THE BALTIC JOURNAL
OF ROAD AND BRIDGE ENGINEERING

ISSN 1822-427X / eISSN 1822-4288
2016 Volume 11(1): 35–42

FROST DURABILITY OF STEEL FIBER SELF-COMPACTING CONCRETE FOR PAVEMENTS

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Abstract. The paper presents the results from the research on self-compacting concrete with different steel fibre type addition. The reference self-compacting concrete mix with water/binder = 0.33 was prepared, then modified with steel fibres in the amounts of 0–60 kg/m^3 and air entrained with polymer microspheres (40 µm diameter). The major objective of the research was to determine the effect of steel fibre and air content on the self-compacting concrete mix properties and hardened concrete frost durability. The tests also included internal cracking and scaling resistance evaluation for concrete specimens subjected to cyclic freeze-thaw process – two beams were frozen in air and two beams were partially submerged in water and then frozen. The scaling resistance was tested using the slab method on the specimens with sawn surface and on the specimens with natural finished surface. Non-air entrained steel fibre-reinforced concretes, despite their high strength class (C55/67–C60/75) and medium absorption (4.34–5.11%), showed unsatisfactory resistance to internal cracking and scaling tests. The beams partially submerged in water failed after 100 freeze-thaw cycles, which confirms a significant influence of water uptake from moist environment during freeze-thaw cycles and the acceleration of the damage process. Test results indicate that air entrainment with polymer microspheres is a very effective method and allows obtaining very good air pore structure parameters and frost resistance results. The specimens with top – finished surface exhibited less damage in the scaling resistance tests in relation to the specimens with sawn surface.

Keywords: air-entrainment, freeze-thaw durability, microspheres, self-compacting concrete (SCC), steel fibres.

1. Introduction

Over the last several years rapid advancement has been observed in the technology of self-compacting concrete (SCC) and its use in ready-mix concrete applications, production of precast concrete products and repairs of the existing structures (bridges, tunnels etc). SCC is used along with high performance self-compacting concrete (HP SCC) and fibre-reinforced self-compacting concrete (FR SCC). A concrete mix is classified as the SCC mix (according *The European Guidelines for Self-Compacting Concrete* of 2005) when four conditions are satisfied:

– it is able to flow and completely fill the formwork (filling ability);
– it has high viscosity that influences the mix stabilization in time;
– it is able to flow through spaces between steel reinforcing bars without blocking (passing ability);
– no segregation or sedimentation occurs.

Similarly to high performance concrete, the microstructural properties of SCC are the main factors determining the mechanical properties and the durability behaviour (Ye *et al.* 2007).

A smooth, crack-free and impermeable concrete able to resist chloride attacks and freezing and thawing processes is required for durability. This quality concrete is made with a special mix with powders and a very low water-cement ratio of 0.35 (Rostam 1996).

The properties of the mix and hardened SCC concrete are modified with various ingredients (flying ash, silica fume, ground granulated blast furnace slag, limestone powder, plasticizers etc.).

Interesting test results (Skripkiūnas *et al.* 2012) have been obtained from the application of a small amount of sodium silicate solution (containing undissolved SiO_2 nanoparticles of 1–2 mm in diameter), which produces dense hydrated cement paste and increases the durability of concrete used in road structures.

The action of capillary forces between powder particles in the surface layer packs the surface concrete to a hard dense shell which has different properties and exerts

doi:10.3846/bjrbe.2016.04
http://www.bjrbe.vgtu.lt

a significant influence on the durability of concrete (Rostam 1996).

SCC mixes (Zhu, Bartos 2003) showed significantly lower values of water permeability and sorptivity coefficients compared with traditional concretes of the same strength grade. The chloride diffusivity depended on the type of powder added to the concrete. It appeared that the SCC mix without additional powders but with a viscosity controlling agent to maintain stability of the fresh mix had the higher values of permeability, sorptivity and chloride diffusivity.

The modification of the SCC concrete properties through the addition of discontinuous fibres is not a new idea. This area, however, requires further research. Most investigations are usually focused on determining the relationships between the fibre content and the resistance to cracking, where the primary goal of adding the fibres is to increase the deformability of concrete and its load capacity in the post-cracking phase.

The flow limit and plastic viscosity increase with increasing steel fibre dosage (Ponikiewski, Cygan 2011). Other factors of significant importance include the fibre shape (straight, hooked, undulated) and geometric parameters (length, diameter and slenderness). Maximum fibre content varies depending on the fibre type and reference mix composition (Grünewald, Walvaven 2001). High content of steel fibre (1–1.5% volume) has a bearing on the distribution of the mix components or causes fibre clumps or blocks aggregates. The mixes with reduced flow limit and plastic viscosity, i.e. with lower stability, tend to segregate or cause sedimentation.

One of the basic requirements for pavement and bridge concrete is to ensure its frost durability. Two issues have to be considered: internal cracking resistance of the concrete and its resistance to scaling. In theory, good frost resistance is achieved through the use of very dense, impermeable concrete (water/cement < 0.38) or through air entrainment (Philleo 1987). Concretes with a very low water-cement ratio have no capacity for freezable water or become so impermeable that saturation by water is impossible in most natural conditions.

Whether air entrainment is really needed in HPC is still an open and often discussed question (Rostam 1996). The concrete mix design may become a problematic task because in practice it is difficult to maintain a stable air void content and satisfactory air void distribution without air voids clustering.

Because air-entraining admixtures reduce the strength of concrete, most builders try to eliminate or limit the application of air entrained concretes (Philleo 1987). It is easy to achieve well air-entrained concrete using only air-entraining admixture without water-reducing admixtures. It has been proved that the use of conventional water-reducing agents slightly increases the spacing factor. The problem seems to be increased with the introduction of highly effective superplasticizers. It is not a problem to obtain the specified total air content but to create the satisfactory spacing factor criterions.

Using mineral additives and admixtures at the same time lead to difficulty in maintaining the air pore system stability. Instability of air pores (Fagerlund 1990) is due to: floating of large air bubbles, dissolution of air bubbles smaller than 0.10 mm, or air bubble coalescence. Viscosity level of SCC enhances those negative phenomena (Szwabowski, Łaźniewska-Piekarczyk 2008).

An innovative approach (Ozyildirim 1982) that helps avoiding most of the problems mentioned above is the application of polymer microspheres – preformed spherical particles that do not disappear or coalesce but ensure the proper pore system. The research results (Wawrzeńczyk, Molendowska 2011) showed that the application of polymer microspheres as an air entraining agent confirmed high efficiency of this method for traditional bridge concrete.

Further problems are involved inh the methodology of laboratory tests for the assessment of concrete deterioration when freeze-thaw cycles cause scaling and internal structural damage. There are numerous national freezing and thawing tests developed for measuring concrete frost resistance. For the evaluation of the scaling resistance of concrete, three test methods used in Europe Union are described in technical specifications (*CEN/TS 12390-9:2006 Testing Hardened Concrete – Part 9: Freeze-Thaw Resistance – Scaling*) – the slab test as the reference method and two alternative methods. The methods specify the shape and size of the sample: in the slab test the specimen is sawn from concrete test cube (150 mm edge length), or 100 mm cubes or 150×150×50 mm slabs with naturally formed test surfaces are subjected to freeze-thaw attack in the presence of 3% sodium chloride solution.

The differences in the composition and properties of concrete "skin" lead to different behaviour during freezing and thawing of the top surface, the interior, and the bottom surface of the concrete (Panesar, Chidiac 2007). The adequate choice of the freeze thaw examination method has a critical impact on the scaling resistance assessment of concrete.

In practice, the design of FR SCC mix becomes a compromise between rheological properties of a fresh concrete mix, its proper air-entrainment, and the improvement of the composite mechanical properties. Few publications describe mix design problems or deal with practical application of high frost durable steel fibre-reinforced self-compacting concrete pavement concretes.

Interesting data concerning the feasibility of SFR SCC in the full-scale use, based on the tests conducted for in-situ slabs have been reported by (Groth, Nemegeer 1999; Gustafsson 1999). The SCC was made from CEM I 42.5 cement, limestone filler and the air-entraining agent at W/C = 0.40, and an addition of 30–44 kg/m^3 steel fibre. The tests showed that the type of selected fibre has a significant effect on the air entrainment level.

This paper presents the results of the tests conducted on steel fibre reinforced air-entrained and non-air entrained concrete. The innovative and highly efficient method of concrete air-entrainment with the application of polymer microspheres 40 μm in nominal diameter was used for that purpose.

2. Test description

The objective of the tests was to determine how the steel fibre addition and air-entrainment affect the fresh concrete properties and frost durability of hardened SCC. The experiment programme (Table 1) included manufacturing six SCC specimens of two groups:

- Series A – non-air-entrained concrete and
- Series B – air-entrained concrete with an addition of microspheres, to which 0–60 kg/m^3 of steel fibre was added.

The following materials were used in the tests:

- cement: CEM II/A-LL 42.5R (with about 10% limestone powder content);
- ground granulated blast furnace slag 30% by weight of cement;
- natural sand 0/2 mm;
- crushed dolomite sand 0/4 mm;
- coarse dolomite aggregate 4/8 mm and 8/16 mm;
- superplasticizer Viscocrete 5–600;
- polymer microspheres 0.7% by weight of binder;
- Dramix steel fibres – 40 mm in length and 0.62 mm in diameter.

The properties of the cement according to EN standards (*PN-EN 197-1:2012 Cement – Część 1: Skład, Wymagania i Kryteria Zgodności Dotyczące Cementów Powszechnego Użytku* [Cement – Part 1: Composition, Specifications and Conformity Criteria for Common Cements] *(in Polish), PN-EN 196-2:2013-11 Methods of Testing Cement – Part 2: Chemical Analysis of Cement, PN-EN 196-6:2011 Metody Badania Cementu – Część 6: Oznaczanie Stopnia Zmielenia* [Methods of Testing Cement – Part 6: Determination of Fineness] *(in Polish), PN-EN 196-1:2006 Metody Badania Cementu – Część 1: Oznaczanie Wytrzymałości* [Methods of Testing Cement – Part 1: Determination of Strength] *(in Polish)*) are presented in Table 2 below.

3. Research method

Prior to testing, the reference concrete mix was designed (A0-SCC mix without fibre, non-air-entrained) following the self-compaction requirements (Table 3). The aggregate grading had a constant ratio as illustrated by the grain distribution curve in Fig. 1.

The constant water-binder ratio W/B = 0.33 corresponded to the water-cement ratio W/C = 0.44. The composition of the other mixes was modified with appropriate amounts of steel fibre and by air entraining Series B mixes using polymer microspheres.

The ingredients were mixed in a planetary 56 dm^3 capacity concrete mixer. The 10 cm thick 50×110 cm concrete slab was cast in a wooden formwork made in two compartments to make the slabs light enough to be manhandled.

A diamond saw was used to cut the slabs into the following specimens:

- 6 beams 90×100×500 mm to test freeze-thaw resistance;
- 8 slates 48×150×150 mm to measure scaling resistance;
- 8 cubes 100×100×100 mm to measure compressive strength and absorption;
- 2 slates 30×100×150 mm to determine the factors that characterize the structure of air pores.

A standard slump flow test was used to determine the diameter of the spread *D*, spreading time *T*50 and the density of the concrete mix (*PN-EN 12350-6:2011 Badania*

Table 1. The experiment programme

Concrete type	Steel fibre, kg/m^3		
	0	30	60
Non-air entrained	A0	A1	A2
Air entrained	B0	B1	B2

Table 2. Basic properties of cement

Chemical properties		
CaO	%	60.1
SO_3	%	2.6
SiO_2	%	19.8
Al_2O_3	%	4.9
Physical properties		
Density	g/cm^3	3.03
Blaine surface	cm^2/g	4462
Compressive strength		
after 2 days	MPa	31.1
after 28 days	MPa	56.0

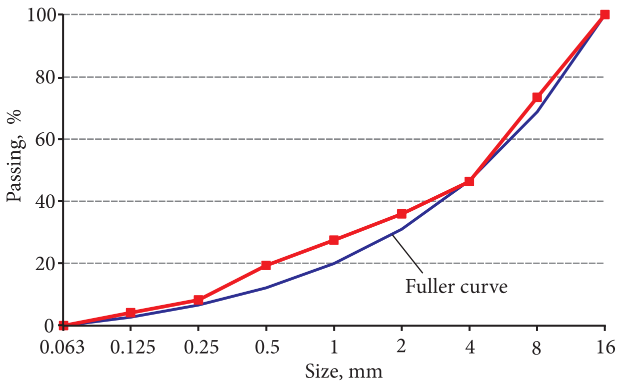

Fig. 1. Aggregate grading curve

Table 3. Composition of reference concrete mix

Ingredients	Amount, kg/m^3
Cement	416
Gra GGBFS	125
Water	185
Sand	255
Crushed sand	596
Coarse dolomite	851
Superplasticizer	12.66
Microspheres	0/0.7 % b.m
W/C ratio	0.43
W/S ratio	0.33

Mieszanki Betonowej – Część 6: Gęstość [Testing Fresh Concrete – Part 6: Density] *(in Polish)*).

Compressive strength was measured on 100 mm cubes (*PN-EN 12350-3:2011 Badania Mieszanki Betonowej – Część 3: Badanie Konsystencji Metodą Vebe* [Testing Fresh Concrete – Part 3: Vebe Test] *(in Polish)*); the three-point bending test was co–ducted on the prismatic samples (*PN-EN 12390-5:2011 Badania Betonu – Część 5: Wytrzymałość na Zginanie Próbek do Badań* [Testing Hardened Concrete – Part 5: Flexural Strength of Test Specimen] *(in Polish)*); water absorption by weight was measured on 100 mm cubes *(PN-88/B-06250 Beton Zwykły* [Normal Concrete] *(in Polish)*).

Two methods were used to study the frost durability of FR SCC – one related to the internal cracking resistance (ICR) and the other to determine the scaling resistance (SR) of the concrete in contact with 3% sodium chloride solution.

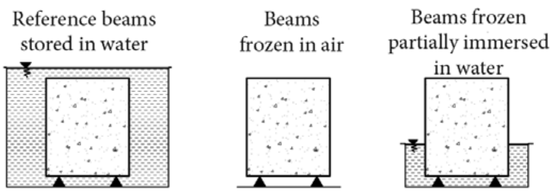

Fig. 2. Different storing method of concrete samples during freeze-thaw tests

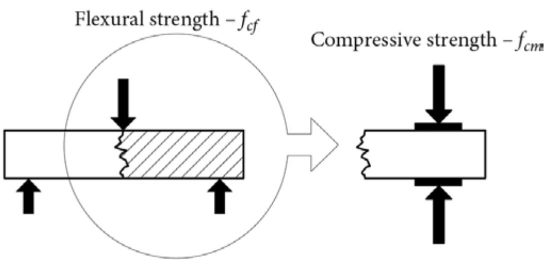

Fig. 3. Strength tests of the beams

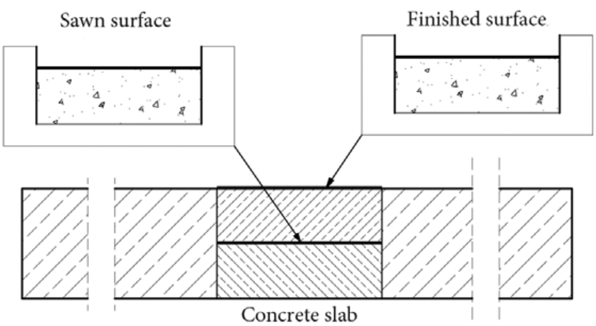

Fig. 4. Specimens prepared for the scaling resistance test

Table 4. Properties of concrete mix

Property	Series A			Series B		
	A0	A1	A2	B0	B1	B2
Density, kg/m^3	2436	2436	2452	2360	2412	2422
T_{500} time, s	8	3	7	6	5	8
Slump-flow diameter, cm	63.5	69	55	76	75	58

The F–T resistance in terms of ICR was determined on 90×100×500 mm beams exposed to 100 cycles of freezing according to the procedure set out in *CEN/TR 15177:2006 Testing the Freeze-Thaw Resistance of Concrete – Internal Structural Damage*. The specimens were frozen in air at −20 °C for 8 hours and then thawed in water of +20 °C for 4 – hours. Two cycles a day were performed. For each series of concrete, two beams were stored in water at the temperature of +20 °C at all times, two beams were frozen in air and two beams were frozen while partially immersed in water (placed in metal containers allowing the specimens to be surrounded by water up to 35 mm of their height) (Fig. 2).

After the completion of the freezing cycles, three-point bending test according to *PN-EN 12390-5:2011* standard was performed to measure the flexural strength f_{cf} of the beams. The beams were tested on the MTS 322 Test Frame. The concrete compressive strength was measured on the halves of the beams using 80×100×30 mm steel pads (Fig. 3).

Scaling resistance was tested with a slab test per *PKN-CEN/TS 12390-9:2007 Testing Hardened Concrete – Part 9: Freeze-Thaw Resistance – Scaling* standard. Two types of specimens were used: four tiles (48×150×150 mm) sawn out of the upper part of the concrete slab to test the finished surface and four tiles sawn out of the bottom part of the concrete slab to tests the sawn surface (Fig. 4). For storage, preparations and tests, standard procedures were followed. The tests involved fifty six freeze-thaw cycles.

The parameters of the air pore structure of the air-entrained hardened concrete (Series B) were determined using a computer-driven system of automatic image analysis (stereoscopic microscope Nikon SMZ800, Prior stage, NIS-Elements program). The measurements and calculations were performed following the *PN-EN 480-11:2008 Domieszki do Betonu, Zaprawy i Zaczynu – Metody Badań – Część 11: Oznaczanie Charakterystyki Porów Powietrznych w Stwardniałym Betonie* [Admixtures for Concrete, Mortar and Grout – Test Methods – Part 11: Determination of Air Void Characteristics in Hardened Concrete] *(in Polish)* standard by the sum of the chord lengths. Two appropriately polished 30×100×150 mm specimens were used in the tests. The following basic air pore parameters were measured:

– air content A in %;
– content of micropores $A300$ with diameters less than 300 μm in %;
– spacing factor $\overline{L}$ in mm.

4. Tests results and analysis

4.1. Mix concrete properties

Table 4 presents the results of the tests performed on the fresh concrete mix. All the fresh concrete series satisfied the self-compaction requirements. The addition of steel fibres was found to negatively affect the workability of the fresh concrete mix.

Table 5. Physical characteristics of hardened concrete

Property	Series A			Series B		
	A0	A1	A2	B0	B1	B2
Absorption, %	5.11	4.46	4.34	5.34	4.40	4.61
Compressive strength, MPa	89.4	87.2	93.0	75.1	86.2	85.0
Strength class	C55/67	C55/67	C60/75	C50/60	C55/67	C55/67

4.2. Physical properties of hardened concrete

Table 5 presents the results of compressive strength and absorption tests. The compressive strength values of non-air entrained concrete (Series A) were in the range of 87.2–93.0 MPa and the compressive strength values of air entrained concrete (Series B) were from 75.1 MPa to 86.2 MPa. The results allowed estimating the concrete strength class. All the concrete used conformed to the requirements set for high strength concrete (min. class C50/60). Concrete of Series B showed lower strength due to higher porosity related to the presence of polymer microspheres.

Absorption values were medium, in the range of 4.3–5.3%.

4.3. Air-void structure

The air pore structure parameters in the air-entrained concrete (Series B) are presented in Table 6. It is commonly assumed that the spacing factor of pores should be less than 0.20 mm and the content of micropores less than 300 μm in diameter should exceed 1.5%. It follows from the test results that the $\overline{L}$ factor value met the requirement of $\overline{L} < 0.20$ mm and the content of micropores for Series B – B0 and B1 – was below 1.5%. Polymer microspheres 40 μm in nominal diameter were used and a large amount of such small pores may result in obtaining low values of $\overline{L}$ at the total air content of $A < 4\%$ and $A300$ micropore content of less than 1.5%. The results indicate that the quality of air entrainment was very high owing to the use of polymer microspheres.

4.4. Frost resistance tests

4.4.1. Internal cracking resistance

Tables 7 and 8 summarize the results of concrete internal cracking resistance tests. The damage level is estimated on the basis of visual evaluation of the beams, changes in mass Δm, drop in the flexural strength Δf_{cf} and compressive strength Δf_{cm}.

4.4.1.1. Non-air-entrained beams frozen in air

Freezing concrete in air is a relatively mild method. The air in the chamber must be continuously stirred, which may cause drying of the specimens.

The decrease in mass after 100 freeze-thaw cycles performed on Series A concrete samples did not exceed 15 g. The fall in flexural strength after 100 freeze-thaw cycles was from 27% to 41%, which means that if the adopted criterion is 20%, the concrete must be regarded as non-frost-resistant. The compressive test results after 100 freeze-thaw cycles were in the range of 84.8–98.6 MPa. The fall in the compressive strength was not significant, reaching 4–8 %. The assessment of frost resistance based on the compressive strength tests is not considered reliable. The results indicate explicitly that flexural strength tests help to discern between damaged and non-damaged concrete.

Table 6. Air void characteristics of hardened concrete Series B according to *PN-EN 480-11:2008*

Concrete type	Parameters of air void structure		
	A, %	A300, %	$\overline{L}$, mm
B0	2.39	1.42	0.122
B1	1.77	1.15	0.115
B2	3.77	2.12	0.084

Table 7. Flexural strength f_{cf} and change in the mass of the specimens after 100 freeze cycles

Property	Series A			Series B		
	A0	A1	A2	B0	B1	B2
Reference specimens						
f_{cf}, MPa	12.3	14.0	13.3	11.2	12.6	13.8
Freezing in air						
Δm, g	9.5	15.0	11.0	10.0	11.0	11.5
f_{cf}, MPa	8.9	8.2	9.4	10.4	10.2	11.2
Δf_{cf}, %	27.0	41.0	29.0	7.0	19.0	19.0
Freezing in water						
Δm, g	127.0	118.0	123.0	10.0	11.0	11.0
f_{cf}, MPa	2.0	3.4	3.9	11.8	11.5	13.7
Δf_{cf}, %	84.0	75.0	71.0	–5.0	9.0	1.0

Table 8. Compressive strength f_{cm} after 100 freeze cycles

Property	Series A			Series B		
	A0	A1	A2	B0	B1	B2
Reference specimens						
f_{cm}, MPa	87.9	101.4	102.6	82.5	92.5	93.4
Freezing in air						
f_{cm}, MPa	84.8	93.5	98.6	80.3	87.9	92.6
Δf_{cm}, %	4.0	8.0	4.0	3.0	5.0	1.0
Freezing in water						
f_{cm}, MPa	55.7	74.5	78.1	79.6	90.6	93.1
Δf_{cm}, %	37.0	27.0	24.0	4.0	2.0	0.0

No significant effect was observed of the steel fibre application on the improvement of the flexural tensile strength.

4.4.1.2. Air entrained beams frozen in air

The air entrained (Series B) specimens showed a mass gain of 10–11.5 g after 100 freeze-thaw cycles. The flexural strength loss was 7–19% and the compressive strength loss was 1–5%. This means that in both cases the limit value of 20% was not exceeded.

The concrete from Series B, air entrained with polymer microspheres, satisfied the requirements specified for frost-resistant concrete after 100 freeze-thaw cycles. The test results confirm that the application of polymer microspheres is an effective method of concrete air entrainment. Moreover, a slight increase in the air content due to the presence of polymer microspheres did not decrease the flexural tensile strength.

4.4.1.3. Non-air entrained beams frozen in water

As illustrated in Fig. 5, non-air-entrained concrete (Series A) specimens frozen in water showed considerable mass gains of 118–127 g, which resulted from internal damage in the concrete due to lack of air entrainment. The onset of the beam deterioration was observed after about thirty freeze-thaw cycles.

Vastly faster destruction of water-frozen concrete beams in relation to the specimens frozen in air is explained by the "pumping" mechanism in accordance with the Erlin/Mather concept (Erlin, Mather 2005). The change in ice volume during the water freezing process and the thermal shrinkage of ice caused by further cooling leads to progressive absorption of supplementary water amounts inside the pores (pumping effect) and increases the saturation degree of the material containing water. Conducting further freeze-thaw cycles lead to total destruction of the concrete structure.

The decrease in the flexural strength of the specimens – beams frozen in water – was significant and ranged from 71% to 84%. The values of flexural strength for Series A concrete were within the range of 2.0–3.9 MPa. The decrease in compressive strength of Series A beams was considerable, in the range of 24–37%.

The non-air-entrained specimens after 100 freeze-thaw cycles must be defined as totally non-frost-resistant.

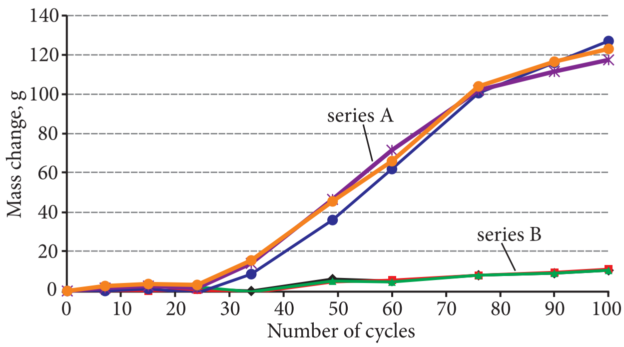

Fig. 5. Mass change of beams frozen in water

Table 9. Scaling resistance of concrete in 3% NaCl

Property	Series A			Series B		
	A0	A1	A2	B0	B1	B2
Mass loss (dm_{56}), g/m^2						
– finished samples	–	131	372	–	61	98
– sawn samples	–	2427	2496	214	184	214

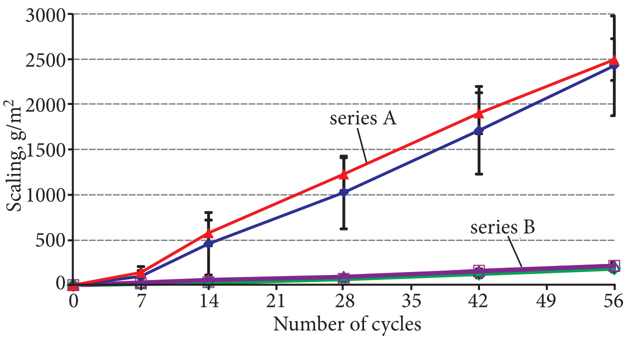

Fig. 6. Scaling of sawn specimens frozen in 3% NaCl solution

4.4.1.4. Air entrained beams frozen in water

An explicit difference was observed in mass change of the air-entrained samples from Series B in relation to the non-air-entrained samples when the specimens were frozen in water. After 100 freeze-thaw cycles, an average mass change of air entrained concrete was 10–11 g. Fig. 5 compares mass changes of the air entrained samples with the non-entrained samples depending on the number of cycles.

The flexural strength of samples from Series B after 100 freeze-thaw cycles ranged from 11.5 MPa to 13.7 MPa. The drop in the flexural tensile strength of the air-entrained beams did not exceed 9%. The drop in the compressive strength was very slight and ranged from 0% to 4%. Such a low mass gain and the strength drop of much less than 20% confirms very good frost resistance, provided by the presence of polymer microspheres in the concrete.

4.4.2. Scaling resistance tests

The results of the tests conducted to determine the scaling resistance of non-air-entrained and air entrained concrete exposed to 3% NaCl are presented in Table 9.

The preparation procedure for the non-air-entrained specimens has a bearing on their scaling resistance. The finished samples showed good resistance to surface scaling dm_{56} = 131 g/m^2 (A1) and 372 g/m^2 (A2), whereas the sawn specimens demonstrated lack of scaling resistance dm_{56} = 2427 g/m^2 (A1) and 2496 g/m^2 (A2) (Fig. 6). All the air entrained concrete specimens had a very good scaling resistance of dm_{56} = 61–214 g/m^2.

It was concluded that the concrete with an addition of polymer microspheres (Series B) showed a definitely higher resistance to frost in relation to the non-air-entrained concrete (Series A).

In each series the finished specimens were more resistant to surface scaling than the sawn specimens. This results from the fact that the finished samples have better surface structure tightness and lower absorption in relation to their internal/deeper portions. The differences in the results obtained from the tests should be taken into account while planning real/in-field concrete pavement tests.

5. Conclusions

This paper discusses the results of the experimental program carried out to investigate the effect of steel fibre and air content on the self-compacting concrete mix properties, frost durability and the mechanical properties of hardened concrete. Two series of air entrained and non-entrained concrete were made with varied amount of steel fibre content (0–60 kg/m^3). The innovative method of air entrainment was applied. It consists in adding particles of constant diameters (polymer microspheres 40 µm diameter) to obtain air pores of specified dimensions. To ensure the uniform distribution of steel fibres in concrete mix volume, all the test specimens were sawn out from the cast 10 cm thick, 50×110 cm slab.

The major objective of the research was to determine freeze-thaw durability. The internal cracking tests were conducted to the Europe Union standard (two beams were frozen in air) and to the modified method (two beams partially submerged in water). In the scaling freeze-thaw tests (the slab method) the specimens with sawn surface and with natural finished surface were examined. The following conclusions were derived from the test results:

1. There was no significant influence of steel fibres addition on the compressive strength of concrete, although the flexural strength increased slightly. It was observed that addition of steel fibres had a negative effect on the workability of the concrete mix.

2. Non-air entrained steel fibre-reinforced self-compacting concretes, despite high strength class (C55/67–C60/75) and medium absorption (4.34–5.11%), showed unsatisfactory resistance to internal cracking and scaling. The beams partially submerged in water were damaged after 100 freeze-thaw cycles, what confirmed a significant influence of water uptake from the moist environment during freeze-thaw cycles and the acceleration of the damage process. The phenomena of water suction from substructure of concrete pavements during freezing may have a significant influence on the frost durability of a structure.

3. In the scaling resistance tests, the specimens with top – finished surface had less damage in relation to the specimens with sawn surface, which is due to the fact that capillary forces and water evaporation from the natural top surface of steel fibre-reinforced self-compacting concrete mix provide better particle packing and create a hard, dense shell, which has better properties than the inner part of the concrete. Choosing the right method of scaling resistance test can have a significant influence on the pavement concrete durability test results.

4. Proper air entrainment was shown to be the determinative factor in frost durability assessment. Air entrainment with polymer microspheres proved a very effective method ensuring very good air pore structure parameters and frost resistance values.

5. The choice of the right frost resistance evaluation method (slab test or capillary suction of de-icing solution and freeze thaw test method) has a significant influence on the ultimate durability values of the pavement concrete. The examination of internal cracking as well as scaling resistance seems to be, in the authors' opinion, an indispensable task.

Acknowledgement

The research project has been provided under the project POIG 01.01.02-10-106/09 *Innovative Measures and Efficient Methods for the Improvement of Safety and Durability of Buildings and Transportation Infrastructure in the Strategy of Sustainable Development*.

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Received 6 February, 2013; accepted 2 May 2013