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The Influence of Admixtures on the Technological Properties of Fresh Concrete Mixture

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In this research superplasticizing (SP), air voids removing (AVR), viscosity modifying (VM) and air entraining admixtures (AE) were used. The dosage of admixtures was chosen from minimum to maximum values recommended by the manufacturers. To sum up, 7 concrete mixture compositions with SP, 6 with AVR and 6 with VM and the last 6 with AE admixture were prepared. Water and cement ratio for all the compositions was kept at the same value. According to the results obtained, the usage of SP admixture resulted in significant increase of mixture`s slump and flow however it reduced mixture`s air content and increased its density. Concrete mixture`s properties: slump and flow were almost not affected by the increase of AVR and VM admixtures, however the air content slightly decreased and the density of concrete mixture slightly increased. With the incline of air entraining admixture, mixture`s slump, flow and air content increased, but the density declined. The authors of this study wanted to express the importance of the close link between concrete mixture`s technological and rheological properties. According to the yield stress of concrete mixture it is possible to prognosticate the future problems or various outcomes during or after the concrete mixture`s casting process.
Keywords: admixtures, slump test, flow table test, air content, superplasticizing, yield stress.

1. INTRODUCTION

Nowadays high-performance concrete contains not only main constituent materials such as: cement; water; coarse and fine aggregates, but various admixtures as well. Wide variations in terms of workability properties can be caused by different interactions between various mixture`s constituents. Concrete workability is typically evaluated in the field by the results of mixture`s slump and flow table test [1]. The most common reason for poor workability is that the addition of fine particles increases the demand of water due to the increased surface area of the aggregates. However, if there is a scarcity in fine particles, segregation or bleeding can occur. The main reason of using VM admixtures is to reduce segregation or bleeding. [2]. It is widely known that the usage of SP admixture increases mixture`s workability properties [3]. SP content has an effect on the physical, mechanical and structural properties of concrete as well [4]. It is also observed that the workability properties of concrete mixtures can be modified with the addition of mineral additives. The big disadvantage of mineral additives against the chemical admixtures is the reduction in strength when part of the cement is replaced by the mineral additives [5]. Air entrainment is the process where many small air bubbles are incorporated into fresh concrete to become part of the matrix that binds the aggregate together in the hardened concrete. This technique is used for achieving better freeze-thaw resistance and also there is a question about how this admixture affects the quality of concrete surface [6]. However, there are many studies conducted about how AE admixtures help to increase concrete`s durability, but on the other hand, there is little information how it affects the workability properties of concrete mixture [7 – 9].

Scientists conducted various tests how mineral and chemical admixtures influence the rheological properties of fresh concrete mixture [1, 2, 10, 11]. Yield stress and plastic viscosity are the main rheological properties [12]. It was stated that with the given SP dosage, the rheological properties of concrete mixture reduced with the addition of AE admixture. With the same slump, the air entrained concrete had higher yield stress and lower plastic viscosity. This means that higher shear stress is required to start the flow in the air entrained concrete, but the flow resistance would be lower [10]. Despite that rheological properties of concrete mixture are very informative and give very useful information about the workability of concrete mixtures, but in order to establish these properties it requires special tool – rheometer, which is very expensive and it is not designed to be used in situ [12]. Workability of concrete mixture, on the other hand, can be defined by the technological properties, like mixture`s slump and flow and these properties can be easily measured at the concrete placing place.

Nowadays, different types of admixtures are used when projecting concrete mixture [13]. The aim of this article was to analyse and establish the complex influence of different use admixtures to the technological properties of concrete mixture.

2. MATERIALS AND METHODOLOGY

JSC “Akmenes cementas” (Lithuania) Portland cement CEM II/A-LL 42.5 R was used. Physical and mechanical properties obtained from manufacturer of Portland cement CEM II/A-LL 42.5 R are given in Table 1. Kvesu quarry washed sand with the fraction of 0/4, bulk density of 1710 kg/m^3 and fineness module of 2.62 was used as fine

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aggregate for concrete mixtures. 0/1 sand fraction ($\rho = 1520$ kg/m^3, fineness module 1.78) was also used as fine aggregate. Gravel with the fraction of 4/16 and bulk density of 1327 kg/m^3 was used as the coarse aggregate. Granulometric composition of aggregates is conducted according to LST EN 12620:2013 and presented in Table 3.

Table 1. Physical and mechanical properties of the Portland cement, CEM II/A-LL 42.5 R

Specific surface area, m2/kg	410
Particle density, kg /m3	3.05
Normal consistency of cement paste, %	26.5
Volume stability, mm	0.8
Initial setting time, min.	195
Compressive strength after 2 days / 28 days, MPa	27.1/54.0
Loss on ignition, %	5.05
Insoluble materials, %	–
SO_3, %	2.48
Cl^-, %	0.015
Alkalis, calculated by Na_2O equivalent, %	<0.8

7 concrete mixture compositions with SP (CMsp), 6 with AVR (CMavr) and 6 with VM (CMvm) and the last 6 with AE chemical admixtures (CMae) were prepared. Table 4 shows the concrete mixture compositions with different admixtures used. The amount of each admixture was chosen according to recommendations of the manufacturers. Concrete mixture compositions were constructed according to LST 1974:2012 standard requirements.

Table 2 describes admixtures which were used in this research.

Table 2. Description of admixtures used in the research

	Glenium SKY 628	Rheomix 880	Rheomatrix 100	Microair G (LP)
Purpose	Super-plasticizer (SP)	Air voids remover (AVR)	Viscosity modifier (VM)	Air entertainer (AE)
Compound-based	Polycar-boxylate	Propoxylate – etoxylate	Synthetic – copolymer	Modified – resin
Dosage, %	0.6 – 1.8	0 – 0.3	0 – 1.1	0 – 0.3
Density, g/cm3	1.06 – 1.10	0.97 – 0.02	1.0 – 1.02	0.98 – 1.04
Viscosity, mPa·s	–	<600	–	–
pH	–	–	6 – 9	9 – 11
Chloride quantity, %	<0.1	–	<0.1	<0.01

Firstly SP was added to concrete mixture in order to determine the optimal quantity. The optimal quantity was determined according to mixture`s workability. Mixture`s slump and flow was pushed as high as possible avoiding segregation. The same addition principle for other chemical admixtures was used.

During the research, dry aggregates were used for concrete mixtures. Cement and aggregates were dosed by weight while water and chemical admixture were dosed by volume. When preparing the concrete mixture, 90 % of water was instantly poured to the mix. Super-plasticizing admixture was mixed with 10 % of water and poured into the mixer. Remaining admixtures were dozed directly to the mix.

The consistency of fresh concrete mixture was evaluated according to: LST EN 12350-2:2009 and LST EN 12350-5:2009 standards. Density was evaluated according to LST EN 12350-6:2009 standard. Air content was evaluated according to LST EN 12350-7:2009 standard. The results were calculated as the average of two tests conducted.

Table 3. Granulometric composition of the aggregates

Radius of the sieve's mesh, mm	The amount of poured out material, %		
	Sand fraction 0/1	Sand fraction 0/4	Gravel fraction 4/16
16.0	100.00	100.00	98.80
8.0	100.00	100.00	42.10
4.0	100.00	95.10	4.30
2.0	99.80	81.80	1.00
1.0	99.10	54.60	0.52
0.500	77.40	12.40	0.44
0.250	2.20	0.70	0.36
0.125	0.50	0.30	0.32
0.000	0.00	0.00	0.00

Table 4. Concrete mixture compositions

Materials	Unit	Concrete mixture compositions marking. Amount of materials for 1m^3 concrete mixture			
		CMp	CMar	CMv	CMae
Cement	kg	380	380	380	380
Water	l	178	178	178	178
Course aggregate, gravel – 4/16	kg	986	986	986	986
Fine aggregate, sand – 0/4	kg	574	574	574	574
Fine aggregate, sand – 0/1	kg	286	286	286	286
Superplasticizing admixture	%	0.6 – 1.8	1.4	1.4	1.4
Viscosity modifying admixture	%	–	–	0.1 – 1.1	–
Air voids removing admixture	%	–	0.05 – 0.3	–	–
Air entraining admixture	%	–	–	–	0.05 – 0.3
Water and cement ratio	–	0.47	0.47	0.47	0.47

3. RESULTS

3.1. The influence of SP admixture on the technological properties of concrete mixture

Fig. 1 indicates how the technological properties of concrete mixture are influenced by SP admixture. The compositions of concrete mixtures used in this research are presented in Table 4. The amount (percentages) of admixtures were calculated and changed according to the quantity of cement. SP dosage: 0.6 %; 0.8 %; 1.0 %; 1.2 %; 1.4 %; 1.6 %; 1.8 % of cement.

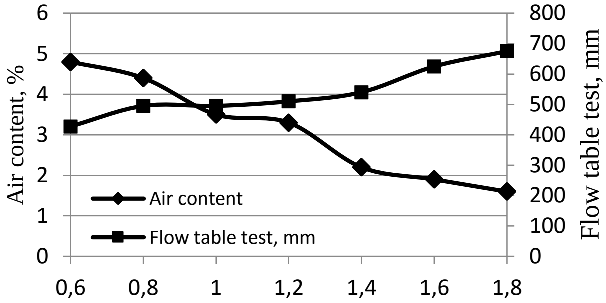

Fig. 1. The influence of SP admixture on the technological properties of CMsp concrete mixture

As can be obtained from Fig. 1 flow table test results indicated the increase from 430 mm (0.6 % of SP) to 680 mm (1.8 % of SP). The class of concrete mixture flow according to LST EN 12350-5:2009 standard changed from F3 (420 mm – 480 mm) to F6 (>630 mm).

The air content was constantly reduced when adding SP. With the optimal amount of SP (1.4 %) the air content was 2.2 %. However, the addition more than 1.4 % resulted in mixture`s segregation, which is considered the bad factor and further this type of concrete mixture is not investigated.

3.2. The influence of SP and AVR admixtures on the technological properties of concrete mixture

Fig. 2 indicates the influence of SP and AVR admixture on the technological properties of concrete mixture. AVR admixture was changed accordingly: 0 %; 0.05 %; 0.10 %; 0.15 %; 0.20 %; 0.25 %; 0.30 % and SP admixture was kept constant at 1.4 % of cement`s quantity.

As can be seen from Fig. 2, the addition of SP (constant 1.4 % of cement) and AVR admixture did not result significant changes in mixture`s flow. Mixture`s flow value without AVR admixture was 540 mm. Mixture`s flow with 0.3 % of AVR admixture was 605 mm. Mixture`s flow class increased from F4 (490 mm – 550 mm) to F5 (560 mm – 620 mm).

Air content of concrete mixture was reduced from 2.2 % (without admixture) to 1.95 % (0.3 % of AVR admixture). However, bigger difference between AVR dosage of 0.15 % (air content 2 %) and dosage of 0.3 % (air content 1.95 %) was not noticed. To sum up, this kind of admixture is mainly used to reduce the air bubble quantity in the concrete mixture and therefore to obtained better quality of monolithic concrete surfaces. Research revealed that bigger quantity (> 0.15 % of cement) of this admixture did not influence mixture`s technological properties.

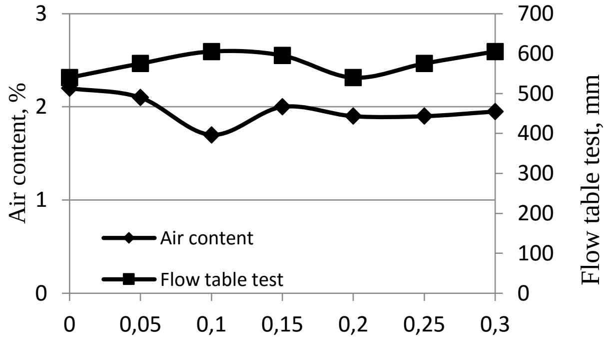

Fig. 2. The influence of AVR admixture on the technological properties of CMavr concrete mixture

3.3. The influence of SP and VM admixtures on the technological properties of concrete mixture

Fig. 3 indicates the influence of VM admixture on the technological properties of concrete mixture. VM admixture was dosed accordingly: 0 %; 0.1 %; 0.3 %; 0.5 %; 0.7 %; 0.9 %; 1.1 % and SP admixture was kept constant at 1.4 % of cement`s quantity.

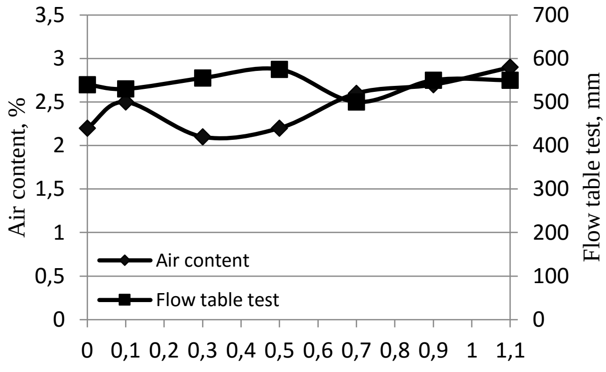

Fig. 3. The influence of VM admixture on the technological properties of CMvm concrete mixture

As can be seen from Fig. 3, the addition of SP (1.4 % of cement`s quantity) and VM admixture did not result significant changes in mixture`s flow. Mixture`s flow without the admixture was 540 mm. Mixture`s flow with 1.1 % of VM admixture was 550 mm. Mixture`s flow class remained the same F4 (490 mm – 550 mm).

The air content of concrete mixture increased with the addition of VM admixture from 2.2 % (without VM) to 2.9 % (1.1 % of VM).

3.4. The influence of SP and AE admixtures on the technological properties of concrete mixture

Fig. 4 indicates the influence of AE admixture on the technological properties of concrete mixture. AE admixture was dosed accordingly: 0 %; 0.05 %; 0.10 %; 0.15 %; 0.20 %; 0.25 %; 0.30 % and SP admixture was kept constant at 1.4 % of cement`s quantity.

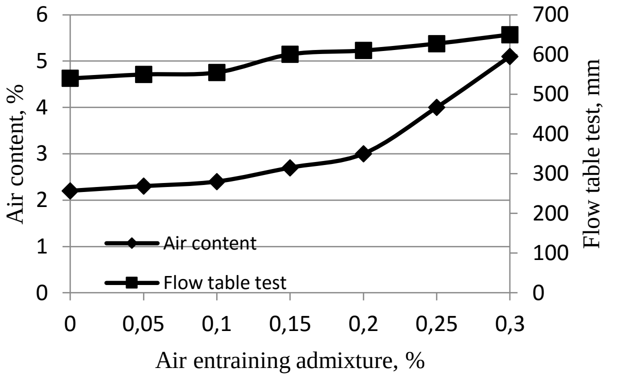

Fig. 4. The influence of AE admixture on the technological properties of CMae concrete mixture

According to Fig. 4, with the addition of SP (1.4 % of cement`s quantity) and AE admixture mixture`s flow increased. Mixture`s flow increased from 540 mm (without admixture) to 650 mm (0.3 % of AE admixture). According to LST EN 12350-5:2009 standard, flow`s class changed from F4 (490 mm – 550 mm) to F6 (> 630 mm).

It is obvious that air content of concrete mixture increased. This happened because air entraining chemical admixture was used. Air content increased from 2.2 % (without admixture) to 5.1 % (0.3 % of admixture).

4. DISCUSSION

Tests with the usage of concrete mixture`s main chemical admixtures were carried out. These results are very useful for contractors who are working with the production of concrete mixture. It is also valuable for in-situ concrete mixture production in low quantities. It combines and explains the findings of the usage of 4 different types of chemical admixtures with the dosages (from minimum to maximum) recommended by the producers.

According to the Eq. 1 [14], concrete mixture`s technological properties are closely connected with mixture`s rheological properties, therefore it is easier to approximately establish concrete mixture`s yield stress just by knowing its slump and density.

$$\tau_0 = \frac{0.00815 \cdot \rho_m}{\left(\sqrt{\frac{0.498}{30 - SL} - 0.001724} - 0.024\right)^2}, \quad (1)$$

where τ_0 is the yield stress, Pa; ρ_m is the concrete mixture`s density, kg/m3; SL is the slump of concrete mixture, cm.

It is said that with the addition of super-plasticizer the yield stress of concrete mixture reduces [10].

Fresh cementitious materials behave as fluids with a yield stress which is the minimum stress for irreversible deformation and flow to occur [15]. Concrete yield stress and viscosity generally increase with the uncompacted void content. Concrete mixture`s rheological properties help to obtain the optimization of the product [16].

Concrete can be considered as a two phase material which consists of coarse aggregate (CA) and mortar [17]. Experimental results indicated that higher content of coarse and fine aggregate result in higher concrete rheological parameters (in this case – yield stress). The quality of fresh concrete can be determined by its homogeneity and the ease with which it can be mixed, transported, compacted and finished [18]. According to the previously conducted test results (Figure 9), if concrete mixture becomes stiffer its yield stress increases (plastic viscosity is not affected) and on the other hand, if mixture becomes more viscous, its plastic viscosity increases (yield stress is not affected). Both: plastic viscosity and yield stress are bound to decrease if the mixture becomes wetter [12]. Authors of this study prepared Figure 5, which represents the influence of admixture type and quantity change on the yield stress of concrete mixture. As can be obtained from Figure 5, most of the admixtures had the trend to decline the yield stress. The most significant drop of yield stress indicates the use of SP admixture. The second biggest decline represents the use of AE admixture and the least decrease is with AVR admixture. On the other hand, the usage of VM admixture had the trend to keep the yield stress of concrete mixture steady.

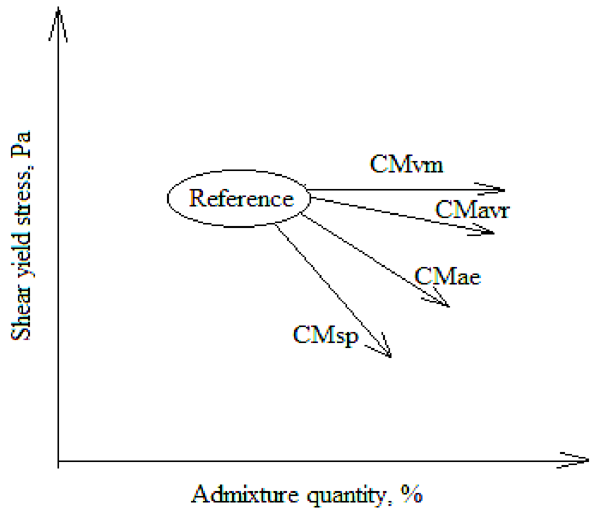

Fig. 5. Principal illustration showing the effect on mixture`s yield stress of adding different admixtures

Table 5 provides data how the yield stress is changed depending on the chemical admixtures which were used in this study. The calculation is conducted according to Eq. 1.

As can be obtained from Table 5, the addition of SP admixture drastically increased mixture`s slump (from S3 to S5 class according to LST EN 206-1:2000) and decreased the yield stress. The density of concrete mixture reached the peak of 2390 kg/m3 with 1.4 % of SP. The addition of AVR and AE admixtures slightly changed mixture`s slump and noticeably decreased its yield stress. Mixture`s slump changed within the S5 class limits with the use of AVR and AE admixtures. The bigger influence on mixture`s density was not noticed. The addition of VM admixture almost did not affect nor mixture`s slump (changed within S5 class limits) or yield stress, but slightly decreased its density.

Based on rheological studies [19, 20], the yield stress values obtained in this research meet the normal concrete mixture`s yield stress values.

Table 5. The dependence between mixture`s yield stress, slump and density as well as the admixture used

CMsp mixture			
SP quantity, %	SL, cm	*ρ*, kg/m3	τ_0, Pa
0.6	14	2360	884.5
0.8	22	2370	391.9
1.0	22	2360	390.2
1.2	22	2360	390.2
1.4	25	2390	233.5
1.6	26	2390	182.8
1.8	27	2390	134.0
CMavr mixture			
AVR quantity, %	SL, cm	*ρ*, kg/m3	Yield stress, Pa
0.05	25	2390	395.2
0.10	22	2390	285.7
0.15	25	2390	233.5
0.20	24	2390	285.7
0.25	25	2390	233.5
0.30	25	2390	233.5
CMvm mixture			
VM quantity, %	SL, cm	*ρ*, kg/m3	Yield stress, Pa
0.10	24	2390	285.7
0.30	25	2390	233.5
0.50	24	2390	285.7
0.70	25	2370	231.5
0.90	24	2370	283.4
1.10	24	2370	283.4
CMae mixture			
AE quantity, %	SL, cm	*ρ*, kg/m3	Yield stress, Pa
0.05	25	2370	231.5
0.10	25	2380	232.5
0.15	26	2360	180.5
0.20	27	2370	132.8
0.25	27	2370	132.8
0.30	28	2360	85.9

The authors of this study wanted to express the importance of the close link between concrete mixture`s technological and rheological properties. According to the yield stress of concrete mixture it is possible to predict the future problems or various outcomes during or after the concrete mixture`s casting process. The value of yield stress can express: the possibility to obtain nice concrete surfaces; the ease with which it is possible to work with the concrete mixture in the forms; the possibility of bleeding occurrence; the risk of segregation; the possibility of rough casting joints to occur; the risk of blowholes to appear; the cohesiveness of concrete mixture and others [21].

5. CONCLUSIONS

1. The consistency of concrete mixture according to slump increased from S3 to S5 and according to flow increased from F3 to F6 while increasing the amount of superplasticizing polycarboxylate based admixture. With the increase of superplasticizer, the air content decreased and mixture`s density increased.
2. In order to change the technological properties of concrete mixture the usage of both superplasticizer and air voids removing admixture is not appropriate, because the significant influence is noticed just by adding superplasticizer alone. The addition of air voids removing admixture did not influence mixture`s consistency.
3. The amount of synthetic – copolymer based viscosity modifying admixture did not influence the consistency of concrete mixture. The slump changed within S5 class limits and flow changed within F4 class limits. Viscosity modifying admixture (with 1.4 % of SP) increased the amount of mixture`s air content by 32 % and decreased its density by 0.8 %.
4. Modified-resin based air entraining admixture in conjunction of with 1.4 % of superplasticizer had bigger influence on mixture`s flow (increased from F4 to F6) than slump (stayed within S5 class limits). With the increase of air-entraining chemical admixture from 0.05 % to 0.30 %, the air content increased about 131 % (from 2.2 % to 5.1 %) and mixture`s density decreased from 2370 kg/m3 to 2360 kg/m3.

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