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Analysis of the Impact of Fly Ashes on the Structure of SCC Concrete Aeration

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Abstract. The paper presents the results of tests of the impact of fly ash admixture on the structure of aeration and on selected physical and mechanical properties of self-compacting concrete (SCC) concrete mix. The effects were compared to those obtained for SCC concrete made solely with the use of Portland cement. Tests were performed on a fresh concrete mix (spread, viscosity and air content by pressure method). The aeration parameters of the fresh concrete mix were determined by Air Void Analyser (AVA) method (total air content A, micropores content A300 and spacing factor \bar{L}). For hardened concretes, the following characteristics were determined: compressive strength (after 2, 7, 28 and 56 days), water absorption, water tightness and frost resistance. Unit prices were also calculated (for prices in Poland) for SCC concrete made solely with the use of Portland cement and separately with the use of fly ash admixture. The analysis of the results demonstrated that the addition of a large amount of fly ashes to SCC concrete clearly has a negative impact on the stability and quality of its aeration characteristics and, as a consequence, significantly reduces its frost resistance and thus durability. The unit price calculated for SCC concretes made with the use of fly ash is clearly lower than of concretes made solely with the use of Portland cement, but in many cases this does not justify the use of fly ash.

1. Introduction

SCC (self-compacting concrete), which has been used in Poland for approx. 10 years, is a fluid construction material which dissolves and de-aerates under its own weight and thus it is ideal for, among other things, tight filling of moulds with irregular shapes and providing "coating" for elements with a very dense reinforcement [2, 5]. SCC concrete can also be used for decorative purposes because it can create smooth surfaces or imitate wood boarding with complicated textures. However, the unit price of self-compacting concrete is clearly higher than the price of ordinary concrete, which limits its use. To reduce the price of SCC concrete, the addition of fly ash is more and more often used. However, the use of fly ashes raises an important question: What is their effect on the stability and quality of the aeration of SCC concrete? In practice, the results of the use of fly ashes are often unsatisfactory. Most frequently, the condition of frost resistance [4] is not met. This paper attempts to answer this question. The proper aeration of concrete has a big impact on the durability of concrete and especially on its resistance to corrosive factors and the destructive impact of freezing water, which is especially important in the case of road and bridge structures.



The paper presents test results of selected physical and mechanical characteristics of two aerated SCC concretes used for bridges. The first (Recipe 1) was made using Portland cement (CEM I 42.5 N-SR3/NA) and in the second (Recipe 2) a part of the cement was replaced with silica fly ash. In both cases, the same aggregates and superplasticizer as well as aerating admixture of good quality were used.

2. Methodology of the study

For fresh mixtures, standard tests for SCC concretes were made: spread and viscosity and the air content were determined by pressure method. Using the AVA (Air Void Analyser) method, the following were determined: total air content A (%), content of air voids with diameter $<300\mu\text{m}$ A_{300} (%) and spacing factor \bar{L} (mm). After 60 minutes, the degree of maintaining SCC concrete parameters and aeration quality were checked. Concrete samples (cubes with sides of 150 mm) were made and after 2, 7, 28 and 56 days of maturation, compressive strength tests were performed. After 28 days of maturation, tests of water absorption, water resistance and frost resistance were performed using a standard method. A comparative price analysis of both types of SCC concretes was also made.

2.1. Materials used

On the basis of literature data and practical knowledge, to achieve proper de-aeration of the mixture under its own weight, the amount of binder in each of the formulations was assumed to equal 440 kg/m^3 . To prepare slurries, cement CEM I 42.5 N-SR3/NA from Kujawy Cement Plant [3] was used for Recipe 1 and a mixture of CEM I 42.5 N-SR3/NA and good quality fly ash - PRO Ash from Janikowo in the amount of 340 kg/m^3 of cement and 100 kg/m^3 of fly ash were used for Recipe 2.

Table 1. Parameters of projected recipe

Class	> C30/37
Spread	SF2
V-funnel	VF1
Air content by pressure method	> 4%
Watertightness	W10
Water absorption	< 4%
Frost resistance	F150

Table 2. Composition of projected recipes.

Component	CEM I 42.5 N-SR3/NA	CEM I 42.5 N-SR3/NA + fly ash PRO Ash
	Recipe 1 (kg/m^3)	Recipe 2 (kg/m^3)
Cement	440	340
Additive	-	100
Water	157	151
Sand 0/2	688	678
Grit 2/8	516	509
Grit 8/16	516	509
Superplasticizer	6.60	6.50
Aerating admixture	2.70	4.10

The fly ash used is characterized by a very good value of the pozzolanic activity index, which is in accordance with standard [12] (80% after 28 days and 98% after 90 days). According to standard [9], it can be used for each of the exposure classes. This is the cement type often used for the production of

road and bridge concretes. In Recipe 2, due to the presence of fly ash difficult for stable aeration, approx. 50% more aerating additive was used. When projecting the composition of the mixture, it was assumed that the concrete should meet the conditions required for "bridge type" concrete. They are presented in Table 1. After preliminary tests, the final quantitative and qualitative compositions of both tested formulas were determined. They are presented in Table 2. For each recipe type, AVA test was made to verify the aeration structure.

2.2. AVA Method

Despite the progress of technology, there is still no completely reliable device analysing the quality of aeration of a concrete mix or hardened concrete, the results of which could be considered 100% reliable. The most common method is the "polishing" method [1] for hardened concretes described in the standard [10]. One of the alternative methods is AVA test method which allows for the assessment of the quality of the aeration of fresh concrete mix (Figure 1). Both methods allow for the determination of basic properties of air voids structure in concrete:

- A [%] – total air content,
- α [mm^{-1}] – specific surface area of air voids,
- A_{300} [%] – content of air voids with diameter $< 300\mu\text{m}$,
- \bar{L} [mm] – spacing factor



Figure 1. Set-up for AVA tests

The AVA method is a relatively new test method developed in Denmark in the 1990s. The AVA study applies Stokes' law, which determines the resistance force of a body in the shape of a ball moving in gas or liquid of known density. Knowing the speed of voids moving, one can determine their size (larger ones move faster). To perform a test, a sample of mortar is taken using a special syringe. The sample is then injected into the AVA apparatus at the bottom of a glass measuring column. Gentle stirring of the mortar results in the release of bubbles and transfer to the liquid placed in the measuring column. The air voids rise and gather under the measuring bowl. Changes, measured within 25 minutes, are the basis for calculating air entrainment parameters. The advantage of this method is the speed of the test. The test lasts for about 45 minutes. However, AVA has a few restrictions. First of all, the ambient temperature during the test must be within a fairly narrow range - from 21 to 25 °C. Secondly, for the measurement to be precise, rooms in which tests are performed should be protected against draughts and vibrations. Due to the fact that the equipment is delicate, it is not possible to carry out the test at the construction site. The sample subject to testing is very small, only 20 cm³.

3. Test results and their analysis

3.1. Testing fresh concrete mix

The results of the tests of the fresh concrete mix for Recipe 1 and 2 together with the results of the AVA tests are presented in Table 3. The analysis of the results presented in Table 3 shows that the concrete mix for Recipe 1 meets the assumed parameters regarding spread, viscosity and air content. A significant increase in the aeration of the mixture (by approx. 100%) was observed after 60 min, which is characteristic for the cement used. The results of AVA study are also satisfactory. The minimum content of micropores A_{300} in concrete, allowed by the German Federal Ministry of Transport regulations ZTV Beton-StB 01 [6, 7] is 1.5% for XF1 and XF2 frost exposure classes and 1.8% for XF3 and XF4 classes. Concrete mix Recipe 1 meets these conditions.

According to the guidelines for the construction of concrete road surfaces ZTV Beton-StB 01 issued by the German Federal Ministry of Transport [6, 7], the value of the spacing factor in concrete should not exceed 0.2 mm. The value of the \bar{L} index obtained in the tests slightly exceeds this value.

Table 3. The results of tests for fresh concrete mix - Recipe 1 and 2

Recipe	1		2	
Testing time	After 10 min.	After 60 min.	After 10 min.	After 60 min.
Spread (mm)	625	690	695	690
Viscosity (s)	6.7	5.9	5.8	6.3
Air content by pressure method (%)	3.0	6.1	3.4	5.4
AVA test results				
Total air content (%)	5.0		2.2	
A_{300} (%)	2.3		1.0	
\bar{L} (mm)	0.244		0.244	

Values required for spread, viscosity and air content by the pressure method were achieved for Recipe 2 (Table 3). As in the case of Recipe 1, a significant increase in aeration was observed after 60 min (about 60%). The results of the AVA study are surprising as according to this test the total air content is only 2.3%, and the content of air pores with a diameter $<300\mu\text{m}$ is only 1.0% (Figure 2).

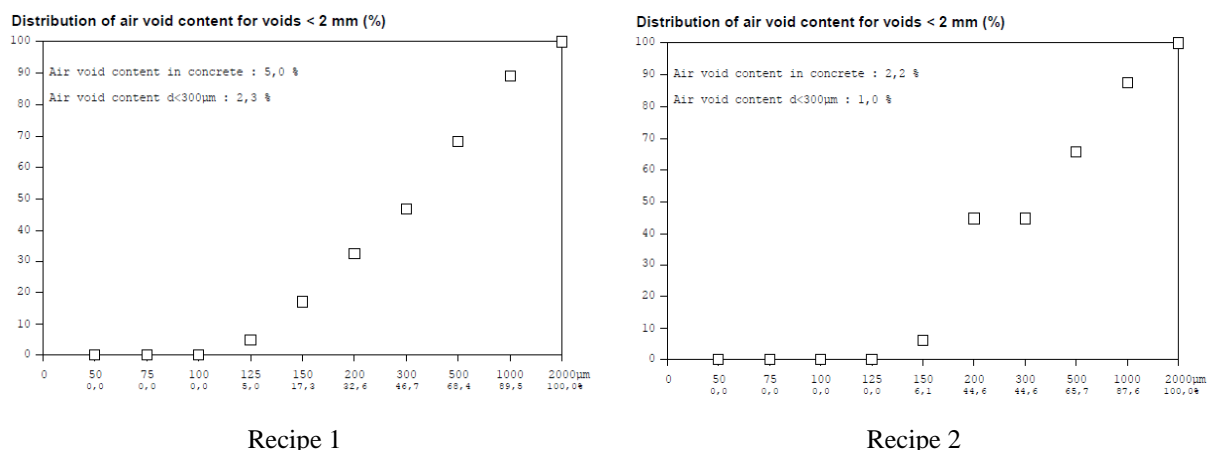


Figure 2. Distribution of air voids in % determined by AVA method for Recipe 1 and 2

These results are definitely unacceptable and the frost resistance of the concrete cannot be achieved. Attention should be paid to the differences between Recipe 1 and 2. The amount of all components used in both mixtures are similar. Only the amount of aerating admixture in Recipe 2 is

about 50% higher than in Recipe 1. Even such a relatively high amount of aeration additive did not allow achieving positive results in the AVA study (2.2%). There is a significant contrast between the results obtained in the AVA study and the air content obtained in the tests by pressure method, amounting to almost the optimum value of 5.4%. As in the case of Recipe 1, the value of \bar{L} index obtained for Recipe 2 slightly exceeds the limit value acceptable by the German Federal Ministry of Transport (≤ 0.2 mm).

3.2. Testing hardened concrete

3.2.1. Compressing strength tests. The obtained compressive strength test results are presented in Table 4. Analysing the obtained results, it can be concluded that both mixtures exceeded the assumed minimum class C30/37. Both mixtures reached the strength class C35/45. The strength for both mixtures after 56 days corresponds to the class C40/50. Such high strength values were achieved due to the need of using a large amount of binder. It was necessary to achieve the self-compacting effect of the mixture. In bridges, an important element are two-day results, on which the time of deforming of the given element may depend. Concrete which was prepared according to Recipe 1 achieved satisfactory 2-day compressive strength, i.e. 29.3 N/mm² (approx. 30 N/mm² required). For Recipe 2, the compressive strength obtained in the tests was slightly too low (22.9 N/mm²). The obtained value of the strength development index is adequate for the adhesive used - for CEM I 0.55 (fast development) and for concrete with fly ash addition 0.46 (moderate development).

Table 4. Results of compressive strength tests for concretes prepared

Number of days after which compressive tests were made	Recipe	
	1	2
	N/mm ²	
R2	29.3	22.9
R7	44.4	37.6
R28	53.5	49.9
R56	57.7	57.0
Compressive strength development (R2/R28)	Fast (0.55)	Moderate (0.46)

3.2.2. Water absorption tests. Tests were carried out according to the recommendations contained in standard [11]. For Recipe 1, the value of 4.1% was obtained and for Recipe 2: 4.0%. The values achieved are within the range accepted by the standard.

3.2.3. Water tightness tests. Tests were performed according to the recommendations contained in standard [8, 11]. In both cases, the tested concrete reached the assumed water resistance level of W10. For Recipe 1, the depth of water penetration after completing the test was 17 mm and for the Recipe 2 it was 50 mm.

3.2.4. Frost resistance tests using standard method. The test was carried out according to the recommendations contained in standard [11]. The results achieved are shown in Table 5. Concrete made according to Recipe 1 met the requirements for frost resistance equalling F150 (average weight loss <5% and average loss in compressive strength <20%). Concrete samples prepared according to Recipe 2 after 120 freezing cycles got damaged.

Table 5. Results of frost resistance tests.

Recipe	1		2
Average mass decrease [%]	- 0.18	- 0.31	The samples withstood max. 120 cycles and got damaged
Average decrease of compressive strength [%]	- 5.6	- 1.5	

4. Comparison of prices of tested concretes

Table 6 presents average prices of specific raw materials in Poland in PLN (1 Euro = approx. PLN 4.2), used for the preparation of projected concretes (Recipe 1 and Recipe 2).

Table 6. Price analysis of projected recipes

Recipe:	1		2	
	Volume [kg/m ³]	Price [zł/m ³]	Volume [kg/m ³]	Price [zł/m ³]
Cement	440	140.8	340	108,8
Additive (fly ash)	-	-	100	9,5
Water	157	0.6	151	0.6
Sand 0/2	688	15.1	678	14.9
Grit 2/8	516	41.3	509	40.7
Grit 8/16	516	43.9	509	43.3
Superplasticizer	6.60	23.1	6.50	22.8
Air entraining additive	2.70	5.4	4.10	8.2
Total price (PLN):	270.2		248.8	

The component which has the biggest impact on the price of the prepared concretes is cement CEM I. It constitutes approx. 52% of the price of concrete made solely with its use. When using fly ash as an additive, the amount of cement and thus its price is reduced to approx. 43% of the mix. The price of 1 m³ of aerated SCC concrete made with the use of Portland cement with the addition of fly ash is about 10% lower than that of the concrete made using only the Portland cement.

5. Conclusions

As a result of a comparative analysis of the test results obtained for SCC concretes prepared with the use of CEM I (Recipe 1) and CEM I with the addition of fly ash (Recipe 2), it can be concluded that:

- The addition of fly ash has practically no negative effect on the basic physical and mechanical characteristics of concrete. Both the compressive strength as well as water absorption and water tightness are similar for both tested recipes.
- The analysis of the obtained results shows that the concrete mixes made according to Recipe 1 and 2 meet the assumed parameters for SCC concretes regarding the spread, viscosity and air content by pressure method both after 10 and 60 minutes.
- According to AVA tests, the total air content for the mixture no. 2 (containing fly ash addition) is only 2.2% (required > 4%), and the content of air voids with a diameter <300µm (A₃₀₀) is only 1.0% (required > 1.8%).
- According to AVA tests, the total air content for the mixture no. 1 (without the addition of fly ash) is 5.0% (required > 4%), and the content of air voids with a diameter <300µm (A₃₀₀) is 2.3% (required > 1.8%).
- The addition of fly ash clearly lowers the unit price of concrete (by approx. 10%).
- Concrete made with the addition of fly ash did not meet the requirements for frost resistance equalling F150.

To sum up: the addition of large quantities of fly ash to SCC concretes clearly has a negative impact on the stability and quality of their aeration and, consequently, significantly reduces their frost resistance and thus their durability.

The unit price of SCC concretes prepared with large quantities of fly ash is clearly lower than the price of concretes made solely with the use of Portland cement. The use of fly ash is an environmentally-friendly approach (utilization of troublesome industrial waste, reduction of CO₂ emissions from the production of cement clinker to the atmosphere,). The technologist projecting the SCC concrete composition therefore faces a very difficult choice: What is more important: quality, price or ecology?

References

- [1] K. Zielinski, P. Knast, "The structure of air entrainment of cement concrete by means of protein preparation and modern factory produced admixture". *BFT INTERNATIONAL – Betonwerk+Fertigteil-Technik*, vol. 83, pp.40-47, 2017.
- [2] J. Szwabowski, J. Gołaszewski, "Technology of self-compacting concrete", *Stowarzyszenie Producentów Cementu*, Kraków 2010, (in Polish).
- [3] A. Paszkowski, K. Pytel, "The use of cement CEM I 42.5R and CEM I 42.5N-SR3 / NA in self-compacting concrete for bridges - formal requirements and test results", *IX Konferencja Dni Betonu, Tom I, Stowarzyszenie Producentów Cementu*, Kraków 2016, (in Polish).
- [4] Z. Rusin, "Technology of Frost resistant concrete", *Polski Cement*, Kraków 2002, (in Polish).
- [5] J. Gołaszewski, "Technology of self-compacting concrete – practical issues", *Rheology in the technology of concrete*, *Wydawnictwo Politechniki Śląskiej*, Gliwice, pp. 57-68, 2009, (in Polish).
- [6] M.A. Glinicki, "Methods of qualitative and quantitative assessment of concrete air entrainment", *Cement Wapno Beton*, T. R. 19/81, pp. 359–369, 2014, (in Polish).
- [7] M.A. Glinicki, "European requirements for aerated concrete in XF environment class", *Drogownictwo*, , pp. 86–88. *Instytut Podstawowych Problemów Techniki PAN -Warszawa*, 2005, (in Polish).
- [8] A.M. Neville, "Properties of Concrete", *Fourth Edition*, *Wydawnictwo Polski Cement*, Kraków 2000.
- [9] EN 206+A1: 2016: Concrete - Part 1: Specification performance, production and conformity.
- [10] EN 480-11:2008: Admixtures for concrete, mortar and grout - Test methods - Part 11: Determination of air void characteristics in hardened concrete.
- [11] PN-B-06250:1988 Plain concrete.
- [12] EN 450-1:2012: Fly ash for concrete - Part 1: Definition, specifications and conformity criteria.