FROST RESISTANCE OF SELF-COMPACTING CONCRETE


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Summary

Based on the actual state of knowledge, and in accordance with the PN-EN 2006-1:2003 norm, it is recommended to use air entrainment as a basic way of assuring the frost-resistance of concrete. To verify if the self-consolidation process has an effect on air-void stability, concrete samples were put on test of 300 cycles of freezing and testing of porosity structure according to PN-EN 480-11. The results of concrete testing showed that, the parameters of porosity structure are not included in precisely set limits but self-compacting concrete gets frost-resistance F300 according to PN-88/B-06250. Issues connected with this fact are the subject of this paper.

Keywords: Concrete, self-compacting concrete, porosity structure, critical parameters of porosity structure, frost resistance

1 Introduction

The key issue concerning durability of concrete is frost-resistance. Basing on the actual state of knowledge, in accordance with the PN-EN 2006-1:2003, using air entrainment as a basic way of assuring the frost-resistance of concrete is recommended.

According to the actual state of knowledge, concrete is frost-resistant if the values of porosity structure parameters are values presented in **Tab. 1**.

Tab. 1 Porosity structure parameter is included in precisely set limits [8]

Parameter	Unit	Value
$\overline{L}$	mm	0,20 – 0,22
A	%	4 - 7
A_{300}	%	> 1,5 – 1,8
α	mm^{-1}	> 15 - 20

Self-compacting concrete (SCC) is a highly workable concrete that can flow under its own weight without segregation [9], [10]. In the case of self-compacting mixture the process of its self-compacting, depending in fact on autogenous release of random air bubbles from its volume, can significantly affect the final value of concrete porosity structure parameters. When the SCC is air entrained it can substantially affect the frost-resistance of self-compacting concrete.

The high flowability of SCC can destabilize entrained-air bubbles during transport, which can affect the final air-void system of the hardened concrete [6], [7].

The influence of this admixture must be particularly related to the characteristic of the cement and air-entraining admixture (AEA) types [10]. As a result, self-compacting process can significantly affect the final value of concrete porosity structure parameters, and it can influence frost-resistance of self-compacting concrete.

One should pay special attention to the degree of the flowability of self-compacting concrete mixture. The values of rheologic parameters should be g < 2 Nm and h < 10 Nms [4], [10].

2 Method and analysis results of porosity structure of self-compacting concrete

In the foundation stage of investigation [8] 25 different self-compacting concrete (**Tab. 2**) was put to the frost resistance tests, according to PN-88/B-06250. In order to check the influence of four factors (kind of mineral addition (m.a), cement paste-aggregate ratio φ_{kz} (Fig. 13) dosage of air entraining admixture (%AEA) and w/b) on frost resistance of SCC – a composition of 25 sorts of SCC was prepared according to the method of experimental design.

Tab. 2 Composition of self-compacting c concrete S1-S25 [8]

m.a. / AEA (%)	**CEM II 32,5R B-S**	**CEM II 32,5 R B-V**	**CEM II 32,5 R B-M**	**CEM III 32,5 N**	**CEM I 32,5 R + 10% PK**
0	**S11** φ_{kz} = 1.5 w/b = 0.29	**S1** φ_{kz} = 1.2 w/b = 0.32	**S6** φ_{kz} = 1.4 w/b= 0.35	**S16** φ_{kz} = 1.1 w/b = 0.38	**S21** φ_{kz} = 1.3 w/b = 0.41
0,005	**S12** φ_{kz} = 1.1 w/b = 0.32	**S2** φ_{kz} = 1.3 w/b = 0.35	**S7** φ_{kz} = 1.5 w/b = 0.38	**S17** φ_{kz} = 1.2 w/b = 0.41	**S22** φ_{kz} = 1.4 w/b = 0.29
0,010	**S13** φ_{kz} = 1.2 w/b = 0.35	**S3** φ_{kz} = 1.4 w/b = 0.38	**S8** φ_{kz} = 1.1 w/b = 0.41	**S18** φ_{kz} = 1.3 w/b = 0.29	**S23** φ_{kz} = 1.5 w/b = 0.32
0,015	**S14** φ_{kz} = 1.3 w/b = 0.38	**S4** φ_{kz} = 1.5 w/b = 0.41	**S9** φ_{kz} = 1.2 w/b = 0.29	**S19** φ_{kz} = 1.4 w/b = 0.32	**S24** φ_{kz} = 1.1 w/b = 0.35
0,020	**S15** φ_{kz} = 1.4 w/b= 0.41	**S5** φ_{kz} = 1.1 w/b = 0.29	**S10** φ_{kz} = 1.3 w/b = 0.32	**S20** φ_{kz} = 1.5 w/b = 0.35	**S25** φ_{kz} = 1.2 w/b = 0.38

After 28 days concrete samples 150×150×150 mm were freezed and thawed in water for three hours in temp. ±20 °C. Since concrete samples were not damaged after 150 cycles of freezing and thawing, the testing of the frost resistance was continued. A laboratory test was stopped when the amount of alternate cycles of freezing and thawing of concrete amounted to 300. It was noticed that only two types of SCC (S1, S12) were not frost resistant (because the decrease of compression strength amounted to more than 20% after 300 cycles according to PN-88/B-06250), **Fig. 1**.

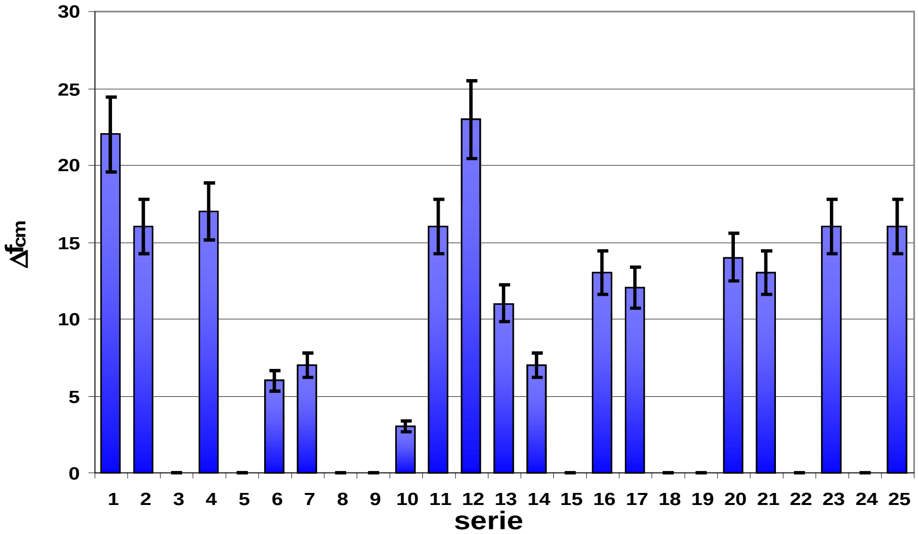

Fig. 1 Results frost-resistance tests according to PN-88/B-06250 [8]

In the following stage of investigation, concrete samples were tested on porosity structure parameters according to PN-EN 480-11 (**Fig. 2**). Unfortunately, because of the limited investment outlays, only eight concrete samples were tested on porosity structure parameters according to PN-EN 480-11. The porosity structure research of eight concrete samples was conducted in IPPT PAN in Warsaw. Among eight concrete samples were two which were not freezeproof and six which were freezeproof, but had different decrease of compression strength amounted to more than 20% after 300 freezing and thawing cycles.

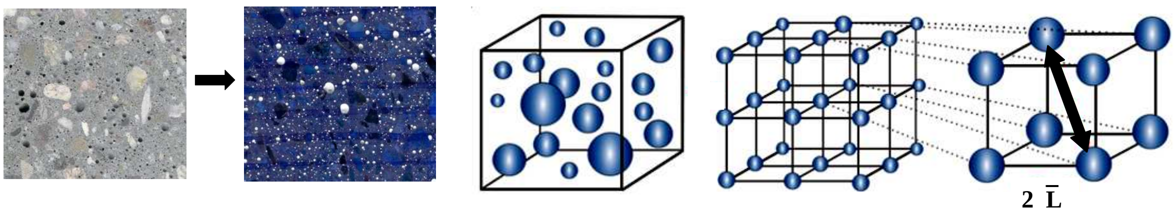

Fig. 2 Testing concrete porosity structure according to PN-EN 480-11 [8]

The results of concrete research according to PN-EN 480-11 showed, in case of samples S21 and S19, porosity structure parameters were adequate moreover quality of air entraining was the highest – although concrete sample S21 contained too much air. Unfortunately, in case of S23, S24 and S25, the quality of porosity structure was inadequate. It was noticed that sparing factor had too high value and parameters α, A_{300} had too low value (**Tab. 3**); it may produce an evidence that porosity structure contained too large pores. Also it was noticed that content of pores with a diameter smaller than 300 μm was inadequate (particularly in case of samples S24 and S25).

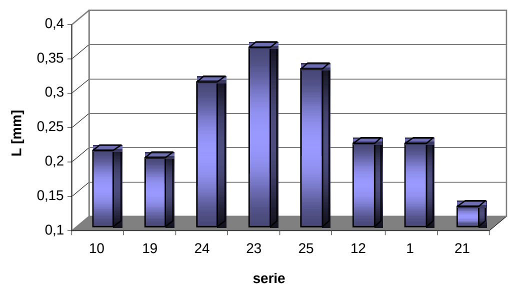

Fig. 3 Results of concrete porosity parameters tests to PN-EN 480-11 [8]

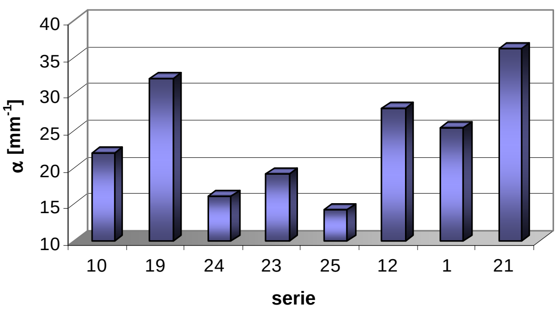

Fig. 4 Results of concrete porosity parameters tests according to PN-EN 480-11 [8]

In the further part of the analysis of the research results it was perceived, that concrete which was characterized by inadequate porosity structure parameters, gets frost resistance degree of the order of F300 according to PN-88/B-06250 (**Tab. 3**).

In order to explain partial discrepancy in research results according to PN-88/B-06250 and PN-EN 80-11, a problem was approached by a detailed analysis of similar researches which are available in professional literature.

Tab. 3 Results of SCC testing according to PN-EN 480-11 and PN-88/B-06250 [8]

No	**Serie**	$\bar{L}$ **[mm]**	**α [mm^{-1}]**	**A [%]**	**A_{300} [%]**	**Δf_{cm} [%]**
1	1	0,22	25,47	4,86	1,74	21
2	12	0,22	27,98	3,69	1,30	23
3	10	0,21	21,93	7,54	1,97	0
4	19	0,20	32,02	3,72	1,18	0
5	21	0,13	36,14	7,19	2,10	14
6	23	0,36	19,04	3,49	0,99	0
7	24	0,31	16,07	5,82	0,91	16
8	25	0,33	14,24	7,30	1,18	0
Suggested [1]:		0,2–0,22	> 5-20	4-7	> 1,5-1,8	< 20

The reasons of partial discrepancy of research results according to PN-88/B-06250 and PN-EN 80-11 are caused by complying with requirements for porosity structure parameters regarding the whole kind of concrete. Fagerlund [2] considers that critical value $\bar{L}$, which was calculated in order to protect concrete from freezing and thawing, in reality depends on cement-water ratio. In order to verify the w/c influence on critical value $\bar{L}$, the author of publication [3] presents the results of laboratory research of freezing and thawing cement paste waterlogged in critical degree as well as the results of porosity parameters research. The results of this research enabled it to estimate the theoretical and practical value of porosity structure parameter $\bar{L}$ (**Tab. 4**). Moreover, it was noticed, that common concrete with w/c of the order of 0,40 ÷ 0,45 and $\bar{L}$ of the order of 0,40 mm can withstand a test of 300 cycles of freezing and defrosting. Whereas, in case of high performance concrete w/s < 0,36 and $\bar{L}$< 0,25 mm ensures, as it was shown [3], adequate frost resistance of concrete.

Tab. 4 Theoretical and practical value of $\overline{L}$ [3]

Freezing	**Critical value $\overline{L}$ [mm]**	
	theoretical $\overline{L}$	**practical $\overline{L}$**
in water	0,22 ÷ 0,25	0,35 ÷ 0,40
with critical salt concentration in water	0,16 ÷ 0,20	0,22 ÷ 0,25

The residual criteria, in respect of critical value $\overline{L}$ in dependence on w/c of high performance concrete, arepres ented in table 5. On the basis of the research results [3], it was concluded, that in case of high performance concrete with silica fume and w/c = 0,30, practical value $\overline{L}$ amounts to **0,40 ÷ 0,50 mm**, and by w/c = 0,25, without silica fume $\overline{L}$ = **0,75 mm**. Further research [3] lead to a conclusion that concrete with compression strength of about 100 MPa, w/c = 0,33, with silica fume 7,5 % m.c., by $\overline{L}$ of the order of **0,80 do 0,85 mm**, withstand a test of 112 cycles of freezing and defrosting in the presence of salt. Whereas concrete with w/c = 0,35, with silica fume 6 %, without air entrainment admixture, possessed a remarkable scaling resistance, and $\overline{L}$ was of the order of as much as **0,90mm**.

Tab. 5 Suggested $\overline{L}$ criteria according to w/c high performance concrete [8]

w/c	**Proposed $\overline{L}$**	**Critical $\overline{L}$**	**Freeze resistance**
> 0,40	0,23 mm	0,26 mm (scaling resistance)	300 cycles ASTM C666 50 cycles ASTM C672
0,40-0,35	0,35 mm	0,40 mm (scaling resistance)	300 cycles ASTM C666 50 cycles ASTM C672
0,35-0,30	0,45 mm	0,50 mm	500 cycles ASTM C666
< 0,30	No data available, above criteria are accepted		

Apart from the shown research results and the visual observation of freezing and thawing concrete constructions [3], which prove that critical value $\overline{L}$ can be of the order of 0,40 or higher, it is still recognized that values in respect of porosity structure are always right.

3 Conclusions

Ensuring the adequate air-void system in concrete is essential for obtaining proper resistance to freezing and thawing. With the increasing usage of highly flowable concrete and SCC, it is important to ensure that this concrete can provide the proper air-void system that remains stable during agitation, placement, and setting. This paper provides information regarding the effect of mixture composition on the stability of the air-void system.

The results of frost resistance research of air entrained self-compacting concrete according to PN-88/B-06250 and PN-EN 480-11 were shown in this paper. On the basis of the presented analysis, it can be noticed, that concrete which is not characterized by adequate values of porosity structure can be freezeproof of the order of F300. Therefore, it can be said that prevalent values of concrete porosity structure are too severe. Moreover, the requirements related to porosity structure parameters are determinated for all kinds of concrete. However, different series of concrete (series of concrete is understood according to PN-EN 206-1: one kind of cement, aggregate, addition type II and admixture) differ from each other for the sake of their porosity structure. Therefore, do requirements related to porosity structure parameters concern the whole series of concrete? Moreover, frost resistance of concrete is estimated on the basis of laboratory research results. Thus what is the procedure to determine critical value $\overline{L}$ to adequate degree of frost resistance of particular concrete?

Different questions concerning critical value of porosity structure and frost resistance of concrete were brought up in this paper. However the problem which was raised is more complicated. In order to find the solution, an adequate laboratory research should be conducted in order to estimate practical values of the porosity structure parameters and advisable frost resistance concrete degree.

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