ARCHITECTURE CIVIL ENGINEERING ENVIRONMENT
The Silesian University of Technology No. 4/2019

doi: 10.21307/ACEE-2019-052

THE INTERACTIONS BETWEEN ANTI-FOAMING AND SUPERPLASTICIZING ADMIXTURES AND THEIR CONSEQUENCE FOR PROPERTIES OF SELF-COMPACTING MORTAR AND CONCRETE

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Received: 5.07.2019; Revised: 11.10.2019; Accepted: 29.10.2019

Abstract
The aim of this paper is to investigate the effects of anti-foaming admixture type (AFA) and time of its introduction on compatibility with two types of PCP-based superplasticizer, air content, rheological parameters, physical adhesion, mechanical strength, microstructure and air-voids size of self-compacting mortar and concrete (SCC). Results reveal that the air content of plastic self-compacting mortars mixture decreases with the implementation of AFA regardless of the time of its introduction. Antifoaming admixture causes the increase of the mortar's flow diameter most when it is introduced together with PCP. The plastic viscosity value depends on the type of AFA significantly. AFA admixtures reduce the physical adhesion of self-compacting mortar. Moreover, test results prove that mortars with AFA maintain initial consistency for a longer time in comparison with mortar with SP only. Too big amount of AFA has a negative effect on mechanical properties and microstructure. Proper dosage of the right type of the anti-foaming admixture does not influence negatively compressive strength of mortar or concrete. The research results proved that too high dosage of AFA may cause compressive strength decrease and microcracking of self-compacting mor-tar or concrete, indicated on the basis of SEM research results.

Keywords: **Anti-foaming admixture; Superplasticizer; Mortar; Concrete; Porosity; Workability; Compressive strength.**

1. INTRODUCTION

Superplasticizers are currently the largest group of admixtures used in concrete technology. As reported by the statistics, in the last few years the consumption of this type of admixtures in the world has been constantly increasing and constitutes over 25% of the entire market. These admixtures were used in prefabrication (obtaining low coefficients of the rapid growth of strength), in ready-mixed concrete (long-term consistency of the mixture), as well as ensured the development of special types of concretes. This situation is probably due to the possibility of any shape of the polymer structure, and thus, deciding on their impact on the selected properties of both the fresh mixture and the hardened concrete.

In cement applications, polycarboxylate PCP superplasticizers based on methacrylate (MPEG), allyl ether (APEG) and isoprenyl (IPEG) [1] are most commonly used. Their structure and steric mechanism of action prevent the flocculation of cement over time. They are built from the main chain and side chains, creating a comb structure. The main chain adsorbs the macromolecule admixture on the cement grain surface, while the function of the side chains is steric action, preventing the formation of agglomerates of cement grains [2]. PCPs are generally macro-trends that always introduce a certain amount of air during the preparation of the concrete mixture. Industrially produced PCP superplasticizers very often contain a significant amount of unreacted macromonomer (on average about 10%), so a strong mechanism of foam generation is common [1]. The sizes of pores formed during PCP action in hardened concrete are too big. The air content in the concrete mixture does not work only for its flow, but above all for final mechanical properties and durability of hardened concrete. There are four types of pores in concrete. Gel pores, the common size of (1.5–2.0) μm, have no negative effect on concrete strength due to porosity. However, they directly affect creep and shrinkage of concrete. Concrete strength is a function of the air volume. An increase in the percentage of macropores by 1% can reduce compressive strength by as much as 5%. It was found that pores with diameters smaller than 20 nm impose a negligible effect on compressive strength [3–6]. Nevertheless, it was claimed that pores from the range of 20–50 nm, rather than with diameters greater than 100 nm, have a greater influence on compressive strength [6]. Concrete shows good resistance to cyclic freezing and thawing and deicing salts when the diameters of the air pores are 300–3000 nm, and the distribution index is not more than 0.2 mm [4, 7, 8, 9]. The increased volume of pores in the range of 350–2000 nm was considered to be responsible for the improved frost resistance durability [10].

Requirements norm for chemical admixtures for concrete EN 934-2 [11] limit the air content in the mixture as a result of the superplasticizer action. The volumetric air content of the modified mixture may be a maximum of 2% higher than the control mixture. In case of self-compacting mortars and concrete, the air entrainment of the concrete mixture, as well as adequate values of porosity structure parameters, are the problematical issues of concrete mixture self-compaction [12–17]. The excessive air-content is mainly caused by lowering the surface tension of the liquid phase into the slurry by the PCP superplasticizer [17]. During intense mixing of a concrete mixture with the addition of the new generation superplasticizer, the air content can increase too high so that better concrete properties achieved by reducing the w/c ratio can be completely lost [7]. That is why producers of the admixtures use antifoaming agents (AFA) to limit the undesirable amount of air in the concrete mixture. However, we struggle with the problem of compatibility and stability of PCP-AFA system.

The components of AFA could be mineral oils, silicone oils, organically modified silicones, hydrophobic constant molecules (silica, waxes, higher fatty acids soaps, alcohols and fatty acids), emulsifiers, polyalcohol, or alcohol derivatives of organic compounds. Mixtures of mentioned above active components could have a synergetic effect. Unfortunately, high price and insufficient recognition of the influence on the fresh mixture and concrete properties do not favour wider use of the anti-foaming admixtures.

Defoaming substances are chemical compounds aimed at destroying foam or preventing its formation. There are thousands of different skimmers in the world. The detailed composition of defoaming agents is known only to manufacturers. The most efficient defoamers show synergistic action of the hydrophobic liquid and solid phase. Effectiveness of defoamers depends on many factors:

- solubility – most of the defrosting admixtures have very low solubility in aqueous solutions;
- the size of the defoamer drops – the force needed by the defoaming subunit to destroy the wall of the air bubble increases with the decreasing size of the drop;
- the presence of hydrophobic solids – mixtures of liquids with solid bodies are usually more effective than each of the components used alone;
- repeated foam exposure – continuous foam exposure eliminates the ability of a defoamer to inhibit foam formation. This is probably due to the hydrophobic molecule separation and too high reduction in the size of the skimmer droplet;
- the concentration of surfactants – a higher concentration of surfactants leads to a reduc-tion in the effectiveness of antifoaming agent by increasing the force needed to overcome the interfacial membrane;
- shear forces – they have significant effects on the defoamer operation. High shear forces reduce the size of the perspiration drops, which become too small to break up the wall of the air bubble so that it is less effective. In addition, shear forces cause intense foam formation;
- viscosity – the viscosity of a defoamer affects the ease of its dispensing and dispersion in the desired medium [31].

The papers [18, 19, 20] compare four different chemical compositions of antifoaming products, mineral oil polyetheremulsified silicone oil and Polyether modified silicone respectively. The bubble breaking speed, restraining bubbles ability and bubbles stability are different when adding different types of defoaming agent. According to the comprehensive performance of concrete, the fluidity of concrete with the addition of the polyether-modified silicone antifoaming agent is the best. The fresh concrete slump, expansion and the density fluctuate less than other types of antifoaming agent. Concrete slump loss was also less than other types of antifoaming agent, at the same time, hardened concrete apparent has no obvious harmful pore. The incorporation of AFA decreases the coarse pore content (>100 nm) and air bubbles with a diameter bigger than 100 μm in the hardened specimen, is playing a positive role in optimising the pore structure and improving strength.

The bubbles' size, number and distribution have a significant effect on the workability, and strength of mortar and concrete. In practical engineering application, we always add an anti-foaming agent to eliminate harmful bubbles. There are many different kinds of an anti-foaming agent, and this paper mainly studies six different kinds of them and their influence on self-compacting mortar and concrete. Moreover, the compatibility of AFA and PCP is important to obtain the expected AFA effect. In the paper, tests results of compatibility of six types of AFA and two types of PCP, the influence of time and type of introduction, from AFA to mortar, and its influence on consistency and air-content of mortar and mixture, compressive strength, the porosity of hardened concrete and its hardened microstructure are analyzed.

2. RESEARCH METHODOLOGY

2.1. Research methodology of compatibility tests of PCP and AFA admixtures

The first of the above tests allows assessing the homogeneity of the ready admixture during its storage. Uniformity is one of the basic features of mortar and concrete admixtures, which is subjected to quality control in accordance with Table 1 in EN 934-1. The test itself consists of placing the prepared admixtures in the oven at 40°C for seven days. Increased temperature causes the acceleration of ageing processes. After one week, the visual stability of the domes is assessed.

2.2. Research methodology of type of AFA and PCP types and ways of its introduction on properties of mortars

The effectiveness of anti-foaming admixture (Table 1) depending on its type and SP type (Table 2) was investigated in tests of flow and air-entrainment of mortar according to EN 1015-3:2000/A2:2007 [21] and EN 1015-7:2000 [22], respectively. Self-compacting mortars were composited with river sand 0–2 mm.

PCP1 is synthesized with long side chains. PCP2 has a rapid absorption to the cement particles and covers less surface, which ensures a large surface of cement particles to react with water and then accelerates the cement hydration.

The process of mixing of the mortars started with dry ingredients. Then the PCP were added:

– at the same moment as superplasticizer or
– after 10 min from induction of superplasticizer to mortar.

The mixing of mortars components was carried out in accordance with the procedure of PN EN 480-1 [23].

The cement CEM II/B-S was used because previous author's research result indicated that most problems with adequate air-content of self-compacting mortar and concrete are in case of cement with mineral additives, like fly ash or granulated blast furnace.

The properties of the mortars were described by density, tested in accordance with EN 1015-10:2001 [24] standard, compression and flexural strength tested according to EN 1015-11:2001 + A1:2007 [25]. To assess AFA influence on the time relating to workability loss of the mortar, the assessment of mortar flow was measured after 10 and 60 minutes, counting from the time of components mixing. All tests of hardened mortars were carried out after 28 days on 4×4×16 cm mortar blocks curing in 20°C water.

Table 1.
AFA components

Symbol of AFA (A)	AFA characteristic
A1	froth breaker based on PDMS / silicone oil / hydrophobic silica
A2	froth breaker based on mineral oil or amidol wax
A3	froth breaker based on alcohol derivative of saturated fatty alcohol, mineral oil and PE wax
A4	fiakyl derivative of saturated fatty alcohol/mineral oil/PE and amidol wax
A5	alkoxyl derivative of fatty alcohol
A6	polyether modified silicone

Table 2.
Mixture composition of mortars

Component/symbol of the mortar	Amount
CEM II/B-S 42.5 R, kg	774.3
Limestone, kg	77.4
River sand, kg	1224.5
w/c, –	0.38
PCP 1 (P1), % mass of cement	0.70
PCP 2 (P2), % mass of cement	0.70
P1A1a	0.50
P1A1b	1.50
P1A2a	0.50
P1A2b	1.50
P1A3a	0.50
P1A3b	1.50
P1A4a	0.50
P1A4b	1.50
P1A5a	0.50
P1A5b	1.50
P1A6a	0.50
P1A6b	1.50
P2A6a	0.50

2.3. Research methodology of AFA and PCP on properties of self-compacting concrete

In next step of the research, self-compacting concrete (Table 3) was made with CEM II/B-S 42.5 R, limestone (LS), 2/8 mm and 8/16 mm fraction gravel aggregate, 0/2 mm fraction sand, tap water, admixtures: PCP1, PCP2, and the most effective in action AFA and compatible with PCP1, indicated on the basis of mortars research result (two-step of the investigation, point 2.2).

The properties of the self-compacting concrete mixture were investigated using the following methods: self-compatibility test in accordance with the procedure [26], density test – in accordance with EN 12350-6:2000 [27], air content – the pressure method according to EN 12350-7:2001 [28].

The compressive strength of concrete was investigated according to EN 12390-3 [30]. The microstructure and porosity of hardened concrete *P1, P2, P1A6b*, after 28 days curing in water, were investigated using the following methods: porosity structure parameters are investi-gated according to PN-EN 480-11 [29], the microstructure of concrete according to SEM (Scanning Electron Microscopy). All tests of hardened concretes were carried out after 28 days on 15×15×15 cm concrete blocks curing in 20°C water.

3. RESEARCH RESULTS AND THEIR DISCUSSION

3.1. Research results of compatibility tests of PCP and AFA admixtures

Table 4 presents the results of ageing tests on the tested compatibility of admixtures. The lack of compatibility between the defoamer and the liquefaction admixture is manifested at this stage of the research by the lack of homogeneity of the liquid sample, e.g. sediment precipitation, delamination of two phases, turbidity. On the basis of research results presented in Table 4, it was concluded that only PCP1 is compatible with all types of anti-foaming admixture, while PCP 2 with AFA 6 only. Compatible admixture systems were selected for further testing.

3.2. Research results of self-compacting mortars

In Figs. 1–5, test results on fresh mortars are presented. It was observed, that different type of PCP produced a radically different volume of air in self-compacting mortars. In case of normally consolidated mortars, 4% of air volume was observed. The mortar with air-entraining PCP1 contained even about 12% of air volume.

According to research results in Figs 3–5, AFA type 6 is most effective in decreasing the air-content and increasing mortar flow diameter without its segrega-

Table 3.
Compilation of the ingredient's proportions in 1 m^3 of the concrete mixture

Symbol	Cement type	Cement [kg]	Lime-stone [% m.C]	w/b	0÷2 mm [kg]	2÷8 mm [kg]	8÷16 mm [kg]	PCP1 [%m.C.]	AFA type 6 [%m.C.]
P1	CEM II/B-S 42.5 R	580	10	0.38	930	500	230	0.70	–
P2		580	10	0,38	930	500	230	0.70	–
P1A6a		580	10	0.38	930	500	230	0.70	0.50
P1A6a/b		580	10	0.38	930	500	230	0.70	1.00
P1A6b		580	10	0.38	930	500	230	0.70	1.50

Table 4.
Visual evaluation of admixtures after a compatibility test

Symbol of the blend of ad-mixture PCP1 (P) and AFA (A)	The appearance of the samples after a week
P1	homogeneous, clear
P1 A1a, b	homogeneous, clear
P1 A2a, b	homogeneous, clear
P1 A3a, b	homogeneous, clear
P1A4a, b	homogeneous, clear
P1A5a, b	homogeneous, clear
P1A6a, b	homogeneous, clear
P2A1a, b	turbid, heterogeneous, white particles in the entire volume
P2A2a, b	turbid, heterogeneous, white particles in the entire volume
P2A3a, b	turbid, heterogeneous, white particles in the entire volume
P2A4a, b	turbid, heterogeneous, white particles in the entire volume
P2A5a, b	turbid, heterogeneous, white particles in the entire volume
P2A6a, b	homogeneous, clear

tion (Figs. 1 and 2). The type of AFA affects the time of flow mortar (plastic viscosity). Test results of mortars showed that AFA based on polyether-modified silicone (type 6), reduce the air-content, plastic viscosity and adhesion of fresh mortar most effectively.

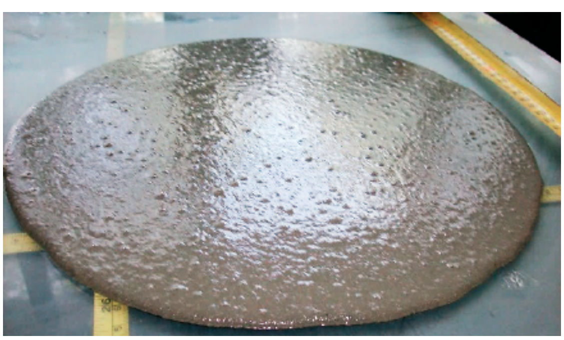

Figure 1.
View of flow diameter of mortar incorporating PCP and AFA

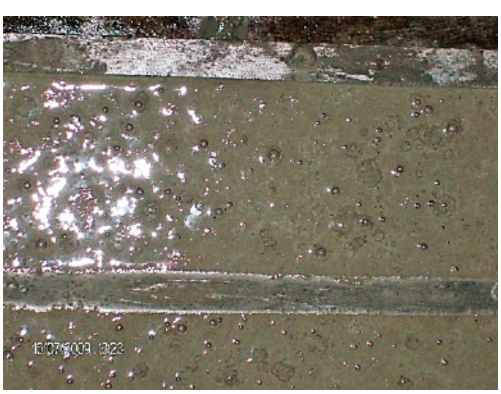

Figure 2.
View of the self-compacting process of mortar incorporating PCP and AFA

In Figs. 3–5, tests results of the fresh mixture containing anti-foaming admixture mixing technology are presented. In one case, the admixture was introduced immediately after PCP addition. In other cases, admixture was introduced 10 minutes after starting the process of mixing and PCP addition.

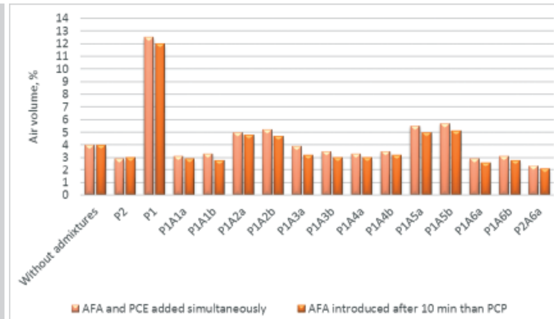

Figure 3.
The air-content in mortar in dependence on-time introduction of AFA and AFA type

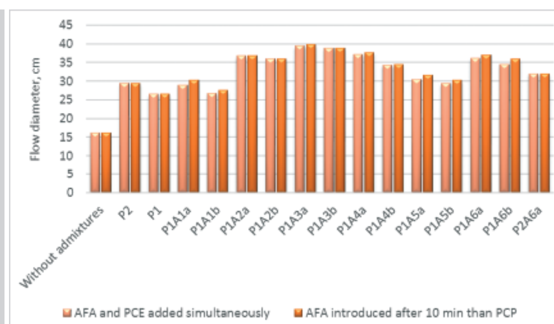

Figure 4.
The flow diameter of mortar in dependence on-time introduction of AFA and AFA type

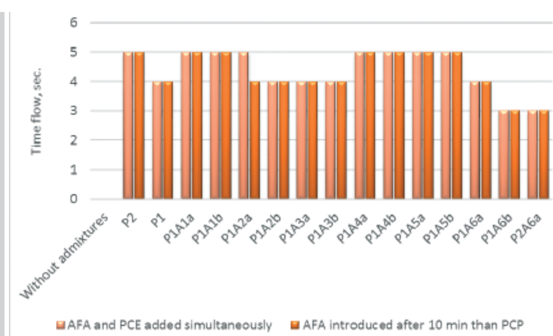

Figure 5.
The flow time of mortar in dependence on-time introduction of AFA and AFA type

The presented tests results prove that the time of introduction of anti-foaming admixture is not essential for the effectiveness of decreasing of mortar's air-entrainment. This conclusion is very important because the application of anti-foaming admixtures may be used in order to: prevent the excessive air-entrainment of the mixture (introducing anti-foaming admixture with air-entrained PCP) or decrease existing air content (produced by air-entrained SP) in the fresh mixture. However, the type of AFA influences on air-content and consistency of mortar, independence when AFA was introduced into mortars (Figs. 6 and 7). Thus, the antifoaming admixture causes the increase of the flow diameter of the mortar and lowers the plastic viscosity, regardless of the time of its introduction. Anti-foaming admixture allows better self-compacting of the mortar. Research results in Fig. 8 indicate that the actions of different ad-mixtures disturb the relationship between diameter flow and air content in mortar.

The results of the tests presented in Figs. 9 and 10 prove that mortars containing AFA maintain consistency longer than mortars without AFA. However, too many AFA negatives affect the mechanical properties and microstructure (Figs. 11 and 20). Moreover, the time of maintaining of consistency of mortar depends on the type of AFA (Fig. 10).

Until laboratory tests of fresh mortars, it was indicated that AFA admixtures reduce the physical adhesion of fresh mortar. Degree of this reduction depends on the type of AFA. This conclusion needs further author's laboratory tests, for the reasoning causes of this. How strong it depends on the type of AFA. The mortar with AFA loosens more easily from the cone to the mortar spreading test. Unfortunately, there is no standard way to test the adhesion of fresh mortars. The mechanism of adhesion has been studied for years. In order to provide an explanation for adhesion phenomena, several theories have been proposed. However, there is no standardized theory that describes all adhesive bonds in general in a compre-

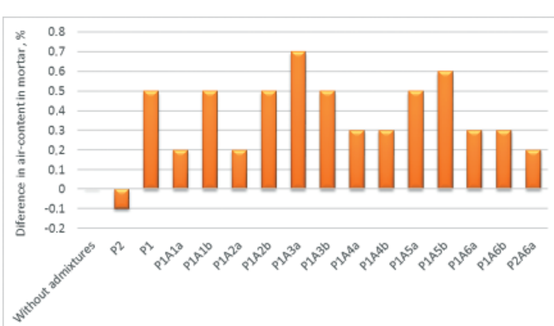

Figure 6.
The difference in the air-content in mortar in dependence on-time introduction of AFA and AFA type

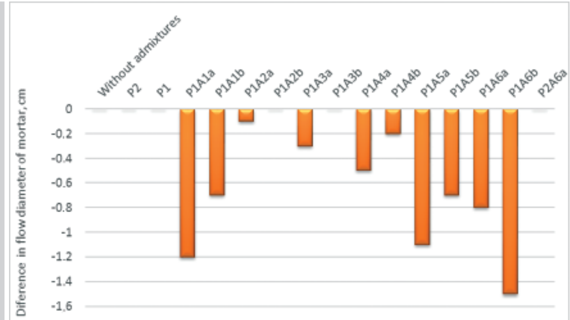

Figure 7.
The difference in the air-content in mortar in dependence on-time introduction of AFA and AFA type

Figure 8.
The relationships between air-content and flow diameter of mortars

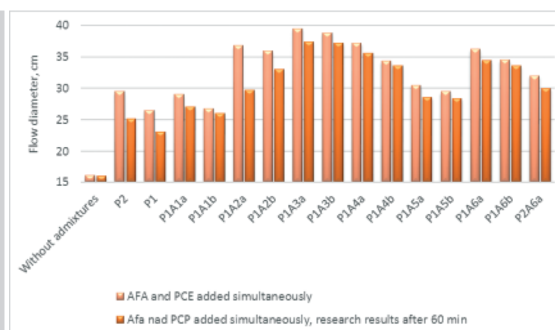

Figure 9.
The air-content in mortar after 10 and 60 min, when AFA and PCP was introduced simultaneously

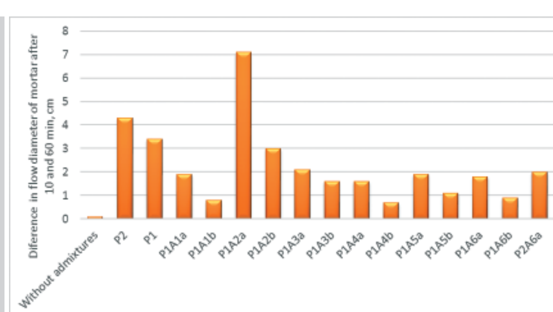

Figure 10.
The flow diameter of mortar after 10 and 60 min, when AFA and PCP was introduced simultaneously

hensive way. The bonding of an adhesive to a substrate includes numerous mechanical, physical, and chemical forces that influence each other. As it is impossible to separate these forces from each other, it can be divided into 5 different adhesion mechanisms, including mechanical, electrostatic, adsorption, chemisorption and diffusion theory [30, 31]. AFA admixtures reduce the physical adhesion of cement mortar. The physical adhesion results from the molecular contact between two materials and these two materials are held together by the "van der Waals" forces (Fig. 11). These are the weakest forces that contribute to the adhesive bonding but are quite sufficient to make strong joints. Van der Waals forces act between molecules of gaseous and liquid substances as well as between molecules in molecular crystal networks. Van der Waals forces can be divided into four main groups: dispersal forces, conformational forces, dipole forces and inductive forces.

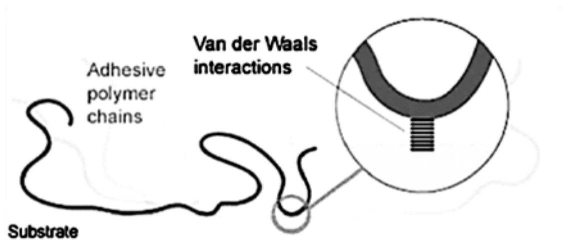

Figure 11.
Surface forces in physical absorption [20]

In Figs. 12 and 13, the test results of mortars are presented. It was noticed that the anti-foaming admixtures significantly improve the compressive strength of mortars, due to reducing of air-content in the mortars. The compressive and flexural strength of mortars incorporating AFA (type 6) is like mortar strength with "not entraining" PCP2 (Figs. 12 and 13). AFA type influences on relationships between air-content and compressive strength of mortar (Fig. 13). Therefore, the compatibility tests of AFA and PCP admixtures should be extended to test the properties of the joints of the cement mortar, especially its strength.

3.3. Research results of self-compacting concrete

In Figs. 14–16 the results of testing mixtures are presented. The analysis of the results indicates that the higher air-content as a result of PCP1 action causes a higher decrease of fresh mixture flow diameter. The introduction of AFA into the volume of SCC, apart from the air content reduction, leads to increase of its

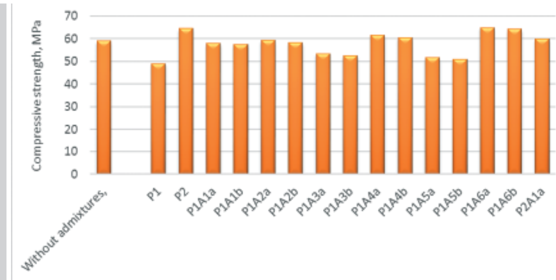

Figure 12.
The compressive strength of mortars with different types of admixtures after 28 days

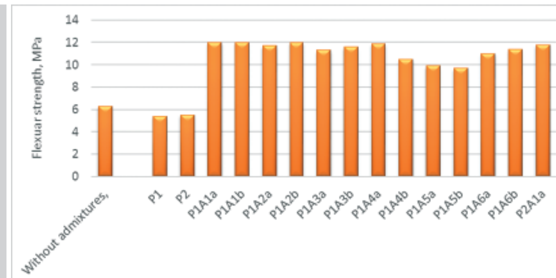

Figure 13.
The compressive strength of mortars with different types of admixtures after 28 days

flow diameter and decreasing of flow time. Again, it has been proven that the presence of AFA, especially with a larger amount in SCC, allows for the initial workability of SCC to be maintained. However, too much AFA in the SCC volume negatively affects the compressive strength of the SCC, although the air content is reduced (Fig. 17).

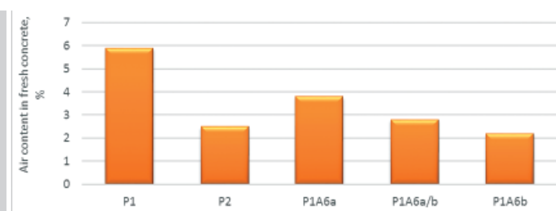

Figure 14.
The air content in fresh concrete with different admixtures type

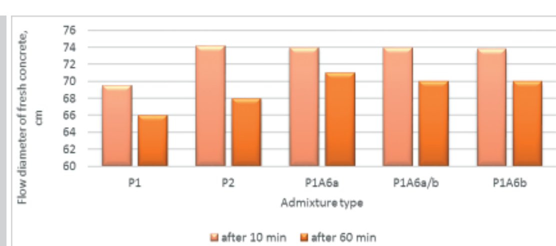

Figure 15.
The flow diameter of fresh concrete with different admixtures type after 10 and 60 min

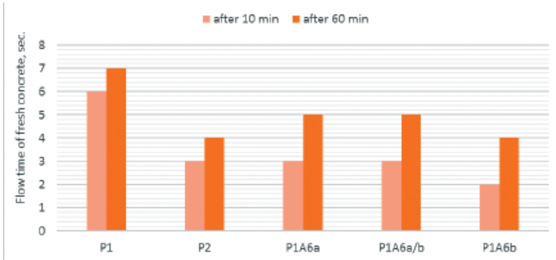

Figure 16.
The flow time of fresh concrete with different admixtures type after 10 and 60 min

A similar effect of the influence of high dosage of AFA was noticed in the publication [14]. The compressive strength of ultra-high compressive strength concrete has firstly raised and then declined with the increasing addition of anti-foaming admixture. The maximum compressive strength of concrete at 28 days reaches 111.6 Mpa, 115.4 Mpa and 109.1 Mpa, being associated with 94.5 Mpa for the blank sample when AFA was added correspondingly. Therefore, these research results prove also that the addition of anti-foaming admixture has a significant increasing effect on strength of concrete. The reason for this may be the cracking of the microstructure (Figure 6).

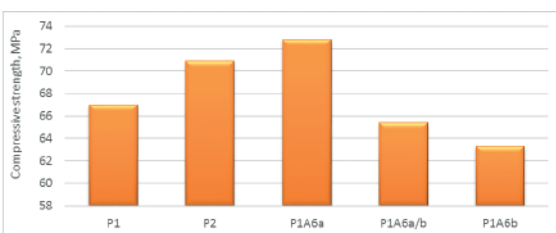

Figure 17.
The compressive strength of concrete after 28 days

Research results according to EN 480-11 are presented in Figs. 21–23. This research showed that AFA changes the size of airvoids and its volume in SCC. The air content in concrete with AFA is more than twice reduced, the value of the air void space factor is bigger when PCP and AFA are incorporated. The minimum point occurs at the dosage level of 0.50%, being in accordance with the strength and air content results mentioned above (Figs. 14–16 and 10).

Figures 4–6 show the results of SEM (Scanning Electron Microscopy) of concrete with PCP 2 research results. It is evidently visible that the type of PCP and AFA admixtures influence significantly the SCC structure. Admixture generates different porosity, CSH structure and contact zone in SCC. The CSH phase of SCC with PCP2 is dense and homogeneous (Fig. 4). The cement paste tightly binds the aggregate. No calcium hydroxide was observed.

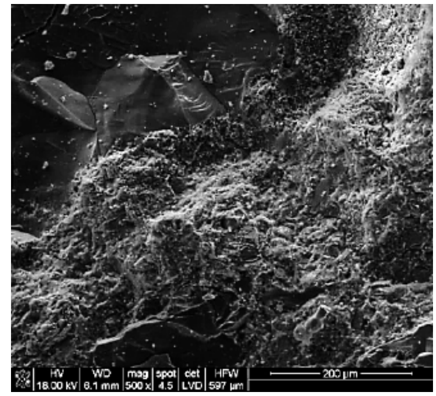

Figure 18.
SEM research results of SCC with PCP2 (series P2)

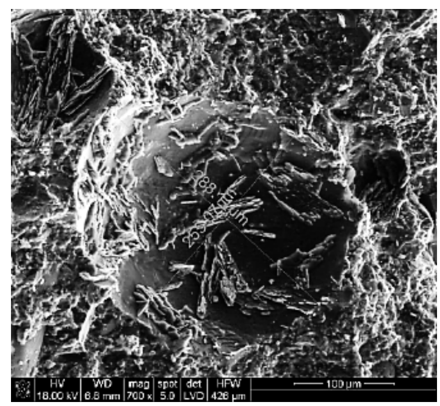

Figure 19.
SEM research results of SCC with PCP1 and without AFA (series P1)

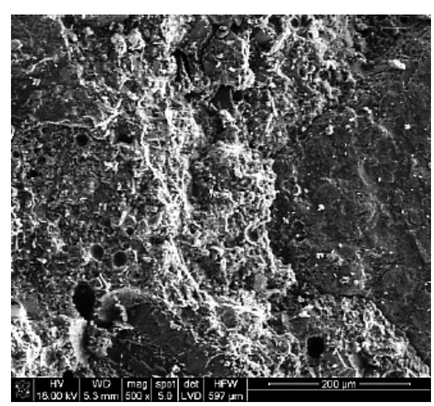

Figure 20.
SEM research results of SCC for PCP1 and AFA type 6. (series P1A6b)

In Figure 5, the consequence of PCP1 action on the concrete microstructure is presented. This structure is the most amorphous, a lot of large pores are present in SCC microstructure. Moreover, a lot of calci-

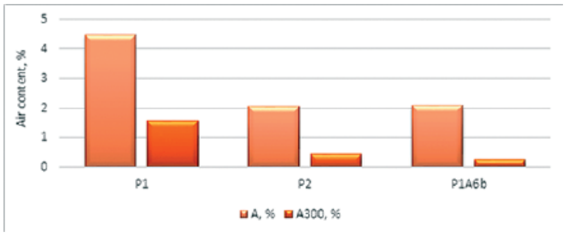

Figure 21.
The air content and air-content of pores with a diameter smaller than 300 μm in hardened concrete with different admixture types

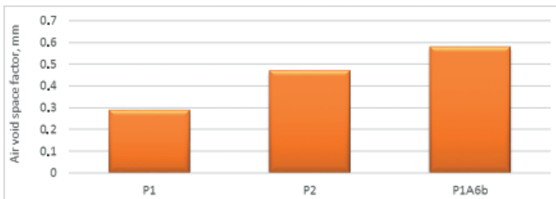

Figure 22.
The air voids space factor in hardened concrete with different admixture types

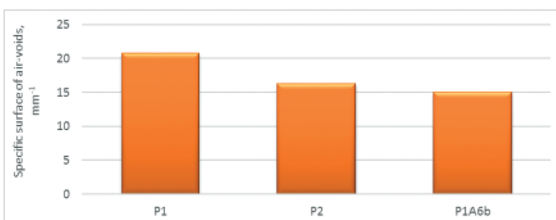

Figure 23.
The specific surface of pores in hardened concrete with different admixture types

um hydroxide (its hexagonal structure) overgrowing the air voids was observed.

In Figure 6, the microstructure of concrete with PCP1 and AFA type 6 was presented. Structure of concrete with AFA and PCP1 is less heterogeneous than the structure of SCC with PCP1 (compare Fig. 5 and 6). Moreover, no calcium hydroxide was found in SCC structure. The CSH phase is homogeneous and dense. The cement paste tightly binds the aggregate. There are no visible large air voids in Fig. 6.

Too much admixture AFA can cause micro-cracking of the concrete microstructure (Fig. 6), which reduces the compressive strength (Table 7). Results [19] also showed that lower yield stress and/or plastic viscosity and higher incorporation of AFA reduce the content of the air bubbles in hardened concrete. Higher mixing speed is more beneficial for reducing the content and average diameter of entrapped air bubble. This conclusion will be the starting point for further research by the author.

4. CONCLUSIONS

In the scope of conducted research it was shown that:

It is necessary to check the compatibility of AFA and PCP admixtures blend. The lack of compatibility between the AFA and PCP is manifested at this stage of the research by the lack of homogeneity of the liquid sample, e.g. sediment precipitation, delamination of two phases, turbidity. Therefore, the compatibility tests of AFA and PCP admixtures should be extended to test the properties of mortar, especially its strength and microstructure.

- Time of introduction of AFA to mortar influences the degree of mortar's fluidity. Introducing antifoaming admixture at the same time as superplasticizer is better for rheological properties of mortar. Time of introduction of AFA is not important to the air-content of mortar. Antifoaming admixture causes the increase of the flow diameter of the mortar and lowers plastic viscosity, regardless of the time of its introduction.
- AFA presence in the volume of SCC, depending on the type of AFA, leads to increasing of its flow diameter and decreasing of flow time. AFA allows the initial slump flow diameter of mortar or concrete to be maintained in the time. However, the time of maintaining of consistency of mortar depends on the type of AFA.
- Test results of mortars showed that AFA based on polyether-modified silicone, reduce the air-content, plastic viscosity and adhesion of fresh mortar most effectively. However, too much AFA in the SCC volume negatively affects the compressive strength of the SCC, although the air content is reduced.
- The compressive strength of mortar incorporating AFA is higher than mortar without AFA, but with PCP which does not cause too high air-content in the volume of mortar, on the condition of the right amount of AFA in the mortar or concrete. Too high dosage of AFA has a negative effect on mechanical properties and microstructure of mortar and concrete. A small dose of admixture effective in reducing the air content of the mortar or concrete does not influence negatively their compressive strength.
- Structure of SCC with AFA type 6 and PCP1 is less heterogeneous than the structure of concrete with PCP1. Moreover, no calcium hydroxide was found in SCC structure. There are no visible large air voids in the microstructure of concrete. Too much AFA admixture can cause micro-cracking of the concrete microstructure which reduces the compression strength.

- AFA changes the size of air-voids and its volume in concrete. The air content in concrete with AFA is more than twice reduced, the value of the air void space factor is bigger when PCP and AFA are incorporated.

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