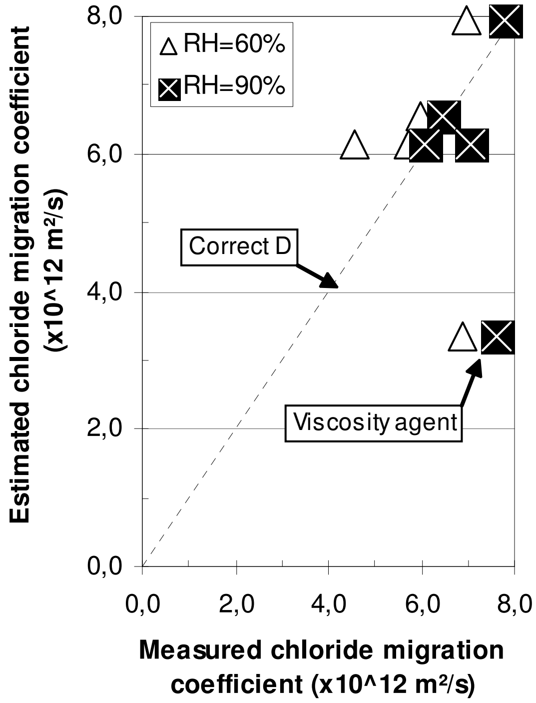

Figure 2 – Estimated chloride migration coefficient versus measured RH = 60% or 90%.

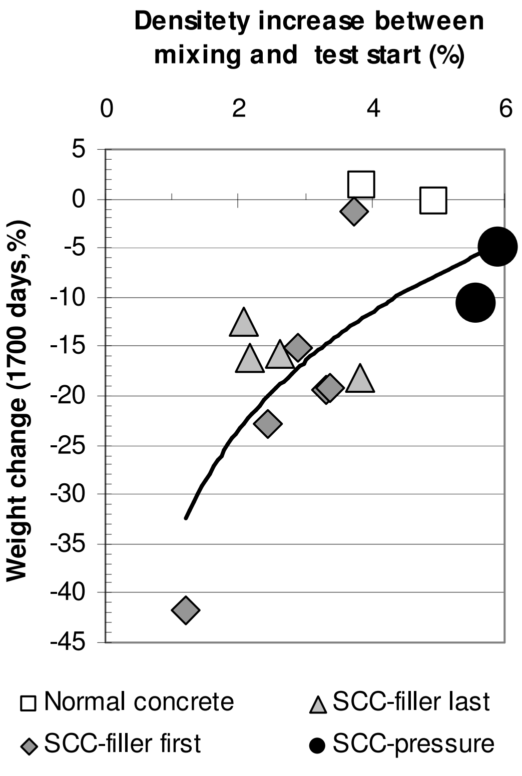

Figure 3 – Five-year effect of TSA on NC and SCC vs density change [11].

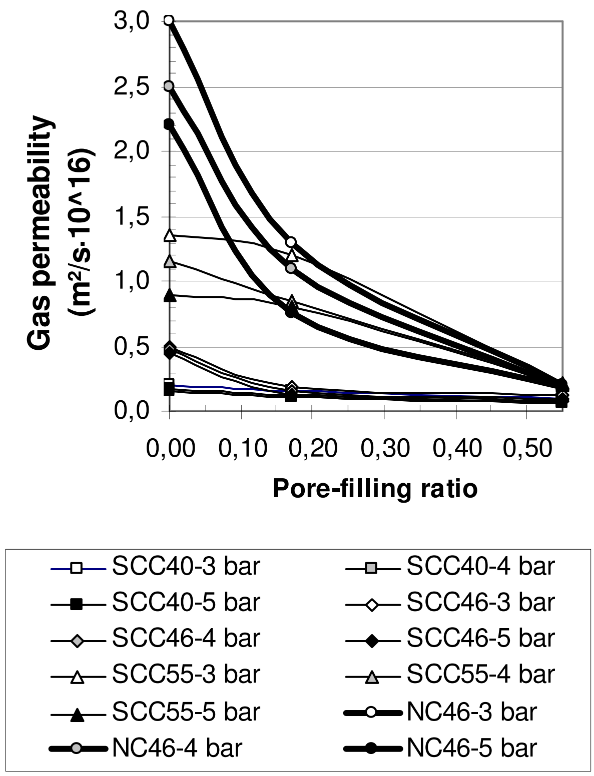

Figure 4 – Gas permeability for NC, and SCC. 40= w/c (%) [15].

2.3 Shrinkage, thermal expansion coefficient and transient strain at high temperatures

Shrinkage and temperature expansion at high temperatures was observed of all specimens without fibres, both NC and SCC, Appendices 3-4 [5,12]. Specimen size was ∅100 x200 mm³. Two start temperatures were used but the internal temperature did not differ much – explosive spalling for concrete without ppf always took place at about 170 °C concrete temperature at 20 mm depth of the specimen, Figure 5 [12]. Figure 6 shows that the thermal expansion coefficient at high temperatures was clearly smaller with 1.4 kg/m³ ppf than without ppf, most probably due to channels formed by melting/evaporating ppf in the surface of the concrete [12].

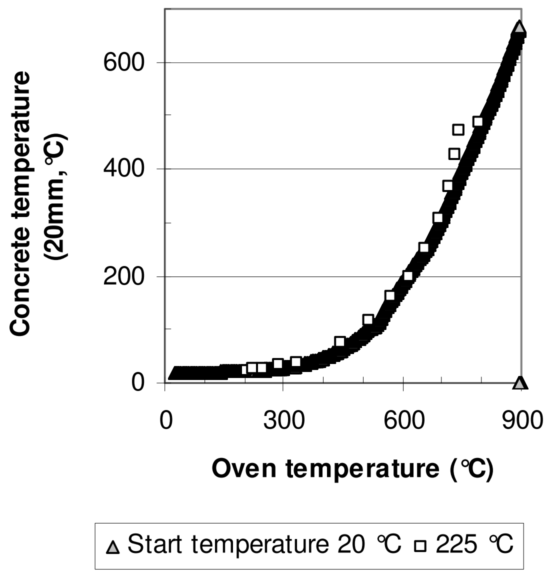

Figure 5 – Temperature at oven tests [12].

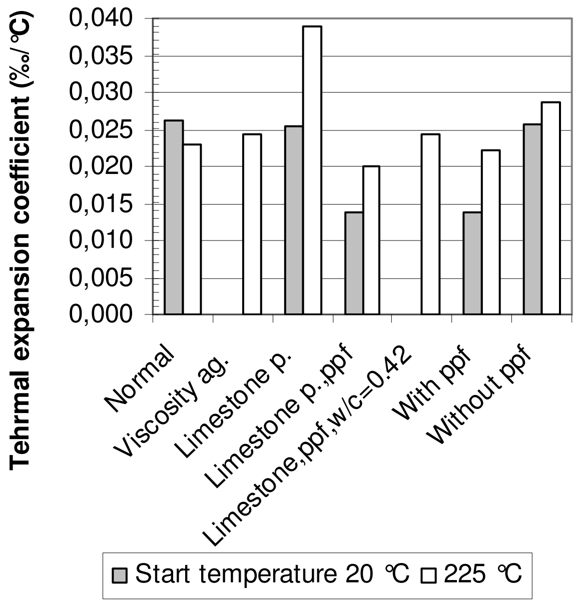

Figure 6 – Thermal expansion coefficient with 1.4 kg/m³ ppf or without [12].

Transient strain of SCC at high temperatures with 1.4 kg/m³ ppf and without was also measured and evaluated after reduction of thermal expansion and shrinkage. Up to 45% loading level of the ultimate strength was studied. All specimens without ppf exploded during the tests and some young specimens at 3 months' age with ppf. Specimens with ppf survived explosive spalling at 10 months' age even though the moisture concrete was about the same as at 3 months' age, 5.3% instead of 5.5%. The SCC specimens without ppf showed the following development of the transient creep coefficient at high temperatures, Figure 7 [5]:

$$d\varphi/dT=(-0.219\cdot(\sigma/fc)-0.011)\cdot w/c+0.127\cdot(\sigma/fc)+0.0173\{0.30<w/c<0.50;0.15<\sigma/fc<0.45\} \quad (2)$$

$d\varphi/dT$ denotes the development of the transient strain reduced by the elastic strain and compared with the elastic modulus, i.e. transient creep coefficient with the temperature.
σ/fc denotes stress applies on the test specimen compared with the ultimate strength at 20 °C.

With ppf the following development of the transient creep coefficient for SCC was observed, Figure 8 [5]:

$$d\varphi/dT=(-0.53\cdot(\sigma/fc)+0.265)\cdot w/c+0.238\cdot(\sigma/fc)-0.0868\{0.30<w/c<0.50;0.1<\sigma/fc<0.45\} \quad (3)$$

Notations are given above. Equations (2) and (3) show that the transient creep coefficient was affected by strength, stress and w/c.

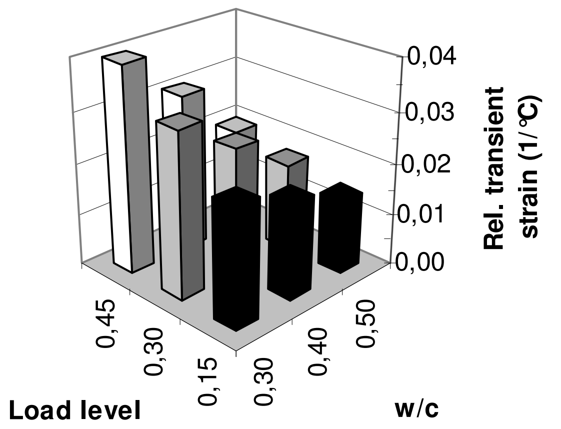

Figure 7 – Relative transient strain rate of SCC without ppf (1/°C) [12].

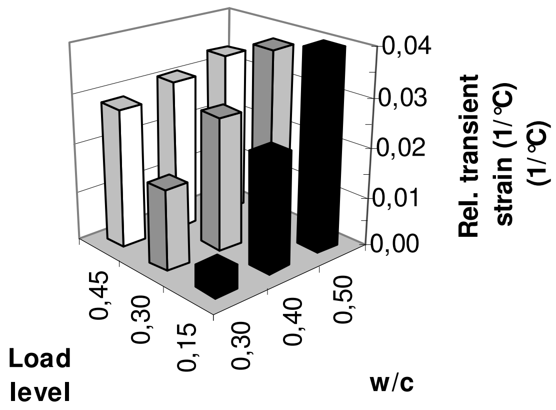

Figure 8 – Relative transient strain rate of SCC with 0.7 kg/m³ ppf (1/°C) [12].

At low w/c when the risk of explosive fire spalling is at its highest, creep, shrinkage and thermal expansion coefficient of SCC were all at their lowest with ppf. This is one reason why ppf in concrete is a way to avoid explosive fire spalling. Since channels of melting and evaporating ppf were formed, the moisture in the concrete left the concrete more rapidly with ppf than without ppf. Dried concrete has lower shrinkage than concrete with moisture [17].

2.4 Frost resistance

In order to ensure good frost resistance it is important to obtain a minimum air void content of about 3–4% in the hardened concrete, which means that about 5–6% of air content has to be entrained besides the natural air in the concrete, which is about 2%. It was extremely difficult to combine sufficient air content of SCC with ppf since the air-entrainment seemed to assemble and leave the concrete rapidly in the fresh state directly after mixing. Even though the mix proportion contained twice the dosage of air-entrainment agent the resulting air content was low, about 3–4% as compared to about 9–10% air content for normal hardened concrete with the same dosage of air-entrainment agent. As regards internal frost resistance with two cycles ± 20 °C per day, a sudden internal deterioration was observed with ppf in the mix proportions, mainly due to low air content, about 4%, Figure 9 [11]. However, w/c of the failing SCC was slightly higher than of the compared ones, 0.42 instead of 0.40. As regards salt frost resistance all SCC were within the maximum amount of scaling to be classified as good frost resistance even through the NC performed with very good frost resistance, Figure 10 [12]. In this case also SCC with w/c = 0.42 instead of w/c = 0.40 showed highest salt frost scaling [12].

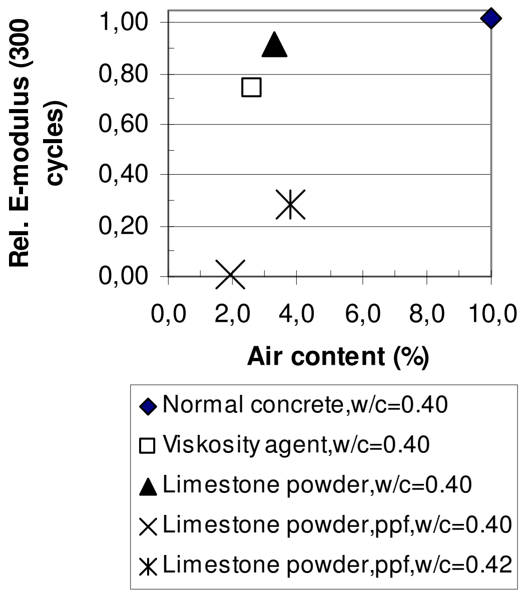

Figure 9 –Relative E-modulus of NC and SCC with 1.4 kg/m³ ppf or without after internal frost tests, 300 cycles ± 20 °C [12].

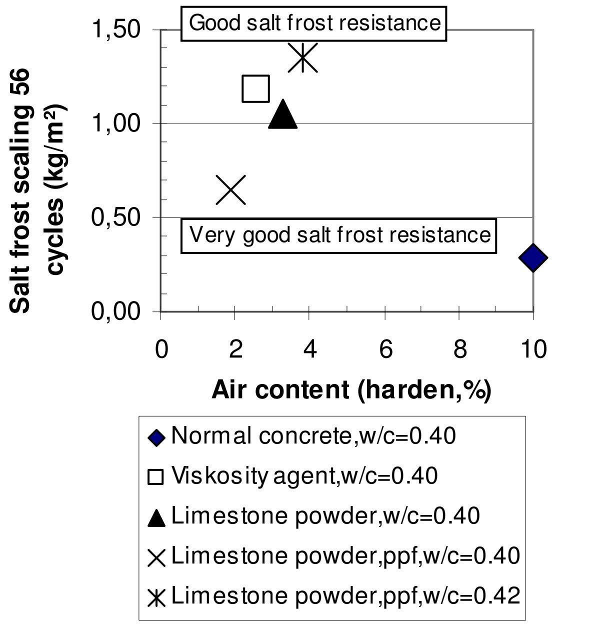

Figure 10 – Amount of salt frost scaling of NC and SCC with 1.4 kg/m³ ppf or without after internal frost tests, 56 cycles ± 20 °C [12].

3. TUNNEL CONCRETE

Tunnel concrete is characterised by its high applied stress, high moisture content, high tightness and large thickness together with distant location from the fire brigade which makes passive protection of the concrete against fire absolutely necessary. Several possibilities exist such as separate roof/wall with insulation, insulation attached to the concrete or passive protection with ppf. The alternative with built-in ppf is the utmost economical since separate insulation is volume-consuming, which means a substantially larger excavation of the ground/mountain. The 42 beams that were used for fire tests, including both NC and SCC, were intended for tunnels or for house construction [3,4]. All beams were 0.4x0.4 m² square section, 2 m in length, and prestressed at about 30% of the ultimate loading [3,4]. The mix proportions included up to 4 kg/m³ 32 μm ppf, which is comparable to half the amount of 18 μm ppf [1]. The number of ppf is more than three times larger with 18 μm than with 32 μm, but on the other hand the resistance to vapour transport is larger with 18 μm channels than with 32 μm channels formed by ppf after high temperature. The resulting efficiency is about twice the efficiency of using 18 μm ppf instead of 32 μm ppf in order to mitigate explosive spalling [1]. From the 42-beam fire test it was observed that more or less all beams without ppf exhibited extensive spalling even at 3% moisture content and high w/c = 0.55, mostly due to a combined effect of large amount of limestone powder in SCC [3,4]. Figure 11 shows that up to 4 kg/m³ 32 μm ppf was required to mitigate fire spalling [3,4]. In another extensive 62-slab fire test NC with w/c varying between 0.36 and 0.64 was studied for slabs 1.4x1.8 m² with thickness 0.3 or 0.5 m, both prestressed and reinforced, normally with about 100 kg/m³ but also with 400 kg/m³ steel reinforcement [17]. The later amount of reinforcement prevented explosive spalling; the former more normal amount of steel reinforcement did not. Only with additive of 1.5 kg/m³ of 18 μm ppf in the concrete explosive was spalling avoided. The moisture content, varying between 2 and 5.2%, did not affect the amount of spalling much, nor did the stress level, from –2% to 24% of the ultimate strength, Figs. 12–13 [18]. It was concluded that 2 kg/m³ of 18 μm ppf was required in order to mitigate explosive spalling [18]. The following results of more than 300 tests were included in the consensus that about 1.5 kg/m³ was sufficient to mitigate fire spalling of SCC with an increasing amount of ppf with an increasing content of limestone powder, equation (4) Table 1, Figure 14 [6,12] (kg/m³):

$$ppf_{tunnel}=(28\cdot(c/p)^2-26\cdot(c/p)-2.4)\cdot\ln(w/c)+45\cdot(c/p)^2-68\cdot(c/p)+24.2 \geq 1.4 \qquad (4)$$

c/p denotes the cement-powder ratio
ln(w/c) denotes the natural logarithm of the water-cement ratio

Equation (4) shows that the amount of ppf was dependent on the how much filler that was used in the mix proportions which in turn affect the permeability of the concrete, and of w/c, i.e. at lower w/c the permeability of the concrete decreased the therefore the risk of explosive spalling became higher. The recommendations also apply for SCC without filler [5]. In figures 11 and 14 the value c/p = 1 means that no filler is used at the tests, i.e. concrete without filler.

Table 1 - Amount of 18 µm ppf to mitigate fire spalling in tunnel concrete, p = powder [6,12] (kg/m³).

w/c = - c/p =	0.85	0.90	0.95	1.00
0.40	2.8	2.3	1.9	1.6
0.45	2.3	1.9	1.7	1.5
0.50	1.9	1.6	1.5	1.5
0.55	1.5	1.3	1.4	1.4

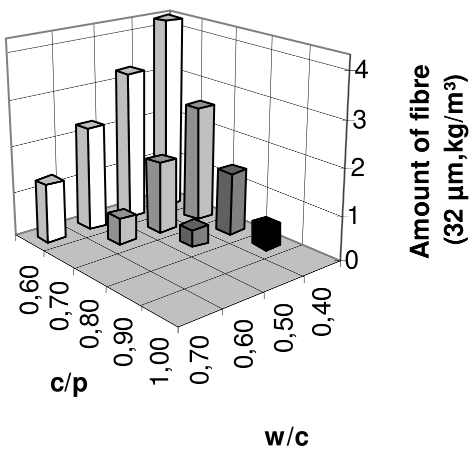

Figure 11 – Amount of 32 µm ppf to mitigate fire spalling. p = powder [3,4].

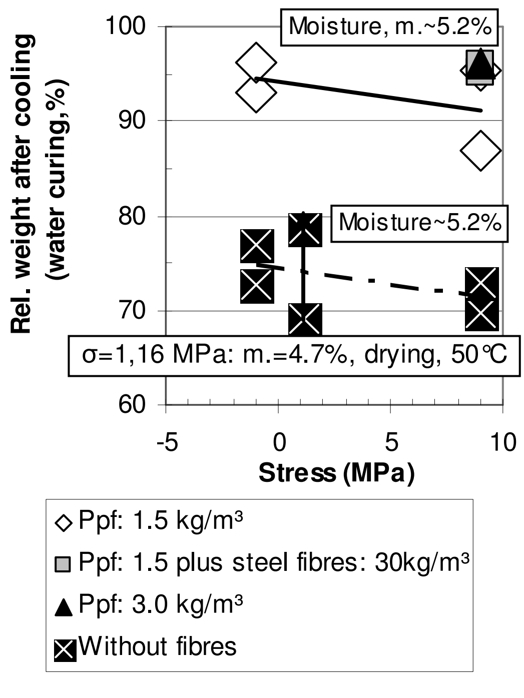

Figure 12 – Effect of stress and ppf amount on fire spalling of tunnel element [18].

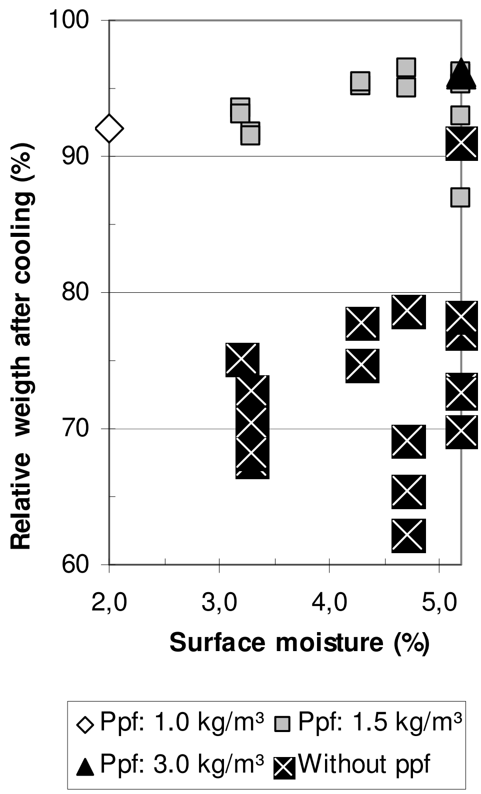

Figure 13 - Effect of moisture on fire spalling with varying ppf amount [18].

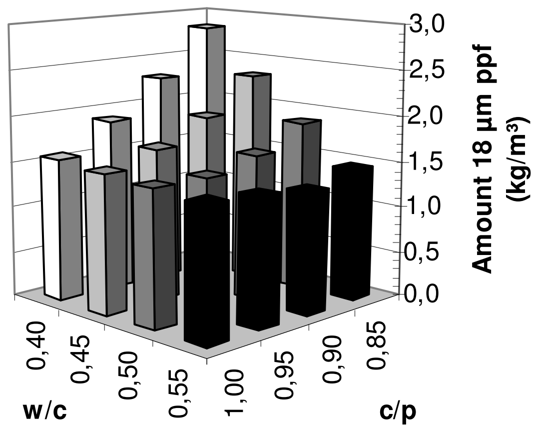

Figure 14 - Total of 18 µm ppf to mitigate fire spalling of tunnel concrete, p = powder [6,12].

4. HOUSE CONSTRUCTION CONCRETE

After a long time the moisture content of indoor concrete will diminish to less than 3%, which seems to lower the risk of explosive fire spalling. In the 42-beam test as shown above, a substantial amount of ppf was also required in indoor concrete when the mix proportions included large amounts of limestone filler. In tests with 34 specimens of NC and SCC, with w/c varying between 0.33 and 0.48, very little, 20 kg/m³, or no limestone powder was included in the mix proportions. The concrete was dried for one year to less than 3% moisture content and then tested at high temperature [5]. More or less all specimens (Ø100x200 mm³ cylinders) without ppf exploded at about 170 °C concrete temperature. All specimens of house construction concrete with 0.7 kg/m³ were durable to exactly the same temperature rise as the specimens without ppf that exploded. Also with the experience of the 300 tests mentioned above, with and without filler, at varying moisture and stress level, the following recommendations may be given for ppf additives in SCC in order to mitigate fire spalling given a water- Portland cement ratio, w/Pc, $0.40 < w/Pc < 0.70$, and moisture content, u, $2.5 < u < 4\%$ [5,6]:

1. 0.7 kg/m³ of 18 µm ppf for all SCC with low filler content (≤ 5% of cement content).
2. 0.7 kg/m³ of 18 µm ppf for SCC with filler (> 5% of cement content), equation (5), Table 2, Figure 15.

$$ppf_{hus} = 0.5\cdot[(13\cdot(Pc/p)-12.3)\cdot\ln(w/Pc)-2.69\cdot(Pc/p)^2+2.65\cdot(Pc/p)-0.2] \geq 0.7 \qquad (5)$$

ln(w/Pc) denotes the natural logarithm of the water-Portland cement ratio
Pc/p denotes the Portland cement-powder ratio

Equation (5) shows that the amount of ppf was dependent on the how much filler that was used in the mix proportions which in turn affect the permeability of the concrete, and of w/Pc, i.e. at lower w/Pc the permeability of the concrete decreased the therefore the risk of explosive spalling became higher.

Table 2 – Amount of 18 μm ppf in SCC with filler for house construction (kg/m³) [12].

w/Pc = -c/Pc =	0.75	0.8	0.85	0.90
0.40	1.3	1.0	0.6	0.7
0.50	1.0	0.8	0.5	0.7
0.60	0.8	0.6	0.4	0
0.70	0.6	0.4	0.3	0

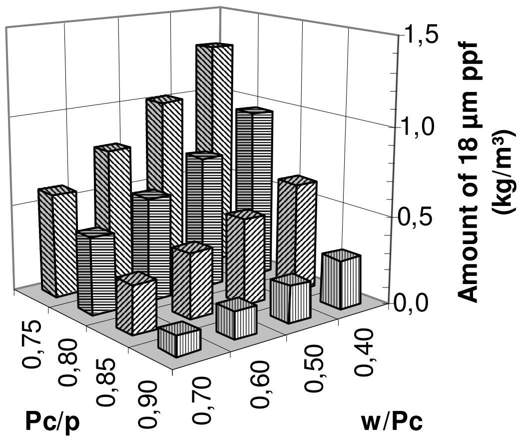

Figure 15 - Amount of 18 μm ppf to mitigate fire spalling of house construction [5,6].

5. CONCLUSIONS

The mitigation of explosive fire spalling by use of ppf has proven to be feasible but the durability aspects of concrete with ppf are hardly known at all. The following conclusions were drawn for the tests:

1. It was extremely difficult to entrain a sufficient amount of air in SCC with ppf in order to obtain sufficient frost resistance, as the fibres seemed to affect the air void system.
2. Chloride resistance did not differ much from that of concrete without fibres.
3. Coefficient of thermal expansion and shrinkage at high temperatures seemed to be some 30% lower in concrete with polypropylene than in concrete without this additive.
4. Also the creep coefficient at high temperatures seemed to be some 30% lower in concrete with ppf than in concrete without this additive.
5. Concrete with limestone powder was severely damaged by Thaumasite Sulphate Attack within 5 years of exposure.
6. For tunnel concrete 1.4 kg/m³ of 18 μm ppf seemed to be sufficient to prevent explosive fire spalling plus addition due to content of limestone powder.
7. For indoor house construction concrete 0.7 kg/m³ of 18 μm ppf seemed to be sufficient to prevent explosive fire spalling plus addition due to content of limestone powder.

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APPENDICES

Appendix 1 – Mix composition (kg/m³ dry); strength of concrete (MPa)

Material/w/c (%)	SCC27	NC32	SCC38	SCC50	SCC80
Quartzite 11-16 mm	800	660	620	525	270
Quartzite 8-11 mm	60	135	305	285	395
Natural sand 0-8 mm	880	694	790	840	1000
Filler sand, 0.063 and 0.125 mm	50	106	145	165	135+50
Cement, low-alkali	500				
Cement, normal alkali		389	400	340	260
Silica fume	50				
Air-entrainment agent, fir oil (g/m^3)		50		24	
Superplasticiser, melamine formaldehyde		3.6			
Superplasticiser, polycarboxylic ether	5.0		2.0	1.2	1.0
Water reducer		1.7			
Water	133	126	153	170	207
Aggregate content	0.72	0.75	0.77	0.78	0.80
Density	2478	2115	2415	2325	2318
Air content (%)	1.3	12	1.4	3.5	1.9
Slump (flow) (cm x cm)	70x72	11	53x54	56x60	54x57
<u>Compr. strength (sealed, MPa):</u> 1 d	19	36	26	23	9
2 d	63	59	65	43	18
7 d	110		76	52	27
28 d	141		86	61	32
90 d	158	55	98	67	34
1 year	171	61	108	76	36
2 years		68			
<u>Compressive strength (air, MPa): 2 d</u>	63	50	65	43	18
7 d	103	54	79	55	27
28 d	124		86	63	32
90 d	134	55	94	67	
1 year	120	64	93	70	35
2 years		62			35
<u>Relative humidity, RH,</u> 1 d <u>(sealed):</u>	0.95		0.89	0.95	0.97
2 d	0.91	0.91	0.87	0.95	0.96
7 d	0.88		0.86	0.92	0.92
28 d	0.86		0.88	0.93	0.96
90 d	0.78		0.85	0.88	0.98
1 year	0.82	0.78	0.84	0.90	0.97
2 years		0.82			
<u>RH, 2 d (air):</u>	0.91	0.88	0.87	0.95	0.96
7 d	0.84		0.81	0.91	0.92
28 d	0.82	0.82	0.85	0.83	0.88
90 d	0.71		0.73	0.82	0.67
1 year	0.62	0.70	0.66		0.56
2 years		0.60		0.77	

Appendix 2 – Mix composition and properties of NC and SCC

Material/mix composition	KN	KOB	KN8	KO	KOT	SO	RO	ROII
Crushed aggregate 8-16 mm	363	371	355	367	363	402	862	876
Natural sand 0-8 mm	853	872	836	864	855	786	715	727
Natural sand 0-2 mm	316	135	309	320	316	422	146	149
Limestone filler	183	375	180	186	184	94	0	
Cement, low-alkali	418	427	409	423	419	416	431	438
Air-entrainment (fir oil, g)	585	213	1203	106	117	125	474	482
Superplast. (polycarboxylic ether)	2.97	4.13	3.2	3.39	3.69	2.99	7.32	5.92
Water	163	167	160	165	163	162	168	171
w/c	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
Air content (%)	5.6	4.9	8	5.5	6.3	5.6	5.8	6.1
28-day cube strength (MPa)	63	84	50	75	75	61	68	63
Slump (flow) (mm)	720	780	735	620	640	710	110	150
Flow time until 500 mm (s)	5	7	8	10	8	5	-	-
Density	2297	2348	2250	2323	2300	2285	2325	2368
Aggregate with filler	0.643	0.654	0.630	0.652	0.645	0.641	0.650	0.661

Notations: B = increased amount of filler; K = 40 µm limestone filler; N = new way of mixing (filler last); O = ordinary way of mixing (filler first); R = reference =NC; S = 15 µm limestone filler; T = 5.5 m hydrostatic pouring pressure instead of 0.23 m; II = second; 8 = 8 % air content.

Appendix 3 - Mix composition and properties of NC and SCC.

Concrete	40N0	4000	40K0	40K2	42K2
Description	NC, w/c=0.40	Viscosity agent, w/c=0.40	Limestone filler, w/c=0.40	Limestone filler, ppf, w/c=0.40	Limestone filler, ppf, w/c=0.42
Crushed aggr 11-16 mm	471	496	474	450	450
Crushed aggr 8-11 mm	139	146	189	208	208
Natural gravel 0-8 mm	1000	1053	912	990	990
Limestone filler			92	97	97
Cement, low-alkali	441	464	430	450	450
Air-entrainment (fir oil)	0.132	0.093	0.089	0.125	0.225
Water	176	186	172	180	193
Viscosity agent		2.3			
Superplast. (polycar-boxylic ether)	2.2	4.6	5.6	32.4	33.7
w/c	0.40	0.40	0.40	0.40	0.43
Polypropylene fibre, ppf				1.4	1.4
Density	2227	2347	2278	2380	2394
Dry density	2049	2156	2109	2179	2178
Binde/density	0.215	0.215	0.205	0.207	0.207
Slump (flow) (mm)	180	620	640	600	600
Air content (%)	7.8	3.3	7.3	2.8	3.3

Notations: ppf = polypropylene fibre, w/c = water-cement ratio, K = limestone filler, N = NC = normal concrete, 2 = 1.4 kg/m³ ppf, 40 = w/c.

Appendix 4 – Mix composition and properties of SCC

Concrete	33H00	33H01	42V00	42V01	48FK0	48FK1	48FK2
Crushed aggr. 11-16 mm			557	557			
Crushed aggr. 8-11 mm	809	803			700	697	694
Crushed aggr. 4-8 mm			222	222			
Natural sand 0-8 mm	969	962	893	892	1050	1045	1041
Limestone filler					20	20	23
Filler cement	456	453	426	426	387	385	389
Air-entrainment agent			0.138	0.138			
Viscosity agent			1.8	1.8			
Superplasticiser (polycarboxylic ether)	5.4	5.4	4.3	4.3	3.2	3.8	3.8
Water	150	156	177	177	185	188	187
w/c	0.33	0.34	0.42	0.42	0.48	0.49	0.48
Ppf		0.7		0.7		0.7	1.4
Density	2386	2377	2277	2277	2344	2338	2337
Dry density	2233	2217	2096	2096	2157	2147	2148
Portland cement/powder	0.86	0.86	0.86	0.86	0.82	0.82	0.81
Filler cement/dry density	0.26	0.26	0.25	0.25	0.22	0.22	0.22
Aggr./dry density	0.80	0.80	0.80	0.80	0.81	0.81	0.81
Aggr./ Filler cement	3.90	3.90	3.92	3.92	4.52	4.52	4.46
Aggr./Portland cement	4.53	4.53	4.56	4.56	5.26	5.26	5.19
Slump (flow) (mm)	720	670	650	600	680	630	600
Air content (%)	3	3	5	5	2	2	2
Age at strength test. (months)	8	8	10	10	10	10	10
Cylinder strength (Ø100 mm,MPa)	62.4	57.2	38.1	42.7	49	50.2	48.4
Cube strength (100 mm,MPa)	86.6	79.5	53	59.2	68	69.9	67.2
Age at oven (months), RH = 30%	12	-	14		14		
RH = 60%	10	10	12	12	12	12	
RH = 90%		13		15		15	15
Fuktkvot (%), RH = 30%							4.1
RH = 60%	3.1	3.6	3.8	3	3.7	3.1	3.2
RH = 90%							2.7
Elastic modulus, estimated (ACI, GPa)	37.1	35.5	29.0	30.7	32.9	33.3	32.7
Elastic def., estimated (ACI, millionths)	26.9	28.1	34.5	32.6	30.4	30.0	30.6