Influence of Cement Type and Mineral Additions, Silica Fume and Metakaolin, on the Properties of Fresh and Hardened Self-compacting Concrete

Sandra Juradin and Dražan Vlajić

Abstract Proportioning and mixing self-compacting concrete is a challenging task because the concrete mixture has to be stable and has to have the ability to fill formwork and to bypass obstacles under the influence of its own weight. Besides that, the final product has to be quality hardened concrete. It is known that even a little alteration of any component can significantly change characteristics of fresh and hardened concrete. In this work, the influences of the type of cement and additions, namely silica fumes and metakaolin on the workability and compressive strength of self-compacting concrete, are experimentally examined. For this purpose, several mixtures of self-compacting concrete were prepared and tested. The properties of fresh mixture were determined by the slump flow method, visual assessment of stability, T50 time, V-funnel method, L-box method and J-ring method. Also, in the hardened state, compressive strengths after 7 and after 28 days were determined. Results obtained in this work were compared with the results of other authors.

Keywords Cement type · Silica fume · Metakaolin · Workability · Compressive strength of concrete

1 Introduction

The basic property of SCC, which has to be achieved, is the ability to fill the formwork. That can be achieved only if the concrete can "flow" under its own weight and fill all types of formwork and if the concrete has good viscosity and resistance to segregation. Therefore, mixture proportioning of SCC is a challenging

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task. Even a small "error" in mixture proportioning of SCC leads to problems in self compacting, because this type of concrete is very sensitive even to the slightest deviation in terms of quality and components dosage.

The main requirement in the process of mixture proportioning has to be the amount of coarse aggregate, paste amount, water-cement ratio and the amount of additions. One of the first methods of mixture proportioning of SCC was developed by Okamura and Ozawa at the University of Tokyo [1, 2]. The basic principles of proportioning are:

- Volume of the coarse aggregate in concrete has to be 50 % of all solids in concrete
- Volume of the fine aggregate has to be around 40 % of the mortar volume
- Water-cement ratio by volume has to be 0.9–1.0; depending on the properties of the cement
- By changing the water-cement ratio and the amount of superplasticizer the effect of self-compacting is achieved.

Petersson and Billberg [3] and Billberg [4] have developed the CBI method according to which concrete is compounded of solids (aggregate) and liquid and of paste. Paste fills the voids in the aggregate skeleton and makes the layer which coats the aggregate particles. To determine the minimum volume of the paste, there are requirements which need to be fulfilled. They are defined as design criteria, void content and blocking criteria.

Mixture design of SCC very often includes testing of mortar properties which are representative enough. Because of that, quality tests can be minimized on concretes.

Erdem et al. [5] compared the rheological properties of SCC with the representative equivalent mortar in which coarse aggregate was replaced with sand. The method of equivalent mortar was used to determine, more easily, the properties of SCC including density of binders and properties of fresh materials. The authors found the correlation between mortar and SCC flow using the factor of correlation r:

$$r = \frac{V_{SCC}}{A_{SCC} \cdot (D_{max})_{SCC}} = \frac{V_{MSCC}}{A_{SMCC} \cdot (D_{max})_{MSCC}} \tag{1}$$

whereas

V_{SCC}	the volume of SCC in slump cone
V_{MSCC}	the volume of equivalent mortar in mini slump cone
A_{SCC}	the area of SCC spread
A_{MSCC}	the area of equivalent mortar spread
$(D_{max})_{SCC}$	the maximum aggregate size in SCC mixture
$(D_{max})_{MSCC}$	the maximum aggregate size in equivalent mortar mixture.

The correlation factor for their tested concretes is roughly 1, but it is important to underline that mixtures were made with additive HRWR (High-Range-Water-

Reducer) and liquid viscosity modifier (VMA). "A small incremental increase in the HRWR can result in a considerable decrease in yield stress and an increase in SCC slump flow. This can reduce the number of trial batches for concrete mixture design needed to ensure high deformability and stability, thus resulting in time savings and reduction in manpower and materials" [5].

Materials used in preparation of SCC are mostly the same as those used in preparation of regular concrete, but in different ratios. Besides cement, aggregate and water, chemical admixtures (superplasticizer, viscosity modifier) and mineral additions like filler, flying ash, pigments, silica fume, metakaolin, etc. are added to the mixture. Silica fume and metakaolin are additions which actively participate in the process of hydration of cement, causing the pozzolanic reaction. The pozzolanic reaction is the chemical reaction between calcium hydroxide and pozzolan. The products of reaction are the products of hydrotation-like C-S-H gel. Metakaolin is a relatively new addition to concrete. Its properties and the pozzolanic reaction can be compared to those of silica fume, but metakaolin is less expensive. The size of an average particle of metakaolin is 2 μm which is much smaller than a cement particle, yet not as fine as particles of silica fume (0.2 μm). Previous studies show that results of mixtures that contain metakaolin are similar to those which contain silica fume [6].

Wild et al. [7] have proved that calcium hydroxide, expressed as a percentage of total Portland cement, in mortars with metakaolin and the equivalent paste shows the minimum after 14 h. This has been explained as a peak in the pozzolanic reaction which shows that more calcium hydroxide is reduced from the paste in the reaction with metakaolin, than new is made by cement hydration. After a year, there is still a significant amount of calcium hydroxide, even in pastes where 15 % of cement is replaced with metakaolin. So it is suggested that the level of replacement needs to be over 15 % to use up completely all calcium hydroxide. Said-Mansour et al. [8] have come to similar conclusions about 3 main factors which affect the behaviour of metakaolin in concrete: filler effect, hydration acceleration and the pozzolanic reaction. Ding and Zongjin [9] have shown "that metakaolin offers much better workability than silica fume for given mixture proportions".

Madandoust and Yasin Mousavi [10] have shown that the addition of metakaolin increases the strength of SCC, especially the early strength at 3–14 days of age. That is in accordance with some earlier studies which showed that the biggest contribution to early strength of these concretes came from the pozzolanic reaction of metakaolin. Also, higher compressive strength is achieved with a lower water-cement ratio. It can be concluded that concrete with addition of metakaolin has a similar hydration progress during time as concrete with addition of silica fume. After workability testing of fresh concrete, the authors have concluded that the spreading of fresh concrete is reduced with a larger usage of metakaolin (20 %). They presume that this can be explained with the fact that the particles of metakaolin have a considerably higher specific area than the particles of Portland cement [11]. These kinds of results are consistent with the known fact that the addition of metakaolin increases the need of superplasticizer. Results of the L-box testing were worse in samples with addition of metakaolin, but they were still in a satisfying range.

Based on the testing results, the authors have concluded that the optimal amount of metakaolin is 10 % of the cement mass in order to satisfy specific requirements of fresh SCC.

Hassan et al. [12] examined the influence of metakaolin and silica fume on SCC with different percentages of addition compared to one control mix without any additions. Metakaolin was added in amounts of 3, 5, 8, 11, 15, 20 and 25 % of cement mass. Silica fume was added in amounts of 3, 5, 8 and 11 % of cement mass. Based on the time T50 result and V-funnel test they concluded that metakaolin increased viscosity of fresh SCC and that the addition of silica fume has no effect. Also, they showed that the increasing amount of metakaolin caused a rise in time T50 and it was in allowed boundaries according to EFNARC [13]. Metakaolin increased the ability to flow through and around obstacles.

When the amount of metakaolin increased from 0 to 25 %, the results of the L-box test raised from 0.63 to 0.89. Also, it was noticed that the addition of metakaolin increased the need for the superplasticizer dosage. However, when compared with silica fume, the addition of metakaolin requires less superplasticizer.

The compressive strength of SCC containing MK increased as MK content increased from 0 to 25 % (as a partial replacement of cement). On the other hand, the optimum percentage of SF in terms of compressive strength was 8 %, and it was similar to that of 8 % MK (both increased the strength of the control mixture by about 14 %). However, raising the amount of MK from 8 to 25 % only enhanced the compressive strength by 7 % (with respect to 8MK).

Other studies [14–16] also showed that SF and MK increased compressive strength of concrete, reduced shrinking, increased chloride resistance and resistance to freezing. Besides that, by replacing certain amounts of cement with SF or MK, the price of concrete can be reduced.

The purpose of this paper is to analyse the influence of those additions on self-compacting concrete. The control mixture was determined by the CBI method and by experiments on equivalent mortar. Eleven mixtures were prepared into which altered types of the cement (cement type I and type III) and percentage of partial replacement of cement by SF and MK were added.

2 Experimental Investigation

2.1 Introduction, Used Materials and Mixtures

The goal of the experimental investigation is to determine the influence of the type of the cement and the amount of SF and MK on the properties of fresh self-compacting concrete and on its compressive strength after 7 and 28 days. For this purpose, 9 different mixtures of SCC were prepared.

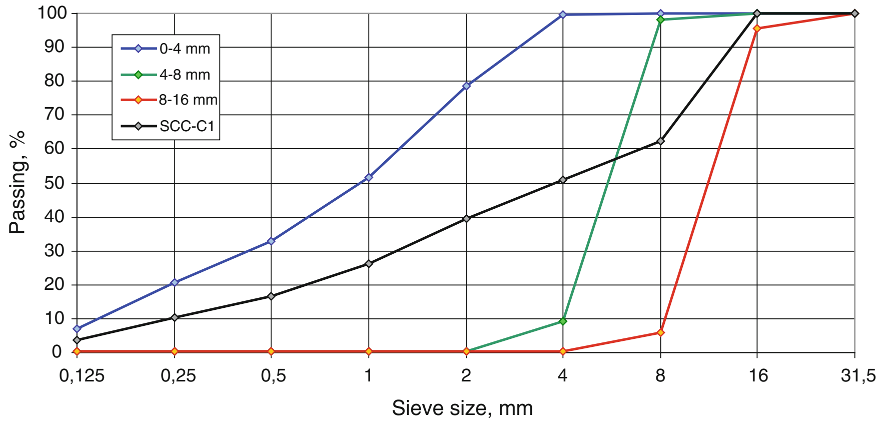


Fig. 1 The granulometric curve of the aggregates and of the reference SCC mixture—C1

Materials that were used:

- cement, types I and III (CEM I 42,5R and CEM III/A 42,5 N LH),
- the aggregate was crushed limestone, with the composition and grain size distribution of which is shown in Fig. 1. In mixtures, three fractions, 0–4, 4–8, 8–16 mm were used,
- silica fume with a specific surface area according to Blaine greater than 15,000 cm^2/g and the specific weight was 2.3 g/cm^3,
- metakaolin, density 2.6 g/cm^3 and specific surface area according to Blaine was around 24,000 cm^2/g,
- filler, which was obtained by recycling old concrete, had s specific surface area according to Blaine 7891 cm^2/g and density 2.45 g/cm^3,
- polycarboxylate superplasticizer.

The composition of each mixture is given in Table 1.

Control mixtures C1 and C3 did not contain any mineral additions. The only difference between them was in the type of the cement that was used. The number after the letter C, in the mixture label, stands for the type of cement. Letters "S" and "M" stand for mineral addition (S-silica fume, M-metakaolin) and the number at the end stands for the percentage of partial replacement of cement by silica fume or metakaolin. All mixtures had the same w/c ratio—0.42. According to the standards HRN EN 206-1, the calculation of the water–cement ratio when silica fume is used as an addition, was done considering the k-concept:

$$w/c = \frac{\text{water}}{\text{cement} + 2 \cdot \text{silica fume}} \tag{2}$$

So, in the mixtures which contain silica fume or metakaolin, the amount of water was determined according to the water-cement ratio which was calculated in this

Table 1 Mixture designs and labels for tested mixtures (mass for 1 m^3 concrete)

Label of mixtures	Cement		Silica fume	Metakaolin	Water	w/c	Superplasticizer	Filler	Aggregate
	CEM I	CEM III							
	kg		kg	kg	kg		kg	kg	kg
C1	400.0	–	–		168.0	0.42	4.0	136.0	1640.3
C3	–	400.0	–		168.0	0.42	4.0	136.0	1640.3
C1S5	381.0	–	19.0		176.0	0.42	4.0	114.2	1637.5
C3S5	–	381.0	19.0		176.0	0.42	4.0	114.2	1637.5
C1S10	363.6	–	36.4		183.5	0.42	4.0	93.8	1634.9
C3S10	–	363.6	36.4		183.5	0.42	4.0	93.8	1634.9
C1M5	381.0	–	–	19.0	176.0	0.42	4.0	116.3	1637.8
C3M5	–	381.0	–	19.0	176.0	0.42	4.0	116.3	1637.8
C1M10	363.6	–	–	36.4	183.3	0.42	4.0	98.3	1635.4
C1M10*	363.6	–	–	36.4	152.7	0.42	4.0	98.3	1755.4
C3S10*	–	363.6	36.4		165.8	0.38	4.0	93.8	1725.0

* All mixtures had the same w/c ratio 0,42 and their w/c = water/(cement +2* addtition) except mixtures marked with asterisk. The water-cement ratio of C1M10* also was 0.42 but it was determined as w/c = water/cement (we didn't taken into account the proportion of addition). The mixture C3S10* with the w/c ratio 0.38 had the lowest value of w/c and in that was differs from C3S10.

way. The concept (2) was also used in mixtures with the addition of metakaolin in order to achieve better workability of the concrete, keeping in mind that used metakaolin particles were finer then those of silica fume. Exceptions were the mixtures C1M10*, where the water-cement ratio was 0.42 but it was determined as in the case when we used only cement without additions, and the mixture C3S10*, where the water-cement ratio was 0.38.

Fresh self-compacting concrete was tested on the flow ability, passing ability, and segregation resistance with the following methods: slump-flow test, T50 time, V-funnel, L-box and J-ring test. The compressive strength of hardened concrete was determined after 7 and 28 days. The results were analysed and compared to the previous results from the listed literature.

2.2 Designing of the Control Mixture C1

The composition of the control mixture C1 was determined according to the CBI method and equivalent mortar method [4, 5]. As previously mentioned, the control mixture C1 was without mineral additions, and grain size distribution of this concrete, shown in Fig. 1, represent the distribution of all concretes. Initial content of this mixture, when 1 % of additive was used, is shown in Table 2.

The volume of paste (cement, water, sand, additive, water and air) in concrete was determined from the first design of the mixture. The amount per volume of the sand (<0.25 mm) was determined from the grain size distribution, see Fig. 1 and Table 2.

The mass ratio of gravel (>4 mm) and the total aggregate (for mixture C1 the mass ratio is 0.5) was calculated using Table 2. With that value, and according to void content criteria and blocking criteria, the minimum required paste volume was determined (see Fig. 2). The difference between the recommended and assumed volume of paste was compensated by adding the filler. The result was a final mixture whose composition is given in Table 1.

Because the method of equivalent mortar was used, the total area of aggregate (fractions 0–4, 4–8 and 8–16 mm) in the concrete was replaced with the fraction 0–4 mm. The tests on mortar showed the best dosage of additive for given values of spreading. For those tests, the amount of additive was 0.8 and 1 % of cement mass. The mixtures had to fulfil two main requirements: stability and spreading size

Table 2 Initial composition of mixture C1

C1	Cement	Water	Superplasticizer	Aggregate			Air	Total
				0–4 mm	4–8 mm	8–16 mm		
Mass (kg)	400	168	4.0	895.85	179.17	716.68	–	2362.9
Volume (dm^3)	132.9	168	4.0	333	66.6	266.4	30	1000

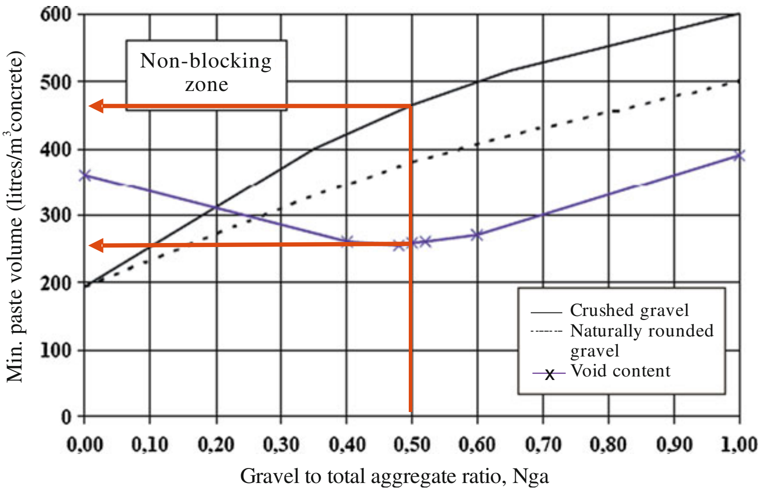


Fig. 2 Required minimum paste volume (using diagram of void content criteria and blocking criteria) [4]

Table 3 Results of measurement on equivalent mortar of mixture C1

Equivalent mortar for mixture C1		
Amount of admixtures (%)	0.8	1
D_1 (mm)	260	300
D_2 (mm)	270	310
SF (mm)	265	305

270–305 mm. The results of the spreading size of mortar had to provide results of spreading size of concrete in the range from 600 to 730 mm [17]. Measured values are in Table 3 and in Fig. 2.

According to the results of spreading and stability of mixture, the selected amount of additive was 1 % of the binder mass. That is, at the same time, the maximum recommended dosage for this additive (Fig. 3).

For all other mixtures the adopted dosage of additive was 1 %, but the filler mass was determined for each mixture in accordance to void content criteria and blocking criteria in order to acquire the minimum necessary volume of the paste (diagram, see Fig. 2). Final mixtures are shown in Table 1.

3 Experimental Results and Discussion

Concrete workability All mixtures were made in volumes of 25 dm^3, in the laboratory, in the mixer with the capacity of 50 dm^3. Mixing was conducted as follows. First, cement, filler, aggregate and mineral addition were mixed together.

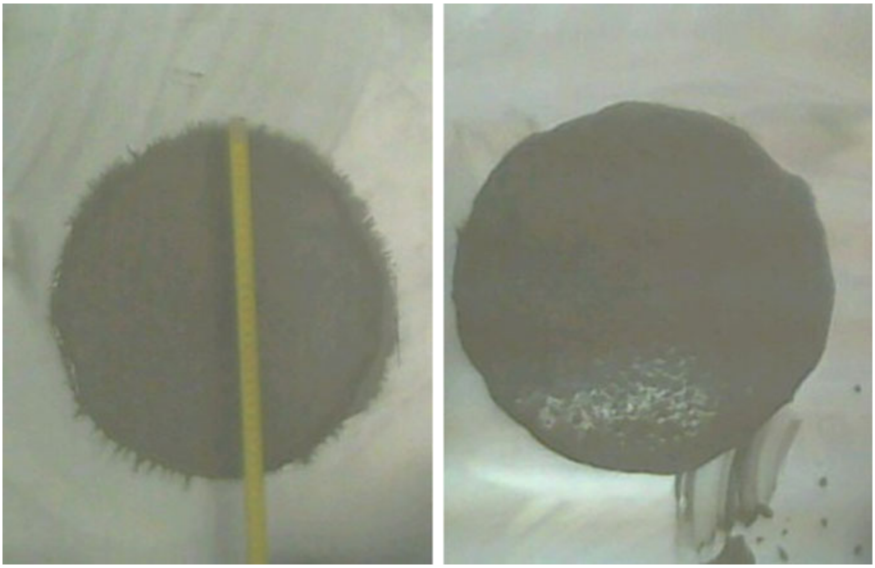


Fig. 3 Tests on equivalent mortar for 0.8 and 1 % of admixture

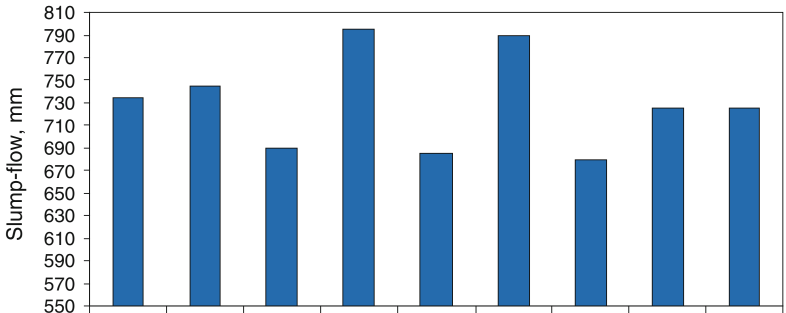
Later, while mixing, water and superplasticizer were added. After that, mixing was continued for a few minutes.

The workability was examined on fresh concrete using the slump-flow method, visual check of stability, T50 time, and with V-funnel, L-box and J-ring. The tests were carried out in accordance with the European standards HRN EN 12350 8-12. Based on test results, concrete mixtures can achieve different labels of consistency according to the classes of European association EFNARC, see Table 4.

In Figs. 4, 5, 6, 7, 8 and 9 the achieved results and effects occurred during the tests are shown.

Table 4 Slump-flow, viscosity and passing ability classes with respect to EFNARC [13]

Slump-flow (mm)	SF1	550–650
	SF2	660–750
	SF3	760–850
T50 (s)	VS1	≤2
	VS2	>2
V-funnel (s)	VF1	≤9
	VF2	9–25
L-box	PL1	≥0.80 (with 2 rebar)
	PL2	≥0.80 (with 3 rebar)
J-ring	PJ1	≤10 (with 12 rebar)
	PJ2	≤10 (with 16 rebar)

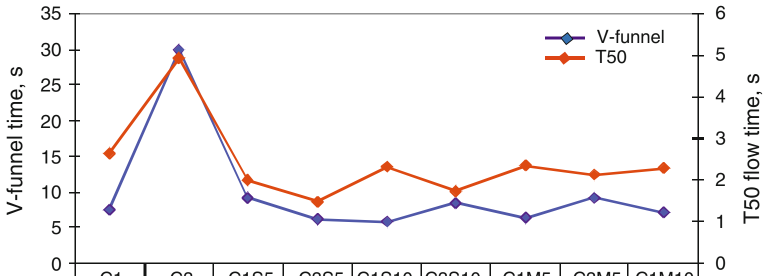


	C1	C3	C1S5	C3S5	C1S10	C3S10	C1M5	C3M5	C1M10
slump-flow, mm	735	745	690	795	685	790	680	725	725
with respect to EFNARC	SF2	SF2	SF2	SF3	SF2	SF3	SF2	SF2	SF2

Fig. 4 Slump-flow results for all mixtures

Fig. 5 Slump-flow test: the mixtures C3S10 (*left*) and C3S5 (*right*)

Fig. 6 Slump-flow test: the mixtures C1S5 (*left*) and C1S10 (*right*)



	C1	C3	C1S5	C3S5	C1S10	C3S10	C1M5	C3M5	C1M10
V-funnel time, s	7.49	30	9.19	6.22	5.86	8.43	6.4	9.19	7.18
with respect to EFNARC	VF1	-	VF2	VF1	VF1	VF1	VF1	VF2	VF1
T50 flow time, s	2.66	4.94	2	1.5	2.32	1.75	2.37	2.12	2.28
with respect to EFNARC	VS2	VS2	VS1	VS1	VS2	VS1	VS2	VS2	VS2

Fig. 7 Flow ability: V-funnel method and T50 time

Fig. 8 Aggregate blocking on bars when the mixture C3 was tested (*left*) and water segregation without aggregate blocking when mixture C3S5 was tested (*right*)

Fig. 9 J-ring test: the mixtures C3S5 (*left*) and C1M10 (*right*)

According to Fig. 4, the slump flow test and the classification of mixtures, only the mixtures C3S5 and C3S10 achieved class SF4. Other mixtures had results for class SF2. The same amount and type of addition had different effects on different types of cement. Silica fume lowered the workability of cement CEM I, and increased spreading of cement CEM III. With visual observation, segregation and water separation on edges were determined in the mixtures C3S5 and C3S10 (see Fig. 5). The most stable were the mixtures C1S5 and C1S10 (see Fig. 6).

So, although replacing a part of the cement CEM I with silica fume resulted with lower spreading size, mixtures remained stable, unlike those mixtures where CEM III was used and had the opposite effect. Replacing 5 % of cement mass with metakaolin lowered the spreading of concrete but all mixtures remained stable. In the mixture C1M10 where the level of replacement was 10 %, water separation and segregation occurred.

Since we had the results of spreading size on equivalent mortar for mixture C1, it was possible to determine the correlation coefficient according to expression (1), see Table 5.

Based not only on results from Table 5, but also on some other tests and achieved results from literature [5], it is clear that the type of additive and adding VMA significantly contribute to the correlation coefficient. In all tests which were carried out without adding a viscosity modifier, the correlation coefficient was less than 1, and it was in a range from 0.23 to 0.66.

Results of the T50 time and V-funnel test are compatible, see Fig. 7.

As it is shown in Fig. 7, the maximum deviation occurred in mixture C3. During the V-funnel test of this mixture, the aggregate blocked the funnel exit and that was the reason why the measured time was 30 s. Metakaolin and silica fume lowered the flow time. The exception was the mixture C1S5. The unstable mixtures C3S5 and C3S10 had the lowest time T50. That shows the test has to be considered in relation to the results of the slump flow test.

Similar to the V-funnel test, blocking the effect in the mixture C3 happened in the L-box test also, see Fig. 6 (on the left). The mixtures which segregated water during the slump flow test, did the same in this test. That was visible during the testing of the mixture C3S5 (see Fig. 6, on the right).

According to Table 6 results, only 4 mixtures satisfied the L-box test—C3S5, C3S10, C3M5 and C1M10. The L-box and J-ring test results are given in Table 6.

The results in Table 6 show that silica fume had a larger influence on mixtures with cement type III and metakaolin on mixtures with cement type I. Neither mixture satisfied the norms for EFNARC classification when they were tested with the J-ring. Mixtures C3S5, C1M5 and C1M10 had the best results (see Fig. 9).

Table 5 The correlation coefficient according to expression (1) for mixture C1

Mixture	r_{SCC}	r_{MSCC}	$r_{MSCC}-r_{SCC}$
C1	0.81	1.47	0.66

Table 6 Passing ability and classification according to EFNARC [13]

Mixture	PL		PJ	
	Measured	Class	Measured	Class
C1	0.78	–	30.5	–
C3	0.69	–	33	–
C1S5	0.72	–	29.25	–
C3S5	0.95	PL2	16.75	–
C1S10	0.65	–	28.5	–
C3S10	0.86	PL2	25	–
C1M5	0.77	–	16	–
C3M5	0.93	PL2	23.75	–
C1M10	0.95	PL2	16.75	–

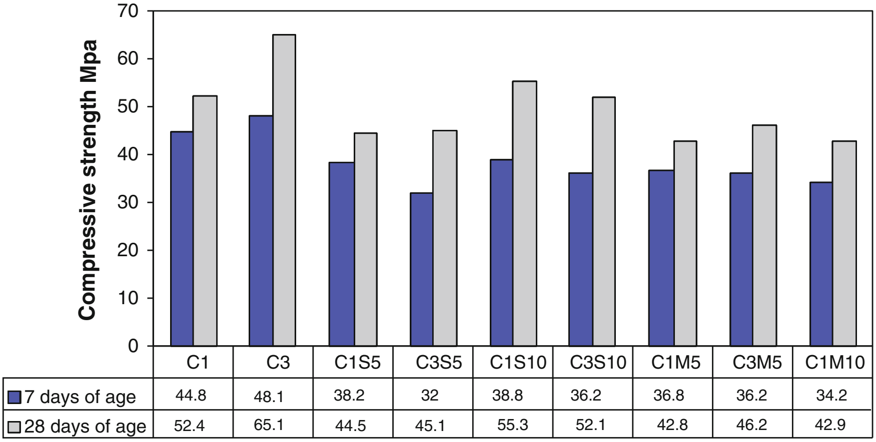
Analysis of mixture constituents of self compacting concrete In Table 7 the constituents of SCC mixtures and evaluation according to EFNARC [13] are shown.

Since [18] points out that these proportions are in no way restrictive and many SCC mixes will fall outside this range for one or more constituents, it can be concluded that tested concretes meet the suggested criteria. However, fulfilling the required criteria does not guarantee the workability of self-compacting concrete.

Compressive strength was determined after 7 and 28 days, and the obtained results are shown in Fig. 10.

Table 7 The constituents of SCC mixtures and evaluation according to EFNARC [13]

Constituent	C1	C3	C1S5	C3S5	C1S10	C3S10	C1M5	C3M5	C1M10	Typical range
Vol of coarse aggregate/m^3 (%)	30.5	30.5	30.4	30.4	30.4	30.4	30.4	30.4	30.4	27–36
Mass sand versus total aggregate (%)	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	48–55
Paste (%) (vol)	38.7	38.7	38.8	38.8	38.9	38.9	38.8	38.8	38.9	30–38
Powder (kg/m^3) (mass)	596.7	596.7	574.8	574.8	554.3	554.3	576.9	576.9	558.8	380–600
Water (kg/m^3)	168.0	168.0	176.0	176.0	183.5	183.5	176.0	176.0	183.3	150–210
Water/ powder ratio by vol	0.80	0.80	0.86	0.86	0.93	0.93	0.86	0.86	0.90	0.85–1.1
Water/ powder ratio by mass	0.28	0.28	0.31	0.31	0.33	0.33	0.31	0.31	0.33	0.28–0.37



	C1	C3	C1S5	C3S5	C1S10	C3S10	C1M5	C3M5	C1M10
7 days of age	44.8	48.1	38.2	32	38.8	36.2	36.8	36.2	34.2
28 days of age	52.4	65.1	44.5	45.1	55.3	52.1	42.8	46.2	42.9

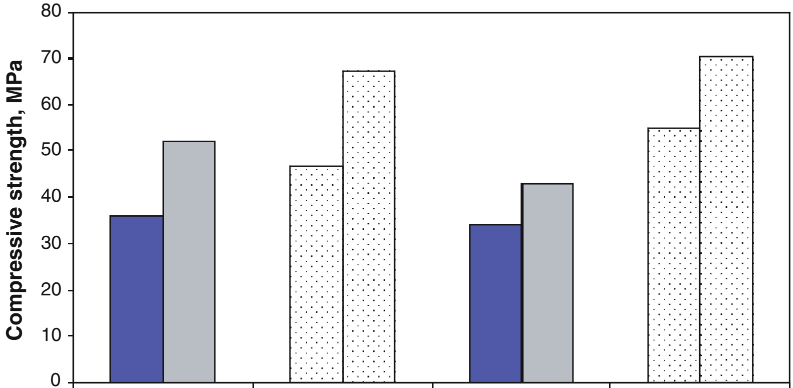
Fig. 10 Compressive strength after 7 and 28 days

Earlier studies show [7–12, 15, 16] that adding silica fume and metakaolin increases 28-day compressive strength of both classic and self-compacting concrete. Also, according to [11] metakaolin has an effect on early strength. In this work, a slight increase in 28-day compressive strength, compared to the control mixture C1, was noticed only when 10 % of mass of cement type I was replaced with silica fume. All other mixtures had 17 % lower compressive strength. Nearly all mixtures with cement type III had lower compressive strength, compared to mixture C3, by around 30 %. Only the mixture C3S10 had lower strength, by 15 %.

Results of additional mixtures Two additional mixtures, whose composition is shown at the bottom of Table 1, were also examined in their fresh and hardened state. The test of fresh mixture with lowest water-cement ratio (0.38)—C3S10* shows that this mixture cannot be fully considered self-compacting concrete. Test samples of concrete-cubes were still made without vibrating. The compressive strength after 7 and 28 days was measured and the results can be seen in Fig. 11.

The second mixture C1M10* did not show the self-compacting properties, but classic concrete ones. It did not have the ability of self-compacting and the test samples were made with vibrating.

The compressive strength results after 7 and 28 days are shown in Fig. 11 together with the results of mixtures with the same composition but which were made with a larger amount of water, according to the k-concept. Although, it can't be considered as SCC, it can be seen that the mixture C3S10* achieved 30 % higher 28 day compressive strength than the mixture C3S10. Mixture C1M10* achieved 64 % higher 28-day compressive strength than the C1M10 mixture. Both results are in accordance with the studies presented in [11]. Thus, it can be concluded that the amount of water influenced greatly the compressive strength of concrete. Also, it



	C3S10	C3S10*	C1M10	C1M10*
7 days of age	36.2	46.9	34.2	54.9
28 days of age	52.1	67.2	42.9	70.4

Fig. 11 Compressive strength of additional mixtures

can be assumed that by reducing the amount of water and with use of a superplasticizer and viscosity modifier, compressive strength would be even higher than those in the reference mixtures C1 and C3, and prepared concrete would be classified as self-compacting.

4 Conclusions

The goal of this work is to determine the influence of type of the cement, silica fume and metakaolin on the properties of fresh and hardened self-compacting concrete. For this purpose, nine different mixtures were prepared that differ in type of used cement, and in level of replacement of cement by mineral addition. Water-binder ratio, mass of binder materials (cement and mineral addition), ratio of coarse and fine aggregate and mass of superplasticizer stayed the same in all mixtures.

- Measured values of spreading size showed that mixtures with silica fume or metakaolin achieved lower results than those achieved by control mixtures without any mineral additions. Similar tendencies were demonstrated in earlier works where it was proven that an increase in level of replacement of cement with silica fume or metakaolin increased the need for amount of superlasticizer in order to achieve the same values of spreading size. Having in mind, that in this work, the maximum amount of superlasticizer was used, it is necessary either to change the type of superplasticizer or/and to add a viscosity modifier.
- Addition of silica fume and metakaolin generally enhances the ability of concrete to fill the formwork because they increase the speed of flow, which was

especially evident for mixtures with cement type III. If the speed of flow is too low, we should be cautious, because that can mean an occurrence of segregation of the coarse aggregate and water.

- Earlier works show that the passing ability of obstacles increases when the percentage of silica fume or metakaolin increases. Based on the L-box and J-ring test results, general conclusions cannot be made. In the L-box test, some mixtures achieved very good results while results of others were in range with those from the control mixtures. Nevertheless, it is obvious that all mixtures with mineral additions had better results than control mixtures in the J-ring test, but still not enough to be classified according to EFNARC.
- The compressive strength results show that 28-days strength is higher only in the mixture with cement type I and cement replacement levels of 10 % with silica fume. Early strength is also higher in control mixtures. Cause for this can be in larger quantity of water as a result of different calculation of water-cement ratio, which was shown on two additional mixtures. They had very good compressive strength but weak workability. This again confirms the need for an increase in dosage of superplasticizer and addition of viscosity modifier. Besides that, because cement CEM III is represented as a cement with considerable strength growth after 28 days of age, the test should be repeated after, at least, 90 days of age.

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