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INFLUENCE OF ANTI-FOAMING ADMIXTURE ON FROST RESISTANCE AND POROSITY CHARACTERISTIC OF SELF-COMPACTING CONCRETE

B. ŁAŹNIEWSKA-PIEKARCZYK[1]

For the decreasing of too high air volume in SCC, application of anti-foaming admixture (AFA) is proposed. In effect, AFA is increasing mix flow diameter and decreasing the flow time. Moreover, the workability loss is lower. In case of mix incorporating AFA, their high fluidity do not generate segregation of the mix, which is possible in case of SCC incorporating only SP. The effect of AFA application on the compressive strength depends on the proportions between SP and AFA. AFA has not a negative influence on the freeze-proof properties of the tested concrete. The advisable influence of AFA on porosity characteristic of SCC is proved by research results according to EN 480-11 code.

Key words: Anti-foaming admixture (AFA), superplasticizer (SP), frost-resistance, porosity, self-compacting concrete.

1. Introduction

The characteristic feature of self-compacting concrete mix is an effective elimination of air bubbles produced during the process of mixing. The effect of the self-compaction depends on the values of the rheological parameters, such as yield stress and plastic viscosity of cement paste. Technological tests, assessing the self-compactibility of the concrete mix (SCC), such as flow test (Table 1 and 2), are carried out because the availability of the direct measurement of rheological properties is limited. The value of SCC flow diameter depends on the mix yield stress τ_{0m}, whereas SCC time flow depends on its plastic viscosity η_{pl}. The diameter and time flow of SCC should correspond with the classes presented in Tables 1 and 2. The European guidelines for self-compacting concrete [10] describe detailed outlines in respect of SCC classes and other technical tests of the self-compacting concrete mix depending on its purpose.

The results of various tests showed that in numerous cases a problem of excessive air-entrainment of concrete mix occurs, [7, 14], despite the fact that fresh mix achieved recommended flow in suitable time according to [10] (Table 1 and 2). Tests of the porosity characteristics of the concrete [14] proved that the excessive air-entrainment

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Table 1

Slump-Flow classes [10].
Klasy rozpływu [10]

Class	[mm]
SF1	from 550 to 650
SF2	from 660 to 750
SF3	from 760 to 850

Table 2

Viscosity classes [10].
Klasy konsystencji [10]

Class	[s]	
	T_{500}	*V-funnel*
VS1/VF1	$\leqslant 2$	$\leqslant 8$
VS2/VF2	> 2	from 9 to 25

of the mix influences the air-entrainment of concrete (during the process of concrete hardening the pores are not filled with the hydration products, due to the fact that the C-S-H gel may form only in water) [11], [12]. The tests results [6] (presented in Table 3), [13] and [14], prove that the new generations of high range water reducer (SP) indicate air-entrainment effect, as well. It should be emphasized that according to standard requirements concerning chemical admixtures (EN 934-2:1999) of the concrete, SP should not produce higher than 2% air formation in the mix, compared to the control concrete mix.

Table 3

The influence of the SP type on the mix air-content in concrete mix [7].
Wpływ rodzaju SP na zawartość powietrza w mieszance betonowej [7]

SP type	Ligno-sulfian, *LS*	Sulfonated Naphtalene Formaldehyde Condensate, *SNF*	Sulfonated Melamine Formaldehyde Condensate, *SMF*	New Generation SP	
				PolyCarboxylate Polyoxyethylene, *PCP*	Amino Phosphonate Polyoxyethylene, *AAP*
Air-content	++	+	0	++	++

The reason for the PCP air-entrained SP effect is its influence on the decrease of the surface tension of the liquid phase in the paste, as it was proved in other tests [5]. The air content, as an effect of SP application, increases when w/b ratio is growing (Fig. 1 and 2). When the liquid phase part in mix is increasing, the air-entrainment effect is higher, similarly as in case of the air-entraining admixture [8], [11].

On the basis of the tests results shown in [3], it could be concluded that the etheric and poly-carboxyl SP of the SCC influence on porosity structure. The tests results presented in Table 5, prove that SP made on the basis of poly-carboxyl ether

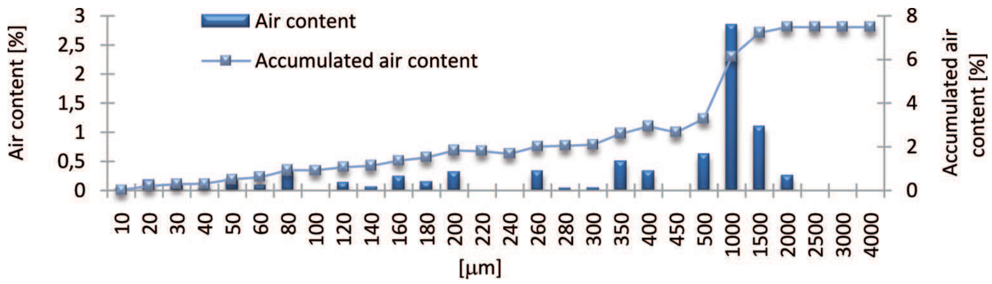

Fig. 1. The porosity characteristics of non air-entrained SCC (CEM I 32.5 R + 10% silica fume; *w*/*b*=0.41) [14].
Rys. 1. Charakterystyka porowatości nienapowietrzonego SCC (CEM I 32.5 R + 10% silica fume; *w*/*s*=0.41) [14]

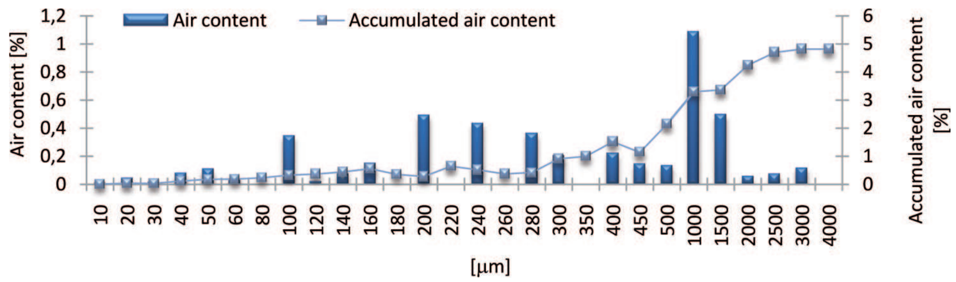

Fig. 2. The porosity characteristics of non air-entrained SCC (CEM II 32.5 R B-S; *w*/*b*=0.29) [14].
Rys. 2. Charakterystyka porowatości nienapowietrzonego SCC (CEM II 32.5 R B-S; *w*/*s*=0.29) [14]

generate considerable SCC air-entrainment. The air-entrainment is higher in case of higher w/c value and amounts even to 8.30%. It should be emphasized that the mix achieved relatively high flow 660 mm (corresponding with class SF2, Table 1). Despite this fact, there was no suitable self-compaction (self-venting). The air-entrainment of fresh mix was probably higher than 8.3%, because the air content measured in hardened concrete is approximately 1÷2% lower than in the mix. The reason for the excessive air-entrainment of the fresh mix is probably the influence of the mechanism of action and structure of SP on the formation and behaviour of the air bubbles in its volume. In case of poly-carboxyl SP, the air content was lower and amounted to 4.45% with *w*/*c* = 0.45. The test results concerning the effects of poly-carboxyl SP comply with other test results published in [14]. The conclusions from the analysis of the test results presented in Table 5 also confirm test results of mercurial porosimeter. In this case, the SP made on the basis of poly-carboxyl ether generates higher SCC air-entrainment. The excessive air content appeared although the fresh mix achieved even 710 mm of flow. When a SP shows the air-entraining effect, a well-founded question concerning the effectiveness of commonly used tests qualifying the mix as self-compacting could be formed.

Table 4

The results of air voids characteristic in SCC [3].
Rezultaty badań charakterystyki porów powietrznych w SCC [3]

Porosity structure parameter	Series			
	A^1	B^1	C^2	D^2
air-content, A [%]	6,7	**8,30**	2,90	4,45
content of micropores below 0,3 mm, A_{300} [%]	1,50	2,96	0,70	1,74
spacing factor, $\bar{L}$ [mm]	0,26	0,11	0,33	0,13
specific surface, α [mm^{-1}]	17	36	21	45

[1] polycarboxylic ether (*PCE*), [2] polycarboxylate (*PCP*)

2. Negative effects of the excessive air-entrainment in self-compacting mix and concrete

The air-entrainment of the fresh mix may decrease its flow depending on the degree of the initial fluidity. The flow decreasing is the result of internal compression of the air bubbles and lower density of the fresh mix. The air-entrainment may also initially increase the flow, when the fresh mix is originally of low fluidity [8], [12]. However, subsequent increasing content of the air-entrained admixture decreases the fresh mix diameter of flow.

The sizes of pores formed during SP action in hardened concrete are too big (Fig. 1÷3). That is the reason why concrete mechanical parameters decrease. The frost resistance and absorbability of concrete deteriorate, as well [14]. In order to protect concrete against the effects of cyclic freezing and thawing, it is beneficial for the bubbles to have 0,05÷0,10 mm of diameter and the distance between bubbles in the paste volume is equal to 0,15÷0,20 mm. However, the problem of the critical value of the air void factor in frost resistant concrete, depending on its type, is still an object of tests [14].

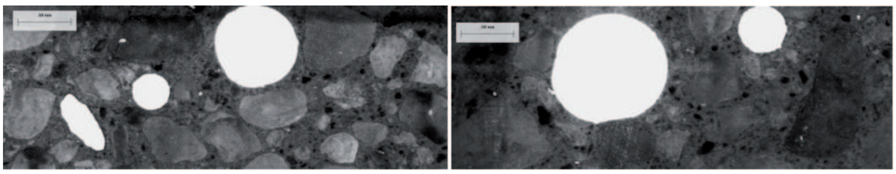

Fig. 3. The porosity characteristics of non air-entrained SCC (CEM II 32.5 R B-S; *w*/*b*=0,41) [14].
Rys. 3. Charakterystyka porowatości nienapowietrzonego SCC (CEM II 32.5 R B-S; *w*/*s*=0,41) [14]

Considering mentioned above tests results, it is obvious that certain SP of new generation produce excessive air-entrainment remaining in the self-compacting volume of the fresh mix and concrete and deteriorating their properties, although the mix meets commonly accepted criteria of technical tests (Table 1 and 2). Desired suitable fluidity of the fresh mix, essential for its effective self-compacting, is not included in any commonly used technical tests. The accepted criteria for such tests are insufficient in this scope and do not guarantee an effective self-compacting. It can be obtained by increasing the fluidity of the fresh mix with the SP, however it may generate its segregation. Due to this fact, in order to prevent the presence of the excessive air-entrainment, the SP should not only be compatible with cement, but also do not create air-entraining effect in the paste. In order to counteract the excessive air-entrainment, the anti-foaming admixtures (AFA) preventing air bubbles formation can be used [6]. Such admixtures are not commonly used in building practice. Hence, the mechanism of their functioning is not well-known, as well as their effectiveness in decreasing the air content in fresh mix and influence on fresh mix and hardened concrete properties. So, it is advisable to carry on proper tests for verification of the influence of anti-foaming admixtures on air-entrainment, rheological properties, stability of self-compacting concrete mix, compressive strength, frost resistance of SCC and porosity characteristic according to EN 480-11. Result of measurements were available as a set of standard parameters for an air void: spacing factor $\bar{L}$ (mm),specific surface α 1/mm), air content A (%), content of air voids with diameter less than 0.3 mm A_{300} (%) and air void diameters distribution (in form of a distribution Table).

3. DESCRIPTION OF EXPERIMENTAL TESTS

SCC consisted of CEM III/A 32,5N-HSR/NA and CEM I 42,5 R, lime stone (LS), silica fume (SF), 2/8mm and 8/16 mm fraction gravel aggregate, 0/2 mm fraction sand, tap water, chemical admixtures: SP (based on polyoxyethylene) and AFA anti-foaming admixture. According to the producer, the SP included a certain type of AFA, but author's research results proved that this SP causes too high air volume in SCC.

The design of the concrete mix had an experimental nature. In Table 5, the proportions of the ingredients in 1 m^3 of the concrete mix are compiled. The aggregate and sand were dried in a drier for 24 hours and cooled before the tests.

The properties of the concrete mix were investigated using the following methods: self-compactibility test in accordance with procedure [10] density test - in accordance with EN 12350-6:200 standard, air content – the pressure method according to EN 12350-7:2001.

The tests were carried out after 28 days on 100×100×100 mm concrete specimens cured in 20°C water. The properties of the concrete were measured according to standard methods: compression strength in accordance to EN 12350-3:2001 and freeze-proof resistance according to PN-88/B-06250. After 28 days, concrete samples were freezing and thawing in water for three hours in temp. ±20°C (four cycles per day). According to this standard, concrete is frost-resistant when its compressive strength decrease is lower than 20% after *n* cycles. Symbol *Fn* describes the frost-resistance degree.

Table 5

Compilation of the proportions of the ingredients in 1 $m^3$of the concrete mix.
Proporcje składników w $1m^3$ mieszanki betonowej

Symbol	Cement type	Cement [kg]	Additive type	Additive amount [% m.C]	w/b	0÷2 mm [kg]	2÷8 mm [kg]	8÷16 mm [kg]	SP [%m.C.]	AFA [%m.C.]
*A*1	CEM III 32,5 N	545	LS	10	0,40	875	423	256	0,95	0,00
*A*2		538	LS	10	0,41	875	423	256	0,95	0,93
*B*1		564	–	–	0,32	900	449	289	1,31	0,00
*B*2		564	–	–	0,32	900	449	289	1,93	0,00
*B*3		547	–	–	0,34	900	449	289	1,93	1,00
*B*4		547	–	–	0,34	900	449	289	1,93	1,00*
*C*1	CEM I 42,5 R	580	SF	10	0,28	950	450	256	3,53	0,00
*C*2		580	SF	10	0,28	950	450	256	3,53	1,49
*C*3		580	SF	10	0,28	950	450	256	3,53	2,20
*C*4		580	SF	10	0,26	950	450	256	3,53	4,33

*after 20 minutes, AFA – modified polyalcohol, SP based on polyoxyethylene, *MW*- lime flour, *w* – water + admixtures

In the following stage of the research, concrete porosity structure parameters are investigated according to PN-EN 480-11.

4. Analysis of the results and discussion

In Table 6 the results of testing *A*1 ÷ *C*4 mixes are compiled. The analysis of the results indicates that the application of AFA, apart from the air content reduction, leads to an increase of its flow diameter and decrease of its flow time. The higher air-content is produced, the higher decrease of fresh mix flow diameter is.

Results of the research (Table 6) shows, that negative influence of the air-content on SCC flow diameter is higher for SCC with low *w*/*b* ratio value.

It should be emphasised that the best effectiveness of AFA, SP and AFA doses should be selected by iteration, so that the biggest flow of the mix at the lowest air content in its volume is obtained (compare *C*2 ÷ *C*4, Table 6).

Comparing the results of *B*3 and *B*4 tests (Table 6), it can be concluded that the moment when AFA is added is important for its effectiveness. To achieve the biggest air content reduction and maximal flow of the mix, AFA should be applied right after the incorporation of SP. The results of the tests [6], indicated that the time of AFA application is not essentials for SCC with higher *w*/*c* value.

In Table 7, the results of *A*1 ÷ *C*4 concrete tests are compiled. The analysis of the influence of AFA on SCC strength leads to the following conclusions. The use of AFA reduces compressive strength by 10 MPa, reduction is bigger when SCC has smaller *w*/*c* values. Furthermore, the influence of AFA on SCC is essentially dependent on the

Table 6

Properties of the self-compacting concrete mix.
Właściwości mieszanki samozagęszczalnej

Symbol	Air content [%]	Flow time [sec.]	Flow diameter [mm]	Concrete mix density [kg/m^3]
*A*1	4,8	3	730	2289
*A*2	2,9	2	770	2290
*B*1	4,0	9	530	2290
*B*2	3,5	4	590	2270
*B*3	2,7	3	640	2310
*B*4	2,7	4	700	2260
*C*1	5,6	13	700	2300
*C*2	3,8	9	740	2320
*C*3	2,8	9	750	2350
*C*4	2,2	8	760	2400

proportions between SP and AFA. In case of insufficient quantity of SP and excess of AFA, the flow of the mix does not increase and air entrainment does not decrease (compare: *C*1 and *C*4, Table 6). Conversely, excessive air content and AFA quantity lead to reduction of SCC compressive strength (compare *C*1 and *C*4, Table 7).

Moreover, compiled in Table 7 research results show, that low air-content in mix and high density of hardened SCC (achieved incorporating AFA; series: *A*2, *B*3, *B*4, *C*2, *C*3, *C*4) does not increase its compressive strength.

The analysis of the influence of AFA on the freeze-proof properties of SCC (Table 7) indicates a very positive change. Moreover, AFA increases the strength of the concrete (up to 16%, compare with *B*4, Table 7) after the freeze-proof tests. The strength of the same concrete without AFA was reduced up to 15.5%. Furthermore, a favourable influence of AFA was clearly manifested in the tested concrete with smaller w/c values, irrespective of the air content in the mix (compare *C*1 and *C*3, Tables 6 and 7). Positive influence of AFA on the concrete mix increases with its volume (compare with *B*3 and *B*4 with *C*2, *C*3 and *C*4, Table 7).

The air content, which is the result of SP action, does not secure *F*300 freeze-proof properties in each case, tested on 10x10x10 cm concrete samples. Interestingly, the same or lower level of air content which is the effect of the joint action of SP and AFA leads to proper freeze-proof properties of the concrete, despite the small size of the concrete samples (compare *C*1 and *C*3, Table 7). The reason of this phenomenon lies probably in the internal structure of SCC, modified by the AFA action.

The research results according to EN 480-11 are presented in Table 8,9 and in Fig. 4. This research proved that AFA generate positive change of values of porosity structure parameters. The value of air void space factor is smaller, when SP and AFA is incorporated. Moreover, the air void volume with diameter smaller than

Table 7

Properties of the hardened concrete.
Właściwości stwardniałego betonu

Symbol	Concrete density [kg/m^3]	Compression strength [MPa]	Reduction of the compression strength after 300 cycles of freezing-thawing [%]
*A*1	2304	55,6	35,0
*A*2	2299	50,8	20,1
*B*1	2294	66,7	34,9
*B*2	2280	66,0	13,0
*B*3	2321	59,1	1,0
*B*4	2275	59,5	-13,1
*C*1	2321	69,0	29,2
*C*2	2332	61,5	10,0
*C*3	2361	59,4	2,0
*C*4	2409	57,3	-0,7

300 μm, is almost two times bigger. These changes are very positive in respect of SCC frost-resistance.

Table 8

The characteristics of air-voids of concrete.
Charakterystyka porów powietrznych betonu

Symbol	A [%]	α [mm^{-1}]	$\bar{L}$ [mm]	A_{300} [%]
*B*1	2,20	12,4	0,65	0,53
*B*2	2,24	10,9	0,72	0,30
*B*3	1,99	17,3	0,49	0,58
*C*2	3,49	10,1	0,63	0,30
*C*4	2,89	12,6	0,55	0,38

Recently the author's research results have shown, that the effect of AFA influence on porosity structure parameters depends on SP type. The interaction between AFA and SP (based on PCE) has negative influence on SCC porosity structure parameters (Table 9). Nonetheless, SCC is still freeze-proof.

Table 9

The research results of porosity characteristics of concrete.
Wyniki badań charakterystyki porowatości betonu

Symbol	A, %	$\bar{L}$, mm	α, mm^{-1}	A_{300}, %
C1, no AFA	4,47	0,29	20,83	1,55
C1, AFA	2,10	0,58	15,04	0,25

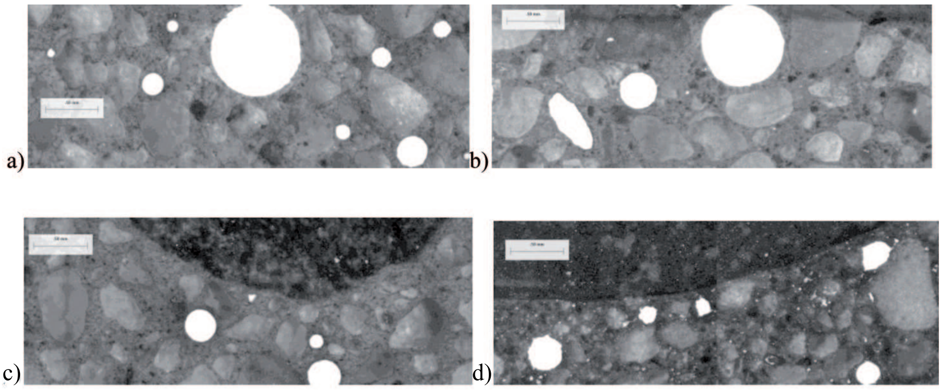

Fig. 4. Air voids in (a) B1, (b) C2, (c) B2, (d) C4.
Rys. 4. Pory powietrzne w (a) B1, (b) C2, (c) B2, (d) C4

However, in case of concrete frost-resistance on scaling, the problem of the suggested value of $\bar{L}$ is still open [14]. Rickne and Nyqvist [9], determined the critical value of $\bar{L}$ = 0,20 mm for the concrete containing various amounts and types of an air-entraining admixture. As the research results show [9], the values of $\bar{L}$ = 0,25 mm to $\bar{L}$ = 0,30 mm also guarantee good frost-resistance of the surface of concrete when defrosting agents are present. However, on the basis of observations of concrete constructions exposed to periodic freezing and thawing, the value of $\bar{L}$ = 0,40 mm or even higher was estimated, ensuring the frost-resistance (Table 10). On the basis of the research results [4] it was concluded, that in case of high performance concrete with silica fume and w/c = 0,30, the practical value $\bar{L}$ reaches 0,40 ÷ 0,50 mm, and by w/c = 0,25, without silica fume $\bar{L}$ = 0,75 mm. Further research [4] lead to a conclusion that concrete with compressive strength of about 100 MPa, w/c=0,33, with silica fume 7,5% m.C., and $\bar{L}$ equal from 0,80 to 0,85 mm, withstands a test of 112 cycles of freezing and thawing 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 $\bar{L}$ reached 0,90 mm.

Table 10

Suggested $\bar{L}$ criteria according to w/c of high performance concrete [1].
Sugerowane kryteria względem $\bar{L}$ w zależności od w/c betonu wysokowartościowego [1]

w/c	Proposed $\bar{L}$	Critical $\bar{L}$	Frost-resistant degree
> 0,40	230 μm	260 μm (deicing salts)	300 cycles ASTM C666 50 cycles ASTM C672
0,40-0,35	350 μm	400 μm (deicing salts)	300 cycles ASTM C666 50 cycles ASTM C672
0,35-0,30	450 μm	500 μm	500 cycles ASTM C666
< 0,30	No data, the above criteria are suggested		

5. CONCLUSIONS

Within the range of the experimental tests the following conclusions may be drawn:

- The use of AFA evokes the reduction of the air content in the tested concrete, and in addition, contributes to favourable changes in the performance and workability of the concrete mix, increased flow diameter and reduced flow time. To achieve better effectiveness of AFA securing the best flow of the mix at the smallest air content in its volume, the quantities of SP and AFA should be selected iteratively. Furthermore, due to the effectiveness, the moment of AFA application is essential.
- The use of AFA leads to the reduction of the compressive strength of the concrete from 5 to 10 MPa, which is even bigger in case of the concrete with lower w/c values. However, it should be emphasised, that the effect of the influence of AFA on the compressive strength depends on the proportions between SP and AFA. In case of insufficient quantity of SP and excess AFA, the flow of the mix does not improve. Conversely, excess quantity of the air and AFA leads to reduction of concrete strength.
- AFA exerts a very positive impact on the freeze-proof properties of the tested concrete, especially manifested in case of the concrete with lower w/c values, irrespective of the air content determined in the concrete mix. Positive influence of AFA increases with its amount. Moreover, the presence of AFA generates a significant improvement of the concrete in respect of its investigated freeze-proof properties in comparison with the concrete without AFA.
- AFA has positive influence on values of porosity structure parameters. The air void factor is smaller when SP and AFA is applied. Moreover, the air void volume, with diameter smaller than 300 mm, is almost two times bigger. Recently, the author's research results have shown that the influence of AFA on porosity structure parameters depends on SP type.

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WPŁYW DOMIESZKI PRZECIWPIENIĄCEJ NA MROZOODPORNOŚĆ I CHARAKTERYSTYKĘ POROWATOŚCI BETONU SAMOZAGĘSZCZALNEGO

Streszczenie

W celu obniżenia zbyt dużej zawartości powietrza w samozagęszczalnej mieszance betonowej można stosować domieszki przeciwpieniące (AFA). Efektem stosowania AFA jest także wzrost średnicy i zmniejszenie czasu rozpływu mieszanki betonowej. Ponadto, utrata urabialności SCC w czasie jest mniejsza. Mieszanka betonowa zawierająca w swym składzie SP i AFA jest bardziej odporna na segregację w porównaniu do mieszanki betonowej wykonanej tylko z SP. Wpływ AFA na wytrzymałość SCC zależy od zastosowanej proporcji między SP i AFA. AFA nie charakteryzuje się negatywnym wpływem na mrozoodporność SCC. Pozytywny wpływ AFA na charakterystykę SCC wykazały rezultaty badań porowatości SCC wg normy EN 480-11.

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