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MODIFICATIONS OF DOLOMITE-BASED SELF-COMPACTING CONCRETE PROPERTIES USING MINERAL ADDITIVES

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Preliminary notes

This paper addresses fresh and hardening properties of self compacting concretes (SCC) made with dolomite filler and pozzolanic materials, fly ash and matekaolin as cement replacement in different amounts. For this study, seven mixtures were prepared with a constant water-to-powder ratio and powder content. Fresh SCC properties were assessed by means of slump flow, L-box and sieve segregation test, while hardened properties were evaluated by means of compressive strength and modulus of elasticity at ages of 2, 7, 14, 28 and 365 days. In addition, the activity of mineral additives was assessed by heat of hydration measurement. Obtained results showed that mixtures containing fly ash exhibited better performance concerning workability properties needed for SCC, while cement replacement with metakaolin enhanced the mechanical properties. Slower pozzolanic activity of fly ash reflected in slower strength development, but ultimate strength obtained at the age of 365 days was not reduced by the presence of fly ash.

Keywords: *dolomite filler; fly ash; fresh properties; hardened properties; metakaolin; mineral additives; self-compacting concrete*

Utjecaj mineralnih dodataka na promjenu svojstava samozbijajućeg betona s dolomitnim filerom

Prethodno priopćenje

U radu su opisana istraživanja svojstava samozbijajućih (SCC) betona spravljenih s dolomitnim filerom i materijalima koji posjeduju pucolanska svojstva, letećim pepelom i metakaolinom, kao zamjena za cement u različitim postotcima. Projektirano je sedam mješavina sa jednakim omjerom voda/prah i jednakim udjelom praškastog materijala. Ispitivanja svježih svojstava su se sastojala od ispitivanja rasprostiranja slijeganjem, ispitivanja L-kutijom i ispitivanja segregacije, a u očvrsnulom stanju je ispitana tlačna čvrstoća i modul elastičnosti za različite starosti betona od 2, 7, 14, 28 i 365 dana. Kako bi se pratila aktivnost dodanih mineralnih dodataka u betonske mješavine, ispitana je i toplina hidratacije. Dobiveni rezultati pokazuju da dodatak letećeg pepela u mješavinama poboljšava svojstva obradljivosti, dok uporaba metakaolina poboljšava mehanička svojstva. Usporena pucolanska aktivnost letećeg pepela usporava razvoj tlačne čvrstoće, ali rezultati dobiveni ispitivanjem nakon godinu dana starosti pokazuju da konačna čvrstoća betona s dodatkom letećeg pepela nije manja u odnosu na referentnu mješavinu.

Ključne riječi: *dolomitni filer; leteći pepeo; metakaolin; mineralni dodaci; samozbijajući beton; svojstva u očvrsnulom stanju; svojstva u svježem stanju*

1 Introduction

Self-compacting concrete (abbreviated in the literature as SCC) is a special type of high performance concrete that fills the formwork with its own weight without the need for vibration during casting. Due to the many benefits of SSC that are reported in the literature (environmental, human, technological and economic) compared to conventional concrete, there is trend for its increased use in the structural applications for both site and precast work [1, 2].

In order to achieve a high flowability and a high segregation resistance between coarse aggregate and mortar required for self-compacting properties, the selection of mixture ingredients is based on high volume of fine particles, higher amounts of high-range water reducing (HRWR) admixtures and smaller maximum size of the coarse aggregate compared to conventional concrete.

High volume of fine particles in SCC is usually achieved by using mineral additives (pozzolanic and non-pozzolanic), since an increase in cement content in concrete mixture leads to a significant rise in material cost and sometimes can have negative effects on concrete properties (e.g. increased thermal stresses and shrinkage, etc.). Among non-pozzolanic materials limestone powder is most often used [3], but scarce data in the available literature show that dolomite powder, also can be satisfactorily used for the production of SCC [4, 5].

Fly ash [6 ÷ 10], ground granulated blast furnace slag [11 ÷ 13], silica fume [7, 14] but in the latest years also metakaolin [5, 13 ÷ 16] are reported in the literature as pozzolanic materials that are usually used in SCC production.

Pulverized fly ash is one of the most widely used additions in concrete, because of the benefits of heat reduction and pozzolanic reactivity. Recommended usage in concrete is about 15 ÷ 40 % replacement of cement [17]. Its usage in concrete reduces the amount of superplasticizer necessary to obtain similar slump compared with the concrete containing only cement as a binder. Because of its slower cementing activity, fly ash contributes towards long-term strength of concrete [18].

Compared to fly ash which is a secondary product from industry, metakaolin, as a thermally activated aluminosilicate material, is a primary product, produced with a controlled process. Recommended usage in concrete is up to 30 % replacement in cement [19]. Among many benefits that can be achieved by using metakaolin in concrete production, it is worth to highlight enhancing strength, shortening setting time and improving the durability of concrete [19, 20]. Since the price of metakaolin is on most markets significantly higher than cement, the main reason for use of metakaolin in concrete is more technological or environmental than economical [13].

2 Experimental work

In this paper, fresh and hardened properties of self-compacting concretes made with dolomite filer and mineral additives as cement replacement were investigated. For that purpose, seven self-compacting concrete mixtures were prepared. The binder for the control of self-compacting mixture included ordinary Portland cement (PC) and dolomite filler (D), while in six other mixtures, beside cement and dolomite, part of the cement was replaced with 5 ÷ 15 % of metakaolin (MK) and 20 ÷ 40 % fly ash (FA)(by weight). Fresh properties included filling, passing ability and segregation resistance of SCC, while the hardened properties included compressive strength and modulus of elasticity development up to 365 days. Additionally, to have the insight into the hydration process within the concrete mixtures, heat of hydration was measured.

2.1 Materials and mixing method

CEM I 42.5 R conforming HRN EN 197-1 [21] was used for all mixtures. Mineral additives used are commercially available at Croatian market. Tab. 1 summarizes properties of the PC and mineral additives used in studied mixtures, while Fig. 1 shows their particle size gradation obtained by the laser analysis with minimum sieve opening of 4,5 μm for cement and 0,1 μm for metakaolin, fly ash and dolomite. The fine and coarse aggregate used was dolomite with a nominal maximum size of 16 mm in order to avoid any blocking effect of SCC. Fig. 2 presents particle size gradation of used aggregate obtained by sieve analysis.

All mixtures were designed in accordance with CBI method developed in Sweden [22], but already satisfactorily applied on the design of SCC mixtures made with available materials in Croatia [23]. Constant powder quantity (670 kg/m^3) and constant water-to-powder ratio (w/p=0,27) were selected for all mixtures, in which the powder content, p, is defined as the sum of the cement, mineral additive and dolomite content. The concrete mixtures were designed to give slump flow of 700±50 mm which was achieved by using the superplasticizer (SP) based on modified polycarboxylic ethers at amounts as indicated in Tab. 2. Tap water used for the production of all concrete mixtures was obtained from the city waterworks.

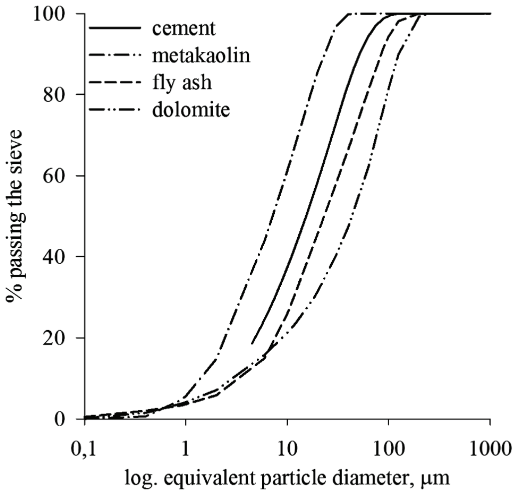


Figure 1 Grading curve of cement and additives

The batching sequence, which is presented in Fig. 3, consisted of homogenizing the fine and coarse aggregates for 5 s in a rotary mixer, then adding about one third of the mixing water at temperature of 20 °C into the mixer and continuing to mix for a half more minute. After cement and mineral additive were added, the mixing was resumed for another 30 s. Then the second third of water content was added and mixing was continued for one more minute. The superplasticizer dissolved with remaining water was introduced, and the concrete was mixed for 1,5 min and then left for a 2 min rest. After the viscosity modifying agent (VMA) was added, the concrete was mixed for additional 2 min to complete the mixing sequence.

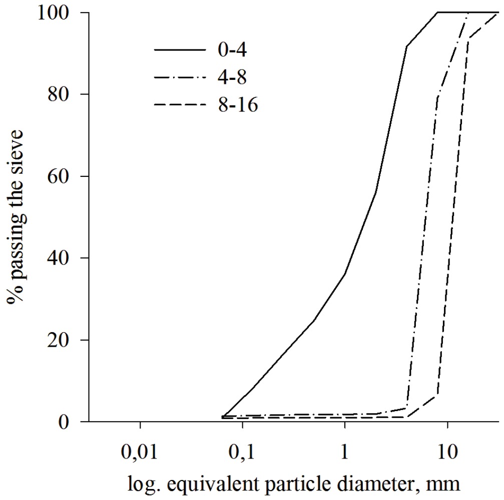
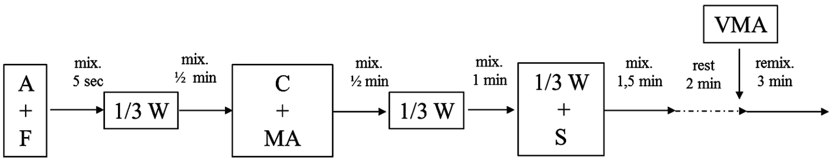


Figure 2 Grading curve of aggregates

Table 1 Properties of cement and mineral additives

Property/Component	PC	D	MK	FA
Chemical analysis, %				
CaO	60,23	30,38	0,55	4,21
SiO_2	19,81	0,00	53,53	51,87
Fe_2O_3	2,71	0,18	1,17	9,22
Al_2O_3	5,38	0,31	41,18	24,46
MgO	2,87	21,84	0,36	1,83
Na_2O	0,28	0,05	0,08	0,23
K_2O	0,77	0,02	0,83	1,14
SO_3	3,07	0,05	0,08	0,56
Loss of ignition, LOI	4,47	47,58	1,36	0,54
Physical properties				
Density, Mg/m^3	3,05	2,86	2,68	2,34
Blaine fineness, cm^2/g	3290	1630	10260	3070
Bogue composition, %				
C_3S	45,80	-	-	-
C_2S	22,50	-	-	-
C_3A	9,68	-	-	-
C_4AF	8,24	-	-	-
Mechanical properties				
Strength f_{c28}, MPa	61,18	-	-	-

All concrete specimens were cast without any compaction and vibration. After casting, the specimens intended for measuring the hardened properties of SCC were kept covered in the laboratory condition for 24 h until demoulding to prevent evaporation of water. Thereafter, specimens were placed in a controlled moist chamber at 20 ± 2 °C and RH ≥ 95 % for next 27 days. After 28 days of curing, the specimens were kept in ordinary environmental conditions (ϑ = 15 ÷ 25 °C; RH = 50 ÷70 %) until the age of 365 days.



A – agregate; F – filler (dolomite); V – water; C – cement; MA – mineral additive;
S – superplastifikator; VMA – viscosity modifying agent.

Figure 3 Mixing procedure of SCC

2.2 Testing procedure of SCC mixtures

Before casting, the concrete mixtures were tested in order to characterize properties needed for self-compatibility of concrete, which included filling, passing ability and segregation resistance of SCC in accordance with set of standards for self-compacting concrete testing [24 ÷ 27]. As mentioned previously, concrete mixtures were designed to give slump flow of 700±50 mm. Additionally, the slump flow time (t_{500}), L-box and segregation resistance were tested for each mixture. Observation of bleeding was visually performed during the slump flow test and was not observed in any mixture. All fresh concrete tests were carried out over a period of 10 ÷ 15 min after the mixing had been completed in order to reduce the effect of workability loss on the variability of test results.

Measuring of heat of hydration was performed using differential calorimeter (Tonical 7336 Heat Flow Differential Calorimeter). During the measurement, the calorimeter was situated in the chamber with controlled temperature conditions (19 ± 2 °C). The specimen for measuring was a cylindrical specimen, 300 mm high with a diameter of 150 mm. After mixing, the concrete is cast in the steel mould without vibration and then put in the body of the device. The average time elapsed between the mixing and start of measuring was about 20 minutes. The measured values are: rate of heat release, total heat of hydration and temperature evolution in the concrete specimen, which were monitored until the age of concrete of 72 hours.

Evaluation of hardened properties comprised compressive strength and static modulus of elasticity tests at the ages of 2, 7, 14, 28 and 365 days.

Compressive strength testing was performed according to procedure described by HRN EN 12390-3 [28] on 150 mm concrete cubes. Testing of static modulus of elasticity in compression was performed according to procedure described by Croatian standard HRN U.M1.025 [29] on cylindrical specimens, 200 mm high with a diameter of 100 mm, when three loading-unloading cycles between 0,5 MPa and the third of the compressive strength, obtained previously, were performed. Modulus of elasticity corresponded to the mean value of secant modulus obtained within the last cycle.

Table 2 Mix proportions (for 1m^3)

Mix ID		M1-ref	M2 (MK5)	M3 (MK10)	M4 (MK15)	M5 (FA20)	M6 (FA30)	M7 (FA40)
Cement, kg		450	427,5	405	382,5	360	315	270
Metakaolin	% c.w.	-	5	10	15	-	-	-
	kg	-	22,5	45	67,5	-	-	-
Fly ash	% c.w.	-	-	-	-	20	30	40
	kg	-	-	-	-	90	135	180
Dolomite, kg		220	220	220	220	220	220	220
Water, l		180	180	180	180	180	180	180
w/c		0,40	0,42	0,44	0,47	0,50	0,57	0,67
Fine aggregate, kg		862	862	862	862	862	862	862
Coarse aggregate, kg		696	696	696	696	696	696	696
SP, l		5,6	4,5	5,2	6,3	4,1	3,6	3,4
VMA, l		0,7	0,7	0,7	0,7	0,7	0,7	0,7

3 Tests results and discussion

3.1 Fresh properties of SCC mixtures

Fresh properties of the studied SCC mixtures and criteria for particular class in accordance to HRN EN 206-9 [24] are presented in Tab. 3.

Filing ability was evaluated by means of slump-flow test including assessing of t_{500}, passing ability by L-box test and resistance to segregation was evaluated by means of sieve segregation resistance test. Comparing the obtained results with the SCC criteria given in HRN EN 206-9 [24] and EFNARC recommendations [30] for particular classes that apply for SCC, it can be seen that all studied mixtures exhibited satisfactory properties in fresh state and can be used for many structural applications.

Since the workability is controlled by particle shape, particle packing effect, particle size distribution and the smoothness of surface texture, utilisation of mineral additive with different mentioned properties lead to different workability properties of studied mixtures.

In Tab. 2, the amounts of SP used in all mixtures to obtain slump flow diameter in the range of 700±50 mm are presented (ranging from 0,5 to 0,9 % per mass of binder). Amount of VMA was kept constant for mixtures and was 0,7 kg/m^3. As seen from Tab. 2, the higher addition of metakaolin increased demand for the superplasticizer, while the lower dosage of superplasticizer is needed for the higher fly ash content. These observations concerning mixtures with metakaolin are in line with Melo et al.[15] who observed that in SCC cement pastes and concretes, higher content of metakaolin demands higher content of superplasticizer. Contrary, coarse particle size and spherical geometry of the fly ash particles reduces the friction at the aggregate-paste interface producing a "ball-bearing effect" at the point of contact, thus partial replacement of cement by FA results in increased workability of mixtures [31].

Table 3 Fresh properties of concrete mixtures

Property/Mix ID	HRN EN 206-9		M1-REF	M2 (MK5)	M3 (MK10)	M4 (MK15)	M5 (FA20)	M6 (FA30)	M7 (FA40)
	Class	Criteria							
Slump flow, mm	SF1	550 ÷ 650 mm	732	720	725	727	720	720	725
	SF2	660 ÷ 750 mm							
	SF3	760 ÷ 770 mm							
Slump flow time (t_{500}), s	VS1	<2 s	2,08	2,35	2,19	2,10	1,66	1,47	1,40
	VS2	≥2							
L-box (h_2/h_1), −	PL1	≥0,8 2 rebars	0,94	0,93	0,82	0,82	0,84	0,87	0,92
	PL2	≥0,8 3 rebars							
Segregation resistance, %	SR1	≤ 20	5	8	10	10	5	6	6
	SR2	≤15							
Unit weight, kg			2499	2485	2482	2488	2462	2438	2419
Air content, %			1,9	2,1	2,4	2,1	2,3	2,0	2,3

In terms of slump flow diameter, all studied mixtures exhibited required slump flow values (Fig. 5). According to HRN EN 206-9 [24] all mixtures satisfied slump-flow SF2 class that is suitable for usual applications, e.g. walls, columns etc.

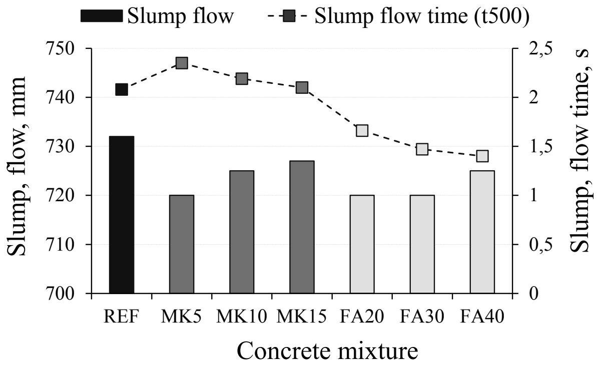


Figure 5 Slump flow and slump flow time of tested SCC mixtures

The slump flow time, t_{500} values, presented in Fig. 5, exceeded 2 s for reference and mixtures containing metakaolin, while mixtures containing fly ash had values below 2 s showing lower viscosity of mixtures. The use of fly ash in mixtures appeared to be the most effective in the reduction of the slump-flow time. Thus, according to viscosity classes defined in HRN EN 206-9 [24], the former can be classified as VS2, while the latter as VS1.

The L-box blocking ratio (h_2/h_1), which characterizes the passing ability, is dependent on coarse aggregate content and viscosity [32]. In order to avoid blocking effect of SCC mixtures, the maximum size of coarse aggregate was kept as 16 mm. As per EFNARC standards [32], there is not generally a blocking risk of the mixture when the L-box blocking ratio is in the range between 0,8 and 1,0. Results in Tab. 3 and Fig. 6 show that all the studied mixtures have remained in the target range for the class PL2 as defined by HRN EN 206-9 [24]. Furthermore, it is shown that increasing the replacing level of the metakaolin L-box blocking ratio decreased, while on the other hand, increased replacing level of fly ash led to increased L-box blocking ratio.

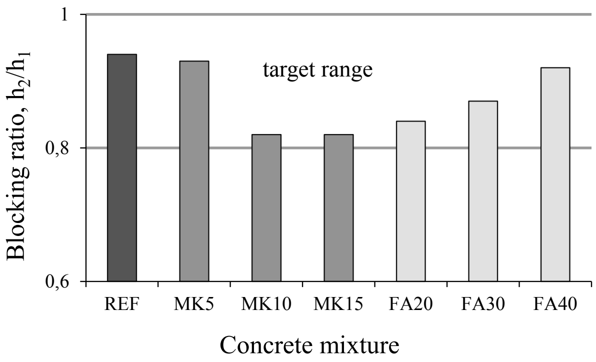


Figure 6 L-box blocking ratio of tested mixtures

In terms of segregation resistance, all mixtures exhibited satisfactory behaviour, satisfying SR2 class, i.e. segregation index was below 15 %. Mixtures containing metakaolin had higher segregation index (8 ÷ 10 %), while mixtures containing fly ash exhibited comparable (5 ÷ 6 %) segregation index to the reference mixture (Tab.3).

In Tab. 3, the unit weight of the fresh mixtures is also presented. The unit weight of the control mixture was 2499 kg/m^3 which was the highest value. Using mineral additives as metakaolin and fly ash, the unit weight of all mixtures decreased because of their lower density (2,68 and 2,43 Mg/m^3 respectively) compared to PC (3,05 Mg/m^3) showing that utilisation of mineral additive can decrease slightly the self-weight of SCC.

3.2 Mechanical properties of hardened SCC

The results of compressive strength testing of seven tested mixtures at ages 2, 7, 14, 28 and 365 days are shown in Tab. 4. The compressive strength at particular age was the average of test results of three specimens. Fig. 7 presents relative compressive strength development at same ages as in Tab. 4. Relative compressive strength presents ratio between compressive strength of particular mixture and reference mixture at the same age.

Table 4 Hardened properties of concrete mixtures

Age	M1-ref	M2 (MK5)	M3 (MK10)	M4 (MK15)	M5 (FA20)	M6 (FA30)	M7 (FA40)
Compressive strength, MPa							
2d / st.dev.	57,3 / ±1,9	49,2 / ±0,8	45,1 / ±1,6	43,9 / ±0,8	39,0 / ±1,4	36,8 / ±0,3	32,1 / ±0,8
7d / st.dev.	69,1 / ±2,0	74,5 / ±2,5	74,6 / ±2,1	74,3 / ±0,6	54,6 / ±1,1	50,3 / ±1,3	44,4 / ±0,2
14d / st.dev.	74,2 / ±1,7	78,5 / ±1,6	83,7 / ±1,8	82,9 / ±0,9	59,9 / ±0,1	56,3 / ±1,2	49,4 / ±0,4
28d / st.dev.	81,1 / ±1,1	82,3 / ±0,2	91,6 / ±2,1	89,6 / ±5,6	67,1 / ±2,2	65,0 / ±1,2	57,5 / ±1,3
365d / st.dev.	104,2 / ±2,4	107,3 / ±1,2	116,3 / ±3,1	118,3 / ±1,8	108,1 / ±3,1	109,0 / ±4,8	109,6 / ±0,8
Es, GPa							
2d / st.dev.	33,7 / ±1,5	30,1 / ±1,9	30,0 / ±1,0	26,7 / ±0,8	27,6 / ±0,9	26,4 / ±1,3	24,4 / ±0,3
7d / st.dev.	39,6 / ±1,6	40,8 / ±2,5	41,4 / ±0,6	40,1 / ±1,1	35,0 / ±0,8	32,9 / ±2,3	30,4 / ±0,9
14d / st.dev.	42,4 / ±2,5	43,0 / ±1,3	43,7 / ±1,2	42,7 / ±0,8	38,7 / ±2,2	36,9 / ±3,0	34,1 / ±0,2
28d / st.dev.	43,3 / ±2,1	43,8 / ±0,7	44,2 / ±0,7	43,9 / ±1,2	41,8 / ±1,5	40,6 / ±0,7	37,9 / ±0,4
365d / st.dev.	51,0 / ±2,3	46,6 / ±1,8	47,7 / ±2,5	47,4 / ±0,5	47,2 / ±0,9	46,4 / ±0,7	45,0 / ±0,6

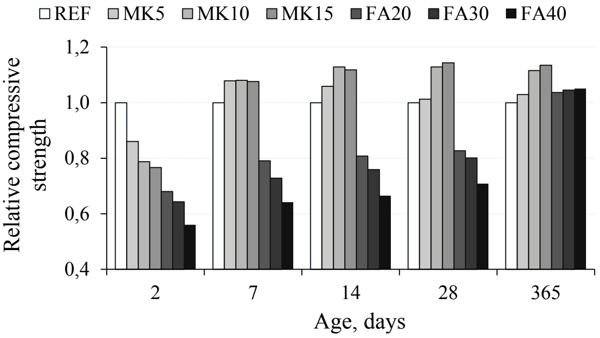


Figure 7 Relative compressive strength as a function of age for mixtures containing metakaolin and fly ash compared to reference mixture

Obtained results show that type of used mineral additive, as cement replacement in particular mixture, clearly affected the compressive strength development. From the results obtained, it is apparent that metakaolin generally produces a beneficial effect on compressive strength. Compressive strength of the mixtures modified with metakaolin developed faster than other groups of concrete (reference mixture and fly ash mixtures) after two days of curing. It can be seen from Fig. 7 that at second day of curing, replacing Portland cement with metakaolin reduces the compressive strength according to replacement level. Beyond the two days, incorporating metakaolin in the mixtures increases the relative strength where maximum contribution occurs at 14 days of curing when, compared to reference mixture more than 11 % (for M3 and M4) of increase is obtained. The same trend remained through the whole studied period (i.e. 365 days). It can be seen that the highest value of compressive strength after 365 days of curing was as high as 118,3 MPa for mixture containing 15 % of metakaolin. The higher aluminium content (41,18 %) and Blaine finesses (10260 cm^2/g) of the metakaolin possibly speeds up the hydration reaction and packs into the cement particle gaps which result in faster compressive strength development.

The obtained results are in good agreement with previous studies carried on normal-vibrated concretes made with metakaolin reported by Zhang and Malhotra [33], Wild et al. [34] and Khatib [35]. According to [34], there are three main factors that affect the positive contribution of MK to strength: 1) filling effect which is immediate; 2) the dilution effect within first 24 hours and 3) the pozzolanic reaction of MK with Ca(OH)$_2$ which reaches maximum between 7 and 14 days, which is obvious in our case.

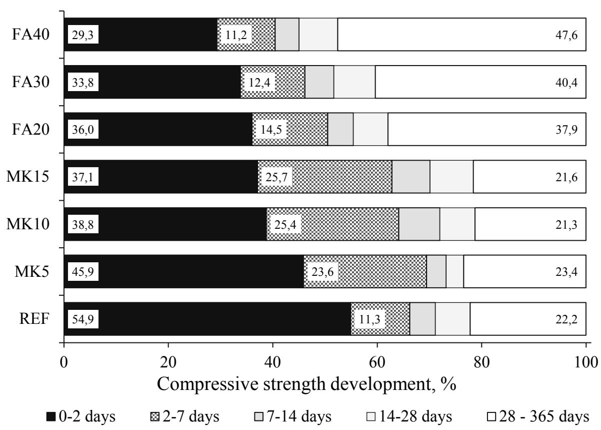


Figure 8 Compressive strength development of SCC mixtures at various ages

From Fig. 8 it can be seen that after 14 days of curing, mixtures containing metakaolin developed 70 ÷ 73 % of the 365 days compressive strength, which is comparable to reference mixture (71,1 %). Mixtures containing fly ash developed from 45,1 % for mixture M7 to 55,4 % for mixture M5 of 365 days compressive strength after 14 days of curing. As expected, the use of FA as a cement replacement decreased the compressive strength for all replacement level till 28 days of curing (as shown in Fig. 8). At 365 days of curing, compressive strength of concrete mixtures containing fly ash is slightly higher (108,1; 109 and 109,6 MPa for mixtures M5, M6 and M7 respectively) compared to reference mixture (104,2 MPa). Obviously, at the early age up to 28 days of curing, pozzolanic reaction of the FA with the Ca(OH)$_2$ was not sufficient to contribute to the increase in compressive strength.

As per compressive strength, influence of particular mineral additive on results of modulus of elasticity, presented in Tab. 4 and in Figs. 9 and 10, is similar for ages of concrete between 2-28 days.

At the age of two and 365 days, reference mixture has the highest value of modulus of elasticity 33,7 GPa and 51 GPa respectively, but from 7 to 28 day, concretes with metakaolin exhibited slightly higher values (up to 3 % for mixture with 10 % cement replacement with metakaolin).

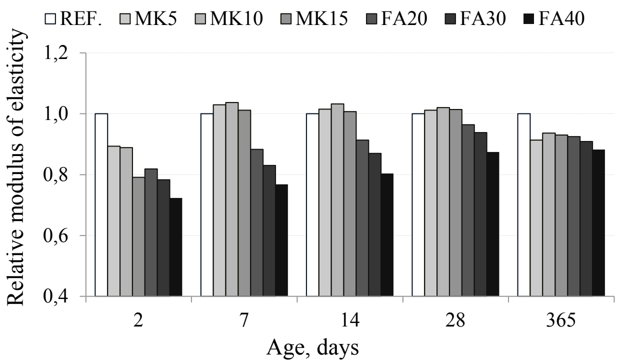


Figure 9 Relative modulus of elasticity as a function of age for mixtures containing metakaolin and fly ash compared to reference mixture

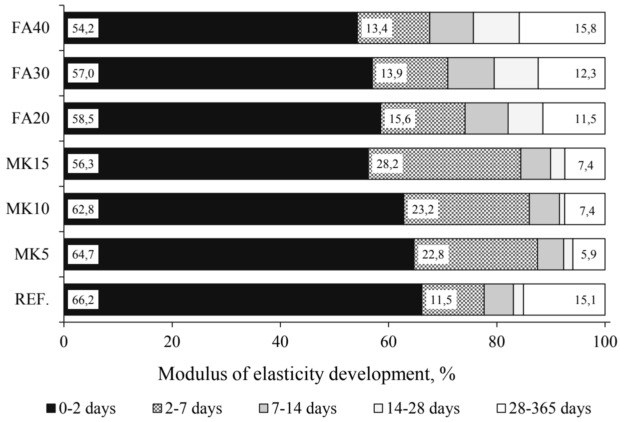


Figure 10 Modulus of elasticity development of SCC mixtures at various ages

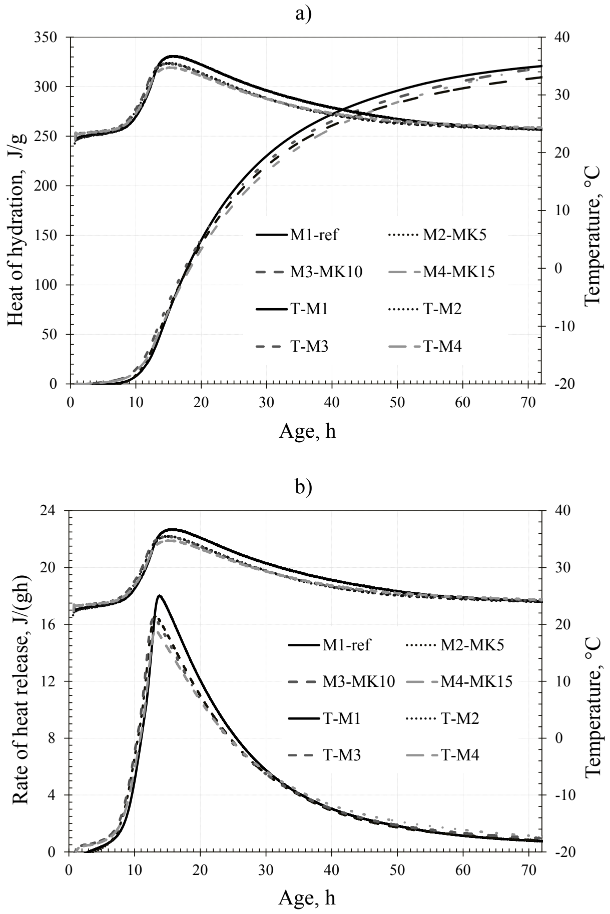

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Figure 11 Evolution of temperature and a) total heat of hydration; b) rate of heat release for mixtures with metakaolin (M2, M3 and M4) compared to reference mixture (M1)

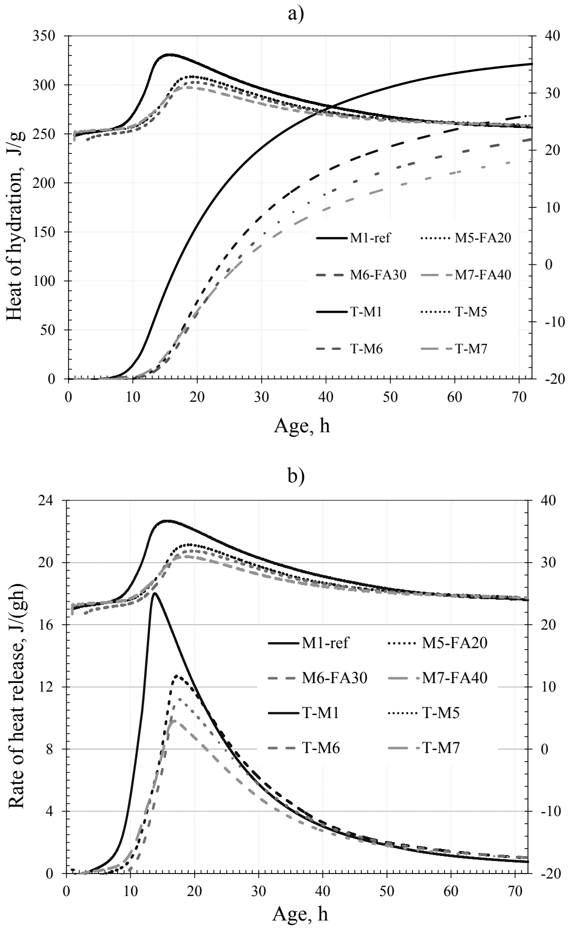
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Figure 12 Evolution of temperature and a) total heat of hydration; b) rate of heat release for mixtures with fly ash (M5, M6 and M7) compared to reference mixture (M1)

Influence of cement replacement on hydration process was monitored through heat of hydration. In Figs. 11 and 12, results of heat of hydration liberated and the rate of heat liberation are presented. In each figure upper curves (designated with T) present the evolution of temperature obtained in the specimens during measurement.

Replacement of Portland cement with metakaolin had a very little effect on liberated heat of hydration in the first 72 days hours of curing. This influence can be noticed in the slight shift in the peak of the rate of heat liberation curves (Fig. 11b). Replacement of Portland cement with fly ash has a very pronounced effect in the reduction of the rate of the heat liberation (Fig. 12a) and heat liberated (Fig. 12b). Larger amount of fly ash further reduced heat liberation.

Because the replacements level of CEM I in mixtures containing fly ash is much higher (20 ÷ 40 %) comparing to the replacement levels with metakaolin (5 ÷ 15 %) it is to be expected that mixtures with fly ash will show greater deviation in properties from reference mixture. Another important fact is that fly ash and metakaolin participate in the overall hydration process through different mechanisms and with opposite effects. Metakaolin practically does not change the heat evolution of concrete, but it increases strength gain development, while fly ash decreases rate of heat evolution and compressive strength gain. This effects indicate that microstructure formed with presence of metakaolin is obviously "better" connected, or, we could say stronger compared to pure Portland cement concrete and the reasons for this should be looked for in the properties of the hydration products formed. But, although the hydration process differs for all tested mixtures, its impact on the long term compressive strength of concrete (365 days) is practically negligible.

4 Conclusions

The following conclusions can be drawn based on the results presented in this paper:

1. Obtained results proved that dolomite powder can be used for making self-compacting concrete with acceptable fresh and hardened (compressive strength and modulus of elasticity) properties.
2. Fly ash as cement replacement ensured better fresh properties of self-compacting concrete with lower dosage of superplasticizer compared to other studied mixtures. Up to 28 days of curing, mixtures containing fly ash exhibited the lowest values of mechanical properties, but at the age of 365 compressive strength was comparable to that of reference mixture, indicating that pozzolanic reaction of the fly ash was not sufficient to increase the compressive strength at early ages. Modulus of elasticity for mixtures containing fly ash had the lowest values for all ages of concrete in accordance with replacement level
3. Metakaolin as cement replacement ensured better mechanical properties of self-compacting concrete beyond two days of curing compared to other studied mixtures. The exception were lower results of modulus of elasticity at the age of 365 days, but with variation less than 10 %, compared to reference mixture.
4. Improved fresh and long-term hardened mechanical properties with variation of 10 % imply that through replacement of cement with mineral additives in self-compacting concrete, the same or even better quality of concrete was achieved but with higher ecological component of sustainable concrete production.

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