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Influence of aggregate composition on self-compacting concrete properties

1. Introduction

The production of light-weight self-compacting concrete is very difficult in spite of a considerable experience related to self-compacting concrete (1, 5, 6). High variation of water absorption properties of the light-weight aggregate due to its porosity is a significant problem in the mix design. Water sorption by the light-weight aggregate pores can lead to a loss of self-compacting properties of concrete. Due to a considerable difference between density of the light-weight aggregate and the surrounding cement matrix, coarse aggregate has a tendency for surface location if cement paste does not have an adequate viscosity and furthermore, these concrete has a stronger tendency to segregation compared to ordinary self-compacting concrete.

There are various techniques available to avoid negative consequences of hydration sorption water by the light-weight aggregate. The most common method is its soaking in water. It is particularly effective in the case of high-performance light-weight concrete, because due to low water-cement ratio there is a possibility of higher shrinkage. The absorbed moisture in the light aggregate is available for internal curing that minimizes the early shrinkage. Another method is the application of a thin protective layer of cement paste on the aggregate to close its pores and block the access of water while maintaining the bond between the aggregates and cement matrix.

This paper presents the test results of workability and mechanical properties of the self-compacting concrete with natural and lightweight aggregate.

2. Mix composition

The tests were performed for concrete mixtures made of Portland cement CEM I 42.5R, fly ash, silica fume, Sika Viscocrete 3 superplasticizer, lightweight aggregate Pollytag 0-4 mm and 4-8 mm, natural sand 0-2 mm and granite coarse aggregate 2-8 mm. The amount of cement paste was constant and share of light-weight aggregate was variable. The initial composition of concrete was based on modification of the SCC with natural aggregates (2, 3).

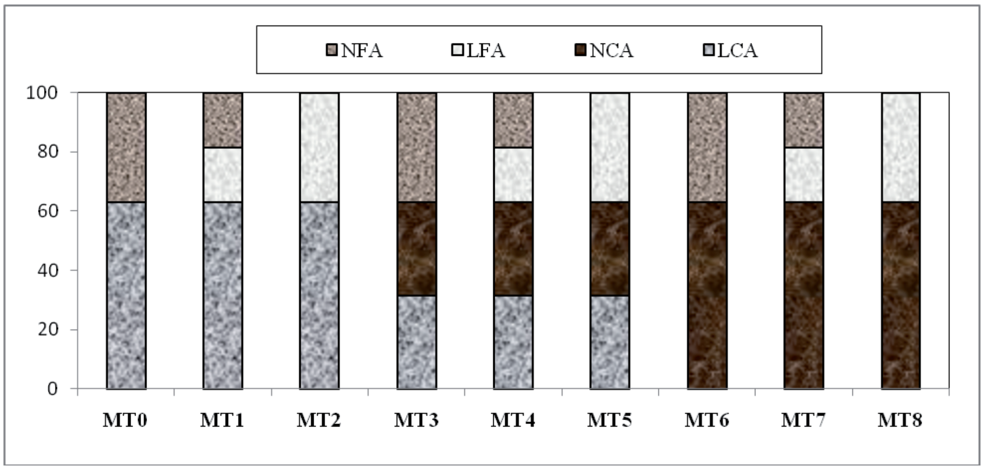

Fig. 1. Aggregate compositions by volume in concrete mixes: N – natural aggregate, L – light-weight aggregate, FA – fine aggregate, CA – coarse aggregate

Table 1

COMPOSITION AND NOTIFICATION OF CONCRETE MIXES

Mix	Cement kg/m^3	Fly Ash	Silica fume, kg/m^3	Water kg/m^3	SP kg/m^3	Aggregate, kg/m^3			
						Natural		Pollytag	
						0-2	2-8	0-2	4-8
MT0	450	72	38	155	7,65	624	-	-	540
MT1	450	72	38	155	7,65	312	-	155	540
MT2	450	72	38	155	7,65	-	-	310	540
MT3	450	72	38	155	7,65	624	536	-	270
MT4	450	72	38	155	7,65	312	536	155	270
MT5	450	72	38	164	8,00	-	-	310	270
MT6	450	72	38	155	10,00	624	1072	-	-
MT7	450	72	38	163	8,00	312	1072	155	-
MT8	450	72	38	164	8,5	-	1072	310	-

The natural aggregate was replaced by the same volume of the lightweight aggregate. Coarse lightweight aggregate was added to the mix after an initial wetting for 30 minutes in water and draining using sieves. The aggregate compositions for 9 mixes are shown in Fig. 1. and the composition of concrete mixes are presented in Table 1.

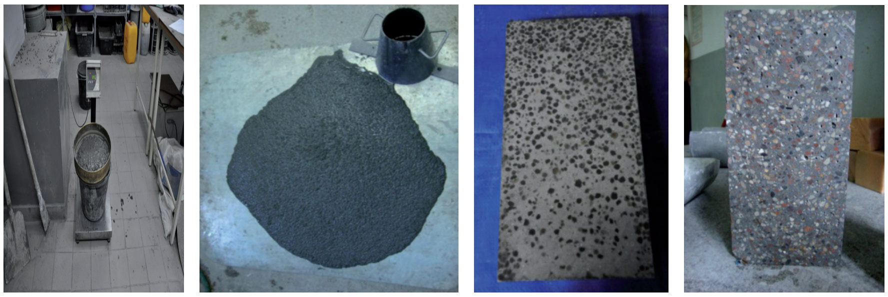

Fig. 2. Evaluation of segregation resistance

3. Test results

3.1. Workability

To determine the flowability of concrete, the slump-flow test, V-funnel test and J-ring test were used. The slump flow test was performed using the Abram's cone. The time was measured for the concrete to reach a 500 mm spread circle (denoted by T_{500}) and the final diameter of the concrete in two perpendicular directions was measured which average value was the slump-flow. The V-funnel is filled with about 12 litres of concrete and the time of flow was measured. The J-ring test was used to characterize the ability of SCC to pass through reinforcing steel. The average of two diameters of the resulting spread, measured perpendicularly, was the J-ring flow of the concrete. The difference between the J-ring test and the slump-flow was the indication of the degree to which the flow of SCC through reinforcing bars was restricted. Test results of workability for all mixtures are presented in Table 2.

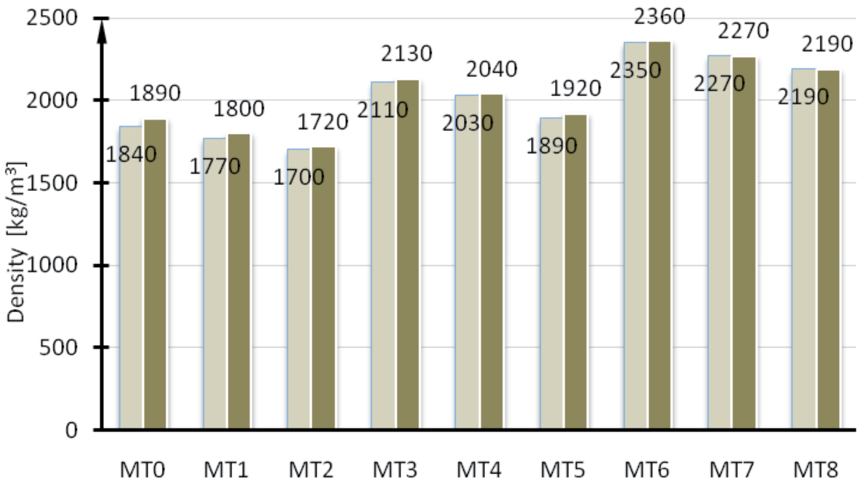

Fig. 3. Fresh and hardened concrete densities

All mixes had slump flow diameter within 600-810 mm, i.e. SF1, SF2 and SF3 classes, and classes of viscosity VS2 and VF2.

3.2. Segregation resistance

It is relatively easy to obtain an SCC mix with adequate flowability, viscosity and air-content, however, the major problem segregation during pouring and before concrete hardening present segregation resistance. Recently, a number of methods was developed for testing and assessment of resistance to segregation. The basis for classification of this resistance (SR) according to European standards is a sieve test. In USA, the recommended method for segregation testing is a column segregation.

A convenient investigations for verification of mix segregation is Visual Stability Index test (VSI) and for evaluation concrete segregation is Hardened Visual Stability Index test (HVSI) (Fig. 2).

The cross sections of samples with variable proportion of lightweight aggregate to natural aggregate are shown in Figure 3.

Concrete mixes with lightweight aggregate and natural sand: MT0, MT1 and MT2 were very well consolidated, but concretes with granite aggregates showed a slight segregation, and coarse lightweight aggregates were partially placed on the samples surface.

Table 2

TEST RESULTS OF CONCRETE WORKABILITY

Concrete	Slump-flow				V-funnel		J-Ring
	D_{max} mm	Class	T_{500} s	Class	t s	Class	D_{max} mm
MT0	755	SF2	2,35	VS2	16,8	VF2	705
MT1	725	SF2	3,17	VS2	13,6	VF2	670
MT2	810	SF3	2,49	VS2	13,5	VF2	795
MT3	725	SF2	2,34	VS2	9,9	VF2	720
MT4	640	SF1	4,58	VS2	15,5	VF2	635
MT5	705	SF2	2,33	VS2	12,2	VF2	665
MT6	600	SF1	5,49	VS2	18,4	VF2	540
MT7	575	SF1	2,9	VS2	9,6	VF2	565
MT8	570	SF1	3,37	VS2	13,7	VF2	550

3.3. Density of concrete

European Standard EN 206 defines lightweight concrete, LWC, as concrete containing lightweight aggregates and having air dry unit weight not exceeding 2000 kg/m³. Figure 3 shows the comparison of the fresh concrete density and density of concrete after 28 days of hardening.

The densities of concrete mixes with Pollytag: MT3, MT4, MT6, MT7 and MT8 were higher than 2000 kg/m³, then they do not satisfy the requirement for lightweight concrete.

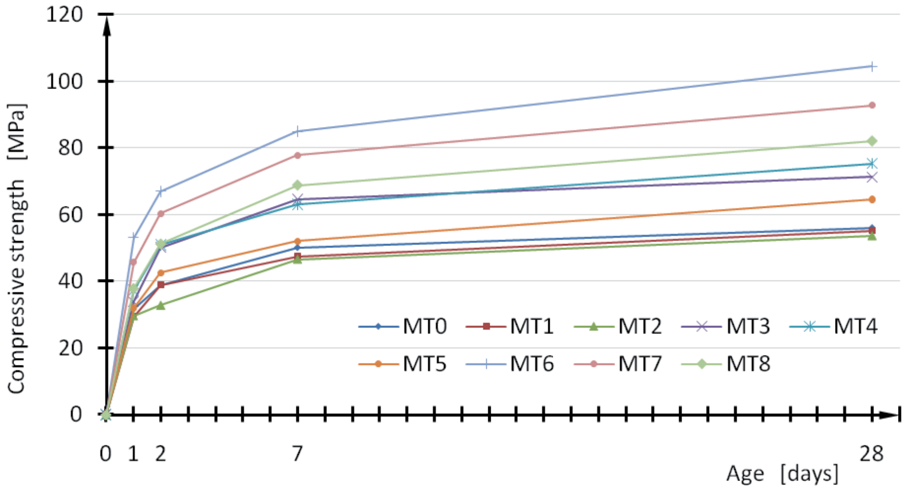

Fig. 4. Compressive strength of concrete

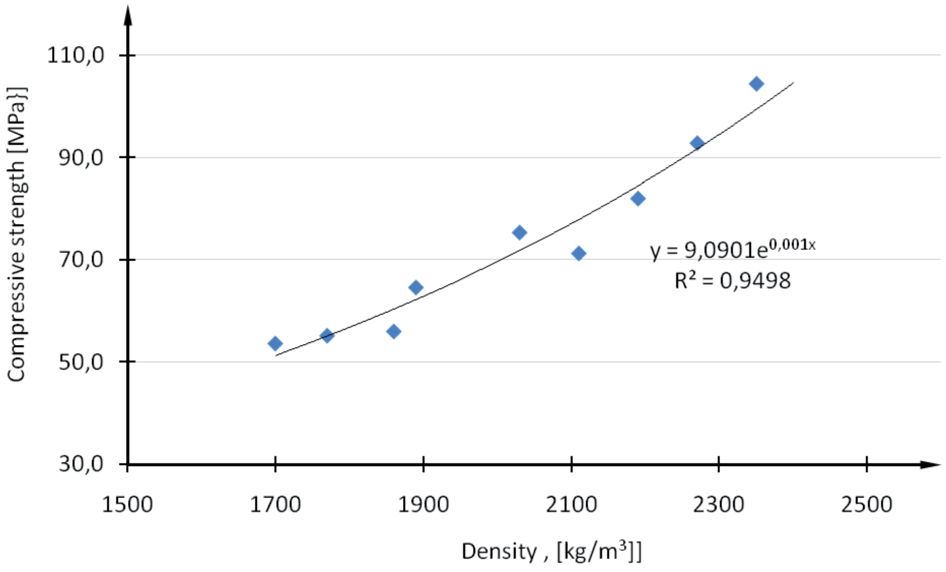

Fig. 5. Compressive strength and density of concrete after 28 days of hardening

3.4. Compressive strength of concrete

The results of compression strength tests are presented in Figure 4. The compression strength was tested on 10 cm cubes. It was found that the highest strength could be obtained for mixtures that satisfy the self-consolidating criterion. Increase or decrease of the slump flow beyond the accepted limits can cause a decrease of the compressive strength.

All concretes after 28 days had the strength in the range of 53.6 MPa to 104.4 MPa, so they can be considered as lightweight high-strength concrete and ordinary high-strength concrete. The highest strength had lightweight SCC MT0 with lightweight coarse aggregate and natural sand, and ordinary SCC MT6 with natural fine and coarse aggregate.

The relationship between the compressive strength and density of concrete after 28 days of hardening is shown in Fig. 5.

3.5. Drying shrinkage

The shrinkage of concrete was tested on samples of 5x5x25 cm cured in constant temperature and constant humidity. The results are presented in Fig. 6.

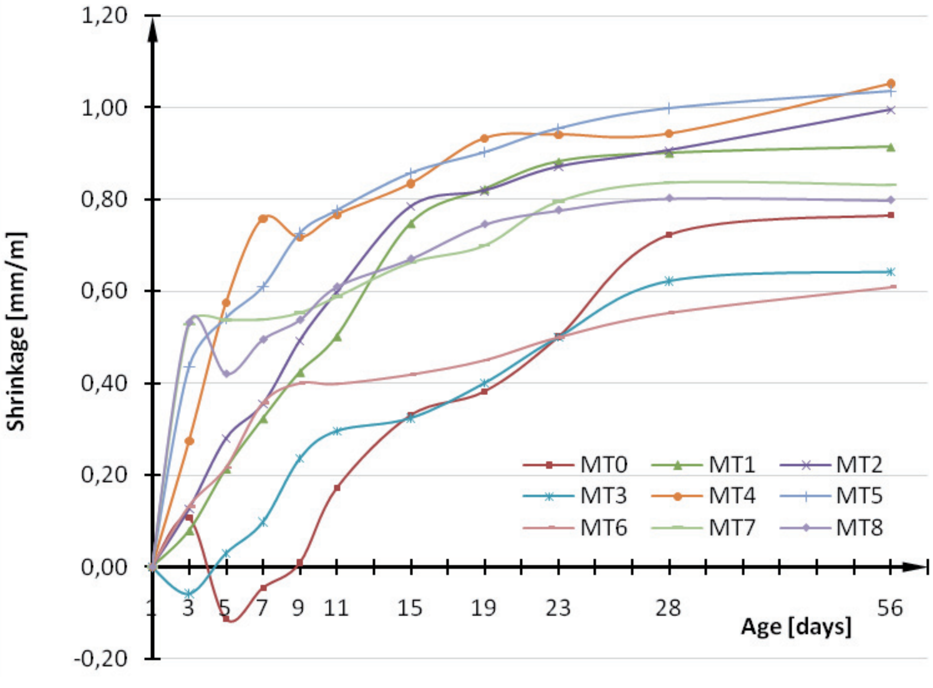

Fig. 6. Shrinkage versus time

The higher shrinkage presented lightweight SCC but it is caused probably by lower modulus of elasticity of these concretes (4).

4. Conclusions

The results of this study confirmed that the use of lightweight aggregate give the possibility of lightweight self-consolidating concrete production. The concrete mixes with lightweight aggregate have good self-consolidating properties and in the majority of cases have the density lower than 2000 kg/m³. Compressive strengths were in the range which can be considered as high-strength lightweight concrete. The required properties of concrete are strongly depended on the fabrication procedure, including initial preparation of aggregate, dosage method and mixing of components. The lightweight self-consolidating concrete requires a careful selection of the aggregate. The highest strength was obtained for concrete with lightweight coarse and natural fine aggregates.

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