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ANTI-FOAMING ADMIXTURE (AFA) AND ITS INFLUENCES ON THE PROPERTIES OF A FRESH SELF-COMPACTING CONCRETE MIX

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Abstract. The properties of a concrete mix should secure the self-elimination of needless air bubbles from its volume. What is interesting, these properties are not taken into consideration in commonly used self-compacting tests. On the basis of different tests concerning self-compacting concrete mixes, it has been discovered that too high air content in their volume was a result of a superplasticiser, in spite of meeting the self-compactibility criteria. To decrease too high air volume in SCC, the use of an anti-foaming admixture (AFA) is proposed by the authors. Because of an AFA introduced into a self-compacting mix, air-content in this mix is decreased, mix flow diameter is increased and flow time is decreased. In case of a mix incorporating an AFA, its high flowability does not cause segregation of the mix, which is possible in case of SCC incorporating only a superplasticiser. However, time of introduction of an AFA is essential to get higher flowability degree, but is not important in achieving low air volume in SCC. Moreover, the workability of a self-compacting mix with an AFA keeps the same level for a longer period of time.

Keywords: anti-foaming admixture (AFA), decreasing the air-volume, self-compacting concrete (SCC), superplasticiser, rheological properties, workability loss.

1. Introduction

The properties of a concrete mix should secure the self-elimination of needless air bubbles, assuming that the mix is self-compacting. These properties depend on the size of rheological parameters: yield stress and plastic viscosity of cement paste (Szwabowski 1999). Because availability of the direct measurement of rheological properties is limited, technological tests are used in building practice, assessing the self-compactibility of a concrete mix (SCC), such as a flow test (Tables 1 and 2). 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 to the classes presented in Tables 1 and 2. In the European guidelines for self-compacting concrete (European Project Group 2005), detailed outlines in respect to SCC classes and other technical tests of a self-compacting concrete mix depending on its purpose are given.

On the basis of the results of various tests it was stated that in numerous cases a problem of excessive air-entrainment of a concrete mix appears (Szwabowski, Łaźniewska-Piekarczyk 2008, 2009), despite the fact that a fresh mix has achieved recommended flow in suitable time according to European Project Group (2005) (Tables 1 and 2). The tests of porosity characteristics of concrete proved that excessive air-entrainment of a mix influences air-entrainment of concrete (during the process of concrete hardening, formed pores are not filled with hydration products, because C-S-H gel may form only in water) (Kucharska 2000; Kurdowski 2003; Szwabowski, Łaźniewska-Piekarczyk 2008).

Table 1. Slump-Flow classes (European Project Group 2005)

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

Table 2. Viscosity classes (European Project Group 2005)

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

Different test results (presented in Table 3) (Ramachandran 1995; Mosquet 2003; Szwabowski, Łaźniewska-Piekarczyk 2008), prove that new generations of superplasticisers (SP) show air-entrainment effect. It should be emphasised that according to standard requirements concerning chemical additives of concrete, SP should not cause air formation in a mix higher than 2% (compared to a mix that is made of the same components but without SP).

One of the reasons for the PCP air-entrained superplasticiser effect is its influence on the decrease of surface tension of liquid phase in paste, as it was proved by other tests (Łaźniewska-Piekarczyk 2008c).

Table 3. The influence of a superplasticiser on mix air-entrainment (Mosquet 2003)

SP type	*LS*	*SNF*	*SMF*	New Generation Superplasticisers	
				PCP	*AAP*
Air-content	++	+	0	++	++

Here: *LS* – lignosulfian; *SNF* – sulfonated Naphtalene Formaldehyde Condensate; *SMF* – Sulfonated Melanine Formaldehyde Condensate; *PCP* – PolyCarboxylate Polyoxyethylene, *AAP* – Amino Phosphonate Polyoxyethylene; ++ means high influence, + means medium influence, 0 means no influence.

Table 4. Test results of rheological properties of concrete mix with the use of Abrams cone (Gorzelańczyk 2007)

Symbol	Binder type	SP based on:	*w*/*b*	T_{500}, [s]	Slump-Flow, [mm]
A	CEM I 42,5, fly ash	PCE	0.34	5.0	680
B			0.45	4.6	660
C		PCP	0.34	4.9	690
D			0.45	4.1	710

Here: PCE – polycarboxylic ether; PCP – polycarboxylate.

Table 5. Concrete air void parameters investigated according to EN 480-11 (Gorzelańczyk 2007)

Porosity structure parameter	Series			
	A	*B*	*C*	*D*
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

On the basis of the tests (Łaźniewska-Piekarczyk 2008b) and the results shown in Gorzelańczyk (2007), we can conclude that an ether-based and poly-carboxyl superplasticiser has influence on SCC porosity structure. The test results of *A* to *D* fresh mix properties are presented in Table 4, whereas in Table 5 test results of porosity characteristics of hardened concrete are shown.

The tests results presented in Table 5 prove that superplasticisers based on poly-carboxyl ether cause considerable SCC air-entrainment. Air-entrainment of concrete is higher in case of higher *w*/*c* value and amounts to even 8.30%. It should be emphasised that the mix achieved relatively high flow, which is 660 mm (which corresponds to class *SF2*, Table 1). Despite this fact, no suitable self-compactibility took place (self-elimination of air bubbles). Air-entrainment of a fresh mix was probably higher than 8.3%, because air content marked in hardened concrete is approximately by 1% to 2% lower than that found in the mix. The reason for the excessive air-entrainment of a fresh mix is probably the influence of the mechanism of working and structure of a superplasticiser on the formation and behaviour of air bubbles in its volume (Łaźniewska-Piekarczyk 2008c). In case of a poly-carboxyl superplasticiser, air content was lower and amounted to 4.45% with *w*/*c* = 0.45. Test results concerning the effects of a polycarboxyl superplasticiser comply with other test results published in Szwabowski and Łaźniewska-Piekarczyk (2008). Excessive air content appeared although the fresh mix achieved even 710 mm flow. A well-founded question is formed concerning the effectiveness of commonly used tests aiming at qualifying the mix as self-compacting (Szwabowski, Łaźniewska-Piekarczyk 2009) in case of a superplasticiser showing the air-entraining effect.

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

Air-entrainment of a fresh mix may decrease its flow depending on the degree of initial fluidity, – as a result of internal compression of air bubbles and lower density of the fresh mix. Air-entrainment may also initially increase the flow when the fresh mix is originally characterised by originally low fluidity (Neville 2000; Łaźniewska-Piekarczyk 2008a). However, other amounts of an air-entrained admixture cause the decrease of the diameter of the flow in a fresh mix (Łaźniewska 2007).

Sizes of pores formed as an effect of a superplasticiser in hardened concrete are characterised by too big sizes (Figs 1–4). Mostly, they are air voids with 1 mm diameter (Figs 1 and 2). They are the reason of the decrease of concrete mechanical parameters and are not beneficial to its frost resistance (Table 6) from the point of view of its absorptivity (Szwabowski, Łaźniewska-Piekarczyk 2008).

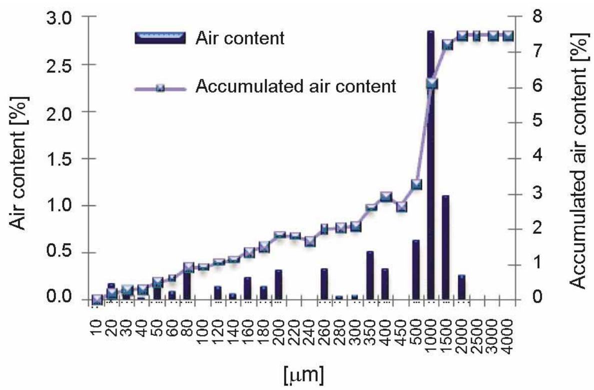

Fig. 1. Air void content according to its size in non air-entrained SCC investigated according to EN 480-11 (2006) (CEM I 32.5 R + 10% silica fume; *w*/*b* = 0.41) (Szwabowski, Łaźniewska-Piekarczyk 2008)

Table 6. The values of non entrained concrete porosity structure parameters (Szwabowski, Łaźniewska-Piekarczyk 2008)

Series	$\bar{L}$, [mm]	α, [mm^{-1}]	A, [%]	A_{300}, [%]	Δf_{cm}*, [%]
SCC-A	0.13	36.14	7.19	2.1	14
SCC-B	0.22	25.47	4.86	1.74	**21**

* after 300 freezing-thawing cycles

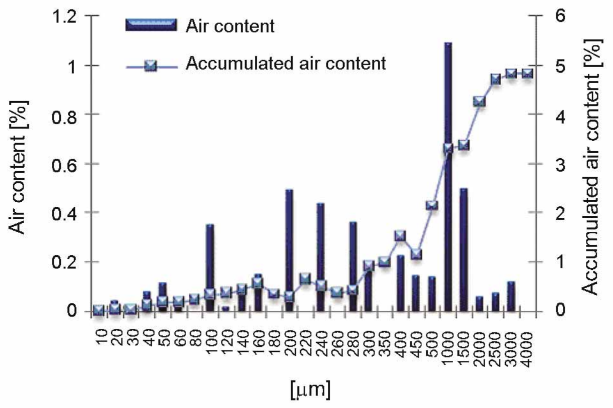

Fig. 2. Air void content according to its size in non air-entrained SCC investigated according to EN 480-11 (2006) (CEM II 32.5 R B-S; *w/b*=0.29) (Szwabowski, Łaźniewska-Piekarczyk 2008)

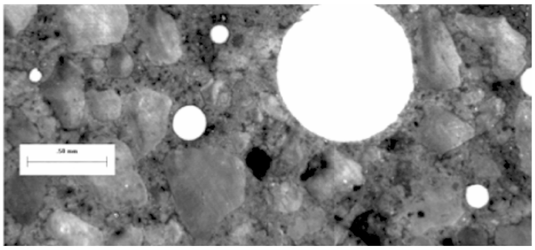

Fig. 3. Air void in non air-entrained SCC, *w/b* = 0.40. Scale on the figure means 0.5 mm (Szwabowski, Łaźniewska-Piekarczyk 2008)

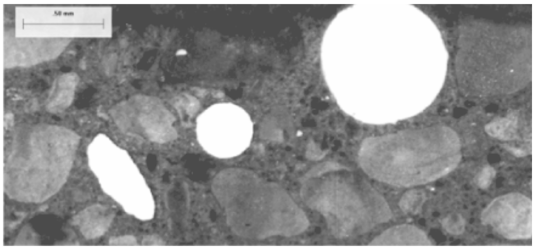

Fig. 4. Air void in non air-entrained SCC, *w/b* = 0.35. Scale on the figure means 0.5 mm (Szwabowski, Łaźniewska-Piekarczyk 2008)

In order to protect concrete from the effects of cyclic freezing and thawing it is beneficial when the bubbles are characterised by diameters of 0.05 to 0.10 mm and are in the paste volume in the range of 0.15 to 0.20 mm from each other (Fagerlund 1999). However the problem of the critical value of pores range in frost resistant concrete, depending on its type, has not been solved (Szwabowski, Łaźniewska-Piekarczyk 2008, 2009). The SCC porosity structure formed as a result of superplasticisers functioning, showing air-entraining activity, can be characterised by adequate parameter values on condition that the level of fluidity of a mixture is not too high.

Analysing the results of other tests shown in Szwabowski and Łaźniewska-Piekarczyk (2008), it has been proved that 4% of air-entrainment (being the result of a superplasticiser) cause the resistance decreases down to 24% when SCC concrete with ratio *w/c* = 0.4 with zero air volume is taken into consideration.

Taking into account the above mentioned test results it may be stated that certain superplasticisers of new generation cause excessive air-entrainment which remains in the self-compacting volume of a fresh mix and concrete, causing deterioration of their properties, although the mix meets commonly accepted criteria of technical tests (Tables 1 and 2). Desired suitable fluidity of a fresh mix, essential for its efficient self-compacting, is not included in any commonly used technical tests. Commonly accepted criteria for such tests are insufficient in this scope and do not guarantee effective self-compacting. It can be obtained by increasing fluidity of a fresh mix with a superplasticiser, however, it may cause its segregation. Due to this fact, in order to prevent the presence of excessive air-entrainment, superplasticisers should not only be compatible with cement, but also should not create air-entraining effect in paste.

To eliminate too high air content in a fresh self-compacting mix, anti-foaming admixtures (AFA) may be used. Unfortunately, AFAs are not commonly used in self-compacting concrete. However, the mechanism of functioning of anti-foaming admixture is known. It may be explained in the following way. The active components are distributed around gas bubbles, displacing surfactant molecules. As a result, the thickness of the lamella wall built from surfactant causes its destabilisation and results in the fracture or coalescence of the bubble (Fig. 5).

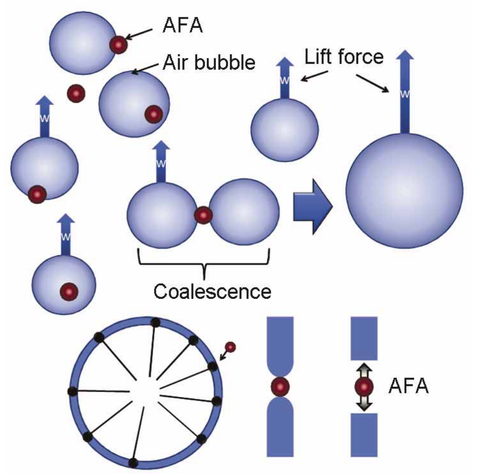

Fig. 5. Stages of the mechanism of action of an anti-foaming admixture (Łaźniewska-Piekarczyk 2008c)

Authors' research results (Fig. 6) show that the effectiveness in decreasing air content in cement paste of anti-foaming admixtures does not consist in increasing the value of surface tension of its liquid phase. The surface tension of water solution of an anti-foaming admixture, a superplasticiser and an anti-foaming admixture are characterised by even smaller value than the surface tension of water solution of air-entraining superplasticiser (Fig. 6).

Because of the fact that AFAs are not commonly used in self-compacting concrete, to identify the wider unknown influence of anti-foaming admixtures on air-entrainment of a self-compacting mix and its properties, suitable authors' tests were carried out.

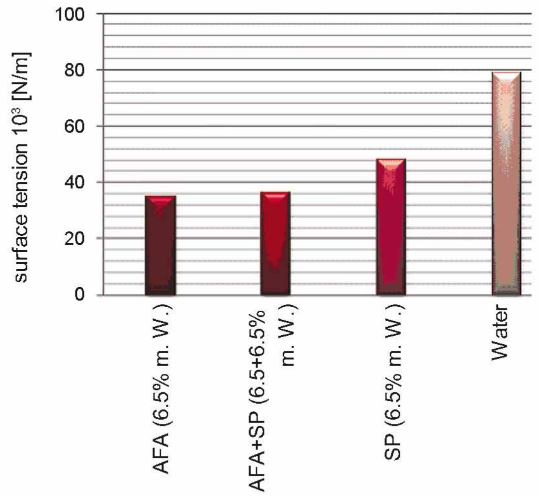

Fig. 6. The influence of a type of admixture on the surface tension of water; SP based on polycarboxylate (PCP); and AFA based on polyalcohol (Łaźniewska-Piekarczyk 2008c)

3. Methodology of the research

The mix proportions of the tested self-compacting concretes are shown in Table 7 and Fig. 7. The characteristics of SCC ingredients are given in Tables 8 and 9.

The process of mixing started with dry components (about 0.5 min). Then water was added where superplasticiser was earlier distributed At the end of the process of mixing, an anti-foaming admixture was added (in case of one series such admixture was introduced after 20 minutes, Table 7), and all ingredients were mixed for another 6 minutes in case of ordinary concrete.

After 20 and 60 minutes, the fresh mix was subjected to another short mixing and then rheological measurements were carried out and the air content in the fresh

Table 7. The mix composition of self-compacting mixes, $w^1/b = 0.41$ (M1-M1a); $w^1/b = 0.42$ (M1bt)

Series	CEM II/ B-S 32,5R	Sand	Gravelly aggregates			SP	AFA
		[kg/m³]					
		0–2	2–4	2–8	8–16	[% m.C.]	
	[kg/m³]	[mm]					
M1	541	890	200	228	256	0.77	0.00
M1a							2.02
*M1bt**							2.02

[1] water + liquid chase of admixture; * AFA added after 20 min.

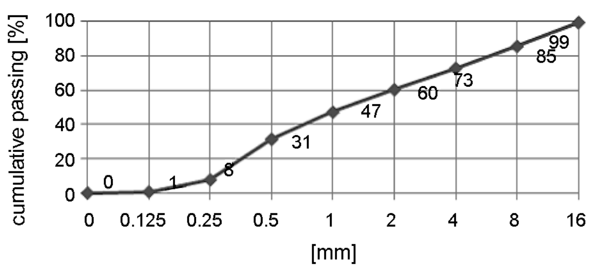

Fig. 7. Curve of aggregate grading

Table 8. Chemical characteristics of CEM II/ B-S 32,5 R

Cement components [%]							Specific surface [m²/kg]
SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	Na_2Oe	SO_3	
24.7	56.7	6.3	2.3	2.9	0.70	3.2	325

Table 9. Characteristics of admixtures

Admixure type	Admixture base	Density, [g/cm³]	Concentration, [%]
Superpasticiser	Polycarboxylate (PCP)	1.09	34
Anti-foaming admixture	Polyalcohol	1.05	30

mix was checked. After filling up the container, the fresh mix was kept for 10 minutes. The air content was defined after proceedings described after EN 12350-7 (2009), mix density after EN 12350-6 (2006), whereas the flow and its time after ASTM C143 (2010).

4. Results and discussion

Research results presented in Fig. 8 show the effectiveness of anti-foaming admixture in decreasing air content in a fresh mix. Self-compacting of the mix is faster and easier.

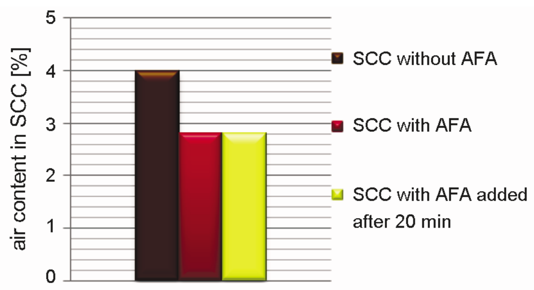

Fig. 8. The influence of AFA on air-content in SCC

The results prove that the time of introduction of anti-foaming admixture is not essential for the effectiveness of this admixture in decreasing the air-entrainment of the mix (Fig. 8). This conclusion is very important because anti-foaming admixtures may be used (with the same results) in order to:

- prevent the occurrence of excessive air-entrainment of a mix (introducing anti-foaming admixture with air-entrained superplasticiser);
- decrease already existing air content (caused by air-entrained superplasticiser) in a fresh mix.

Additional advantage that was achieved due to the use of anti-foaming admixtures, was high increase of fresh mix diameter flow (Fig. 9), and, what was essential, in considerably shorter time (Fig. 10). Using an AFA causes the increase of slump-flow classes (Fig. 10).

In Figs 9 and 10 test results on technology of preparation of a fresh mix containing an anti-foaming admixture are also shown. In one case, the admixture was introduced

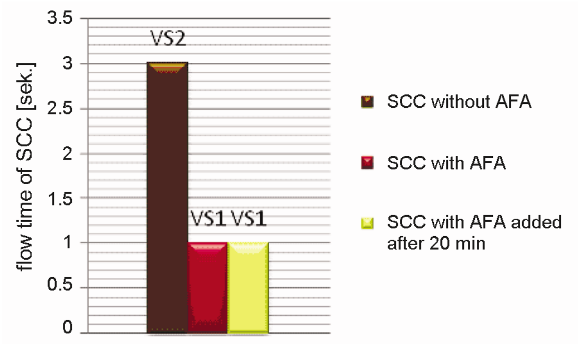

Fig. 9. The influence of AFA and the time of its introduction on flow time of SCC. Symbols VS1 and VS2 represent viscosity classes according to Table 2

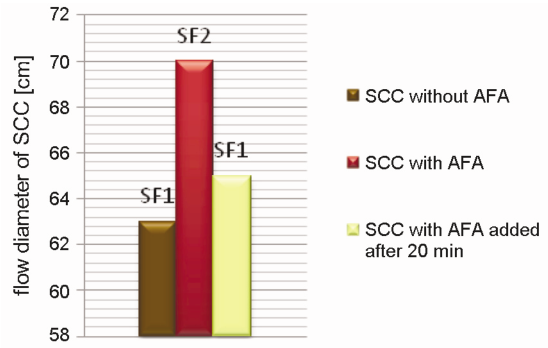

Fig. 10. The influence of AFA and the time of its introduction on flow diameter of SCC. Symbols SF 1 and SF2 represent slump-flow classes according to Table 1

immediately after a superplasticiser, in another one, 20 minutes after starting the process of mixing and introduction of a superplasticiser to the mix volume. The test results presented in Fig. 9 show that the time of introduction of an anti-foaming admixture significantly influences the diameter and flow time of a fresh mix. In order to achieve the highest fluxing of a mix, an anti-foaming admixture should be introduced as fast as possible.

The relationship between air content and flow parameters in AFA introduced SCC mixes is shown in Figs 11 and 12. Of course, with the increase of mix flow diameter the air content is decreased. AFA causes decrease of air-content and the best possible increase of flow diameter when it is introduced immediately after SP (Fig. 9). In case of introducing an AFA after 20 min, the decrease of flow diameter is significantly smaller but the air-content decrease is comparable.

It is important that despite shorter time and lower viscosity of a mix, the segregation did not occur (Fig. 13). On the contrary, a fresh mix containing anti-foaming admixture was more stable than a mix with similar diameter of flow, but containing higher amounts of a superplasticiser.

The advantage achieved as a result of the usage of an anti-foaming admixture due to its fluxing effect was the decrease of the volume of the necessary superplasticiser. As a result, similar consistency was obtained but, what should be emphasised, of non excessively air-entrained self-compacting mix.

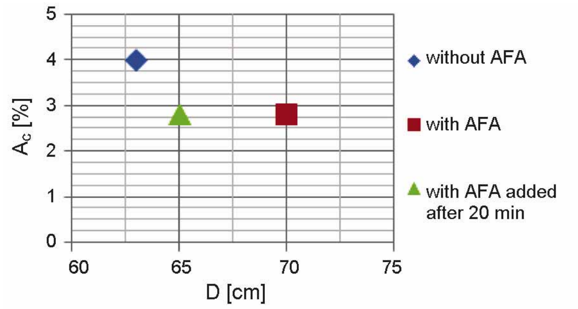

Fig. 11. The relationship between flow diameter of SCC incorporating different admixtures and air-volume

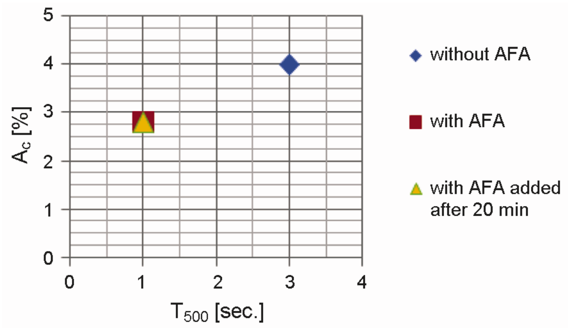

Fig. 12. The relationship between time flow of SCC incorporating different admixtures and air-volume

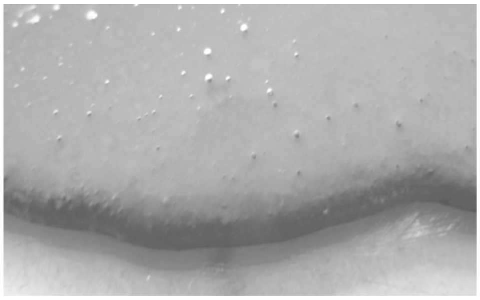

Fig. 13. The view of high stability of a concrete mix incorporating AFA

Moreover, in case of a fresh mix containing AFA, the loss of initial consistency was considerably slower (Figs 14 and 15).

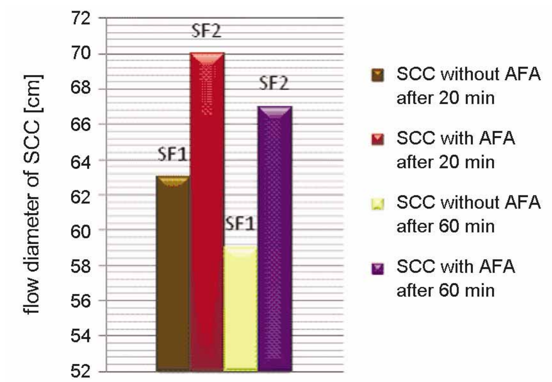

Fig. 14. The loss of initial consistency of SCC with and without AFA. Symbols SF 1 and SF2 represent slump-flow classes according to Table 1

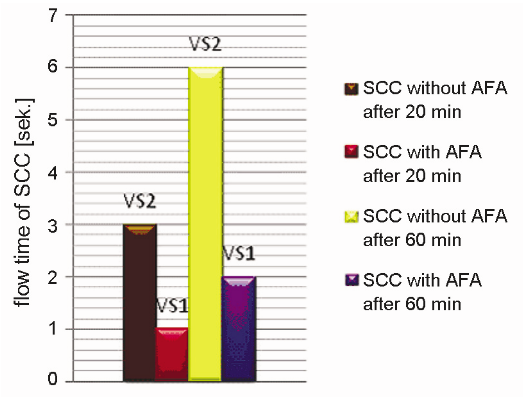

Fig. 15. The change of initial flow time of SCC with and without AFA. Symbols VS1 and VS2 represent viscosity classes according to Table 2

Tests by other authors proved that it was not possible to air-entrain a fresh mix for the second time, if an anti-foaming admixture was introduced. So, anti-foaming admixtures should not be used in case of mixes that were air-entrained on purpose.

Summarising, the anti-foaming admixture:

- decreases the air-content in self-compacting mix;
- increases its flow diameter achieved in shorter time (it is important: without its segregation);
- decreases the loss of its initial consistency;
- should be introduced to a mix immediately after introducing a superplasticiser to achieve bigger mix flow diameter increase. However, the time of introduction of an AFA is not important to the final decrease of air content in concrete mix.

Moreover, the results of another research performed by the authors proved that the biggest air-entraining effect of a superplasticiser on mixes takes place when the *w/c* ratio is high. Even more, the effectiveness of an AFA in decreasing too high air content is the greatest.

Nevertheless, the last tests by the authors proved that using AFA gets high flow diameter of mortars and mixes with extremely low w/c ratio (Fig. 16).

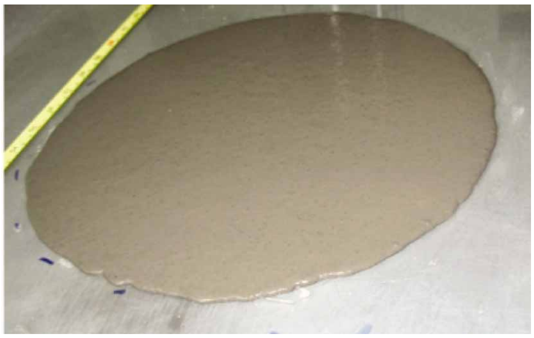

Fig. 16. Slump flow of mortar of self-compacting mortar with *w/c* = 0.15; flow diameter = 39 cm

5. Conclusions

In the scope of the tests which were conducted on anti-foaming admixtures, the following conclusions may be proposed:

1. Anti-foaming admixtures may be used in order to prevent excessive air-entrainment of a mix (introducing anti-foaming admixture with air-entrained superplasticiser), or in order to decrease already existing air volume, caused by air-entrained superplasticiser in a fresh mix.

2. Anti-foaming admixtures decrease air-content in a self-compacting mix, increase its flow diameter achieved in shorter time (and what's important – without its segregation) and decrease the loss of its initial consistency. So, due to the use of anti-foaming admixtures, it is possible to decrease the need of a superplasticiser in order to achieve suitable flow of the mix.

3. What is essential for the above mentioned rheological property modifications developed by the effect of anti-foaming admixtures, is the moment of its introduction to a fresh mix. The best effectiveness is obtained by the introduction of that admixture immediately after a superplasticiser. However, the moment of introduction of this admixture is not essential to achieve the low air volume in a fresh mix.

Summarising, the test research proved that using AFAs is an effective method of decreasing air-volume (that is the effect of some superplasticisers) in a self-compacting mix[J1]. Moreover, workability of self-compacting is higher. Because of using AFA, the mix keeps the initial consistency longer.

The next step of authors' investigation will be the analysis of effects of chemical and physical properties of SCC ingredients (mineral additives and chemical admixtures) on the effectiveness of an AFA. The influence an AFA on hardened SCC properties will also be investigated.

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PRIEŠPUČIO (AFA) ĮTAKA SUSITANKINANČIO BETONO MIŠINIO SAVYBĖMS

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Santrauka

Betono mišinio sudėtis turi būti tokių savybių, kad užtikrintų nereikalingo oro kiekio pasišalinimą. Įdomu, kad į šias savybes dažniausiai nėra atsižvelgiama atliekant susitankinančio betono bandymus. Remiantis įvairiais susitankinančio betono mišinio tyrimais, buvo nustatyta, kad per dideliam oro kiekiui įtakos turi superplastikliai, nepaisant to, kad jie turi tankinančių savybių.

Norint susitankinančio betono mišinyje (SCC) sumažinti per didelį oro kiekį, siūloma naudoti priešputį (AFA). Kadangi AFA įterpimas į susitankinančio betono mišinį sumažina oro kiekį, padidėja mišinio pasklidimo skersmuo ir sumažėja pasklidimo trukmė. Jeigu mišinio sudėtyje yra AFA, mišinio takumas neskatina išsisluoksniavimo, o tai gali atsitikti naudojant SCC tik superplastiklį. Tačiau AFA įterpimo trukmė turi poveikį mišinio takumo laipsniui, bet nėra reikšminga pasiektam mažam oro kiekiui SCC. Be to, susitankinančio betono mišinio su AFA klojumas ilgesnį laiką išlieka to paties lygmens.

Reikšminiai žodžiai: priešputis (AFA), oro tūrio sumažėjimas, susitankinantis betonas (SCC), superplastiklis, reologinės savybės, klojumo nuostoliai.

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