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THE INFLUENCE OF FLY ASH ON THE KEY CHARACTERISTICS OF SELF-COMPACTING CONCRETE

Abstract: The main topic of this paper is to analyze the key characteristics of self-compacting concrete (SCC) containing fly ash and self-compacting concrete containing limestone filler. This paper consists of 5 chapters. The first chapter is an introduction to SCC, the second chapter describes used mineral additives, the third chapter describes the rheology of SCC, the fourth chapter describes the experimental programme and in the fifth chapter the results and analysis from the experimental study are presented. For the purpose of the experimental study fixed parameters are set. The cement content is fixed at 250 kg/m^3, 350 kg/m^3 and 450 kg/m^3, and the volume of fine aggregate is determined to be 40 %, 45 % and 50 % by mortar volume. In general, obtained results for workability of concrete are in same class. The performed tests illustrate that fly ash may replace limestone filler as a mineral additive in SCC.

Key words: self – compacting concrete; fly ash; limestone filler; filling ability; passing ability; segregation resistance

UTICAJ LETEĆEG PEPELA NA KLJUČNA SVOJSTVA SAMOUGRAĐUJUĆEG BETONA

Rezime: Osnovna tema ovog rada je analiza ključnih svojstava samougrađujućeg betona (SCC) koji sadrži leteći pepeo i samougrađujući beton koji sadrži krečnjački filer. Ovaj rad se sastoji od 5 poglavlja. Prvo poglavlje predstavlja uvod u samougrađujući beton, drugo poglavlje opisuje korišćene mineralne dodatke, u trećem poglavlju je opisana reologija SCC betona, u četvrtom poglavlju je objašnjen eksperimentalni program, a u petom poglavlju su prikazani rezultati i analiza iz eksperimentalne studije. Za potrebe eksperimentalnog istraživanja postavljeni su fiksni parametri: sadržaj cementa i zapremina sitnog agregata. Sadržaj cementa je fiksiran na 250 kg/m^3, 350 kg/m^3 i 450 kg/m^3, a zapremina sitnog agregata je određena na 40 %, 45 % i 50 % zapremine maltera. Generalno, dobijeni rezultati za obradivost betona su u istoj klasi. Izvršena ispitivanja pokazuju da elektrofilterski pepeo može zameniti krečnjački filer kao mineralni dodatak u SCC.

Ključne reči: samougrađujući beton; leteći pepeo; krečnjački filer; sposobnost rasprostiranja; sposobnost prolaska; otpornost na segregaciju

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1. INTRODUCTION

Concrete is one of the most used materials in civil engineering which offers many possibilities. There are various types of concrete: traditional “vibrated” concrete (TVC), porous concrete, extruded concrete, sprayed concrete, concrete for roadways, concrete for massive constructions, high-quality performance concrete, ultra-high performance concrete, fiber-reinforced concrete, nano-concrete, self-compacting concrete… The concrete use started from constructions in Roman Empire (Roman Colosseum), and continues today in structures and megastructures. Development of concrete technology over time, allows constant improvement of concrete and development of new and improved concrete types. Self-compacting concrete has been described as “the most revolutionary development in concrete construction for several decades” [1], which has been subject of interest in this paper.

Self-compacting concrete is the concrete of the future. It is an innovative concrete that does not require vibration for placing and compaction. It is able to flow under its own weight, completely filling formwork and achieving full compaction, even in the presence of congested reinforcement [2]. The hardened concrete is dense, homogeneous and has better engineering properties and durability than traditional “vibrated” concrete. The manufacture of 1 m^3 SCC has a higher production cost than manufacture of 1 m^3 traditional “vibrated” concrete, but should still be taken into account that 1 m^3 placed SCC costs similar or less than 1 m^3 placed TVC. The reason why placed SCC costs less than TVC are its advantages, such as reduction in site manpower, faster construction, easier placing, improved durability… SCC composition must have high powder content (400 to 600 kg/m^3 according EFNARC) for obtaining self-compactability. From there SCC contains high quantity of cement which will produce high compressive strength, but will have a negative effect on shrinkage of concrete and cost of SCC.

Mineral additives are often used in SCC, in order to reduce the cement content and for achieving self-compactability. Mineral additives have different positive effects on the properties of SCC, such as rheological properties, compressive strength, deformable characteristics... Today, the world of civil engineering intends to use materials that have a low cost or are “waste”, but these materials should be compatible for concrete composition. Hence, in this paper fly ash with origin from “REK” Bitola was used. Limestone filler as the most used mineral additive for SCC in Macedonia, was used for the purpose of comparison.

It is well known that the superplasticizers based on polycarboxylate ether are specially created for SCC as its essential ingredient, and in this experimental testings polycarboxylate superplasticizer “Superfluid 21 EKO” from the product guide of ADING AD – Skopje was used. Hence, new generation superplasticizer “Superfluid 21 EKO” will confirm its guaranteed quality for using and obtaining a SCC.

2. MINERAL ADDITIVES

Mineral additives are used for improvement and maintaining fresh properties of SCC, especially for improvement of the cohesion, workability, segregation resistance, and according to their type they have influence on compressive strength and other properties of SCC in hardened state. Mineral additives also regulate the cement content and so reduce the heat of hydration. They are classified into 2 groups according to their reactive capacity with water:

- Type I – inert or semi-inert (limestone filler, pigments)
- Type II – pozzolanic or latent hydraulic (fly ash, silica fume, ground granulated blast furnace slag)

2.1. Limestone filler

Limestone filler belongs to type I (inert or semi – inert) mineral additives and should conform to the requirements of EN 12620 [3]. Finely crushed limestone, dolomite or granite may be used to increase the amount of powder. The use of dolomite may present a durability risk due to alkali-carbonate reaction [1]. The limestone filler has a positive effect on reducing bleeding of concrete, permeability, chloride penetration, shrinkage, creep… On the other hand, the use of limestone filler in concrete replaces part of the cement content, which reduces the required energy and CO_2 emissions by cement production. Limestone filler used in this paper originates from quarry “Brazda”, Granit – Skopje. In the table 1 granulometric analysis is illustrated according to EN 933-1 [4], and in the table 2 the particle density according to EN 1097-6 [5].

Table 1 – Granulometric analysis of limestone filler according to EN 933-1

Sieve size [mm]	*Cumulative percentages passing [%]*
0.125	**98.77**

Table 2 – Particle density of limestone filler according to EN 1097-6

Particle density [kg/dm^3]	**2.77**

2.2. Fly ash

Fly ash belongs to type II (pozzolanic or latent hydraulic) mineral additives and should conform to the requirements of EN 450-1 [6]. It is fine-grade inorganic material with pozzolanic properties. For use in concrete, fly ash should have assessment and verification of constancy of performance (AVCP). The fly ash in SCC is used in order to increase the powder content and to improve its properties in fresh and hardened state. The fly ash in SCC have a positively effect on workability, compressive strength, durability, sulfate resistance, bleeding, shrinkage, creep, permeability, corrosion activity, carbonation, alkali-silica reaction, modulus of elasticity, reduce the heat of hydration. Also the use of fly ash contributes to reducing required energy and CO_2 emissions by cement production. Fly ash used in this paper originates from “REK” Bitola. In the table 3 granulometric analysis is illustrated according to EN 933-1 [4], and in the table 4 the particle density according to EN 1097-6 [5], as an alternative method.

Table 3 – Granulometric analysis of fly ash according to EN 933-1

Sieve size [mm]	*Cumulative percentages passing [%]*
0.125	**95.00**

Table 4 – Particle density of fly ash according to EN 1097-6

Paricle density [kg/dm^3]	**1.80**

3. RHEOLOGY OF SELF-COMPACTING CONCRETE (SCC)

Rheology is the science of the flow and deformation of matter under the effect of an applied force [7]. The rheology role in the engineering is to explain a behaviour of the materials, those that belong to the ideal Newtonian model of behaviour, and others who possess more complex rheological behaviour, so-called Bingham model of behaviour.

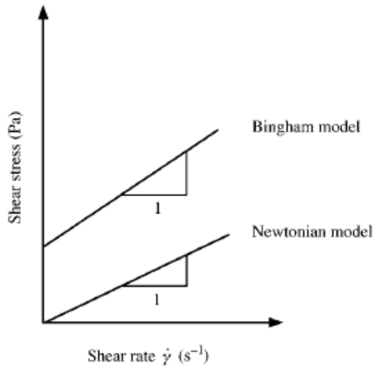

Figure 1 – Diagram of Bingham and Newtonian behaviour of materials

Concrete as a material possesses rheological properties in fresh and hardened state, but the rheology in fresh state is especially important. Traditional “vibrated” concrete is closer to the Bingham model, while SCC is closer to the Newtonian model. The rheology of SCC is very important and should be well studied, because it has a great affect of key characteristics on SCC, which then affects the mechanical properties. The rheological parameters that characterise the fresh behaviour of the SCC mix are:

- τ_Y – yield stress [Pa]
- γ – shear rate [1/s]

The first parameter τ_Y is the measure of the minimum amount of energy required to make SCC flow, which starts once the shear stress becomes higher than the yield stress. However, when it becomes equal or lower than yield stress, the flow stops. The second parameter γ is defined as a shear rate caused by shear stress. The presented in Fig. 1 shows that for certain degree of shear rate on SCC, minimum or zero shear stress is required to start flowing of concrete.

3.1. Key characteristics of fresh self-compacting concrete

It is well known that SCC in fresh state differs from other types of concrete by its own rheology. In order to be classified as a SCC, the concrete must possess three key characteristics:

- passing ability - The ability of fresh concrete to flow through tight openings such as spaces between steel reinforcing bars and gaps without segregation or blocking
- filling ability - The ability of fresh concrete to flow into and fill all spaces within the formwork under its own weight
- segregation resistance - The ability of SCC to remain homogeneous in composition during transport and placing

4. EXPERIMENTAL RESEARCH ON THE IMPACT OF FLY ASH ON THE KEY CHARACTERISTICS OF SELF-COMPACTING CONCRETE (SCC)

The purpose of this study is to research the impact of fly ash on the key characteristics of SCC for confirming the self-compactability. Limestone filler and fly ash were used as mineral additives for necessity of research. For the purpose of the properties analysis in fresh state and establishing certain correlations, the following fixed parameters are set: cement content and volume of fine aggregate. Slump – flow and V – funnel tests were used for confirming the filling ability, L box test was used for confirming the passing ability and for segregation resistance, sieve segregation test was used. All tests were performed in accordance with European normatives, such as: EN 12350-8 for slump – flow test [8], EN 12350-9 for V – funnel test [9], EN 12350-10 for L box test [10] and EN 12350-11 for sieve segregation test [11]. In some SCC mixtures all recommendations of

EFNARC and Prof. Hajime Okamura were respected, the k – value concept for fly ash explained in EN 206 [12], while in some SCC mixtures, part of these recommendations were outside the recommended limits. In Macedonia, the limestone filler is the most commonly used mineral additive in the composition of SCC, so the challenge was to replace the limestone filler with fly ash from “REK” Bitola. Fly ash is a cheap “waste” and this was the first reason for its use, and second reason is to research its effect on the key characteristics of SCC. If the fly ash proves to be suitable for use in SCC, it will also reduce costs of 1 m^3 produced SCC.

4.1. Experimental programme

In order to obtain appropriate correlations on the key characteristics of SCC, depending on the cement content and volume of fine aggregate, it is necessary to make a number of experimental tests on the materials to be used, cement pastes, mortars and finally of SCC mixtures. All testings are made in Central Laboratory Ading – Skopje. The following materials were used:

- Fine aggregate, I - fraction (0/4) mm from separation “Goiva” - Skopje
- Crushed limestone aggregate, II - fraction (4/8) mm from quarry “Govrlevo” - Skopje
- Crushed limestone aggregate, III - fraction (8/16) mm from quarry “Govrlevo” - Skopje
- Cement CEM I 52.5N from cement factory Cementarnica USJE A.D. – TITAN GROUP, Skopje
- Limestone filler (0/0.125) mm from quarry „Brazda“ Granit AD - Skopje
- Fly ash from „REK“ Bitola
- Supeplasticizer: Superfluid 21 EKO from “ADING” AD Skopje

The experimental programme consists of three series SCC mixtures, each serie with different cement content. Each serie consists of six SCC mixtures. One serie has been divided in two sub-series, in which the first has been prepared with limestone filler as a mineral additive, and the second has been prepared with fly ash. The composition of each sub-series mixture has been determined by a different percentage of the volume of fine aggregate. In 9 – SCC mixtures (1.1.1, 1.1.2, 1.1.3, 2.1.1, 2.1.2, 2.1.3, 3.1.1, 3.1.2, 3.1.3) limestone filler was used as a mineral additive, while in the remaining 9 - mixtures (1.2.1, 1.2.2, 1.2.3, 2.2.1, 2.2.2, 2.2.3, 3.2.1, 3.2.2 и 3.2.3) fly ash was used as a mineral additive.

Serie 1 (C = 250 kg/m^3)

Mix. no. 1.1.1 – C = 250 kg/m^3; V_{fa} = 40 % Mix. no. 1.2.1 - C = 250 kg/m^3; V_{fa} = 40 %

Mix. no. 1.1.2 – C = 250 kg/m^3; V_{fa} = 45 % Mix. no. 1.2.2 - C = 250 kg/m^3; V_{fa} = 45 %

Mix. no. 1.1.3 – C = 250 kg/m^3; V_{fa} = 50 % Mix. no. 1.2.3 - C = 250 kg/m^3; V_{fa} = 50 %

Serie 2 (C = 350 kg/m^3)

Mix. no. 2.1.1 – C = 350 kg/m^3; V_{fa} = 40 % Mix. no. 2.2.1 - C = 350 kg/m^3; V_{fa} = 40 %

Mix. no. 2.1.2 – C = 350 kg/m^3; V_{fa} = 45 % Mix. no. 2.2.2 - C = 350 kg/m^3; V_{fa} = 45 %

Mix. no. 2.1.3 – C = 350 kg/m^3; V_{fa} = 50 % Mix. no. 2.2.3 - C = 350 kg/m^3; V_{fa} = 50 %

Serie 3 (C = 450 kg/m^3)

Mix. no. 3.1.1 – C = 450 kg/m^3; V_{fa} = 40 % Mix. no. 3.2.1 - C = 450 kg/m^3; V_{fa} = 40 %

Mix. no. 3.1.2 – C = 450 kg/m^3; V_{fa} = 45 % Mix. no. 3.2.2 - C = 450 kg/m^3; V_{fa} = 45 %

Mix. no. 3.1.3 – C = 450 kg/m^3; V_{fa} = 50 % Mix. no. 3.2.3 - C = 450 kg/m^3; V_{fa} = 50 %

5. ANALYSIS OF THE RESULTS OBTAINED WITH EXPERIMENTAL STUDY

This chapter presents the analysis of the results obtained with an experimental study. The subject of analysis are the key characteristics of SCC. For this purpose and confirmation of the self-compactability, slump-flow, V – funnel, L box and sieve segregation tests, were performed for all SCC mixtures. The SCC compositions containing limestone filler and the results from performed tests are illustrated in the Tab. 5, while the SCC compositions containing fly ash and the results from performed tests are illustrated in the Tab. 6.

Table 5 – SCC compositions containing limestone filler and results from performed tests in fresh state

SCC MIX	CONSTITUENTS							RESULTS									
	Limestone filler [F]	Fine aggregate 0/4 mm $A_{(0/4)\ mm}$	Coarse aggregate 4/8 mm $A_{(4/8)\ mm}$	Coarse aggregate 8/16 mm $A_{(8/16)\ mm}$	Cement - CEM I 52.5N Titan, Usje	Water	Superfluid 21 EKO	Slump-flow	Slump-flow class	t_{500}	VS class	V-funnel	V – funnel class	L box (with 3 bars)	L box class	Segregation resistance	Segregation resistance class
	[kg/m^3]	[kg/m^3]	[kg/m^3]	[kg/m^3]	[kg/m^3]	[kg/m^3]	[kg/m^3]	[mm]	/	[s]	/	[s]	/	(PL)	/	(%)	(%)
1.1.1	383	739	431	356	253	216	4	660	SF2	1:50	VS1	4:50	VF1	0.81	PL2	6.60	SR2
1.1.2	356	911	326	270	249	214	4.3	750	SF2	1:90	VS1	4:00	VF1	0.85	PL2	7.86	SR2
1.1.3	300	1128	212	175	249	230	4.5	730	SF2	1:80	VS1	4:00	VF1	0.85	PL2	8.66	SR2
2.1.1	234	699	478	394	353	212	4	750	SF2	2:75	VS2	6:60	VF1	0.81	PL2	5.70	SR2
2.1.2	227	879	378	312	352	208	4.9	740	SF2	2:00	VS2	7:00	VF1	0.83	PL2	6.30	SR2
2.1.3	204	1089	261	216	351	214	5.3	690	SF2	2:30	VS2	5:30	VF1	0.86	PL2	6.70	SR2
3.1.1	102	662	526	434	454	207	5.5	750	SF2	2:00	VS2	9:84	VF2	0.81	PL2	12.9	SR2
3.1.2	95	840	427	352	454	213	6.3	720	SF2	1:90	VS1	6:06	VF1	0.82	PL2	8.53	SR2
3.1.3	88	1046	310	257	453	213	7.2	750	SF2	2:00	VS2	5:80	VF1	0.89	PL2	6.80	SR2

Table 6 – SCC compositions containing fly ash and results from performed tests in fresh state

SCC MIX	CONSTITUENTS							RESULTS									
	Fly ash [FA]	Fine aggregate 0/4 mm $A_{(0/4)\ mm}$	Coarse aggregate 4/8 mm $A_{(4/8)\ mm}$	Coarse aggregate 8/16 mm $A_{(8/16)\ mm}$	Cement - CEM I 52.5N Titan, Usje	Water	Superfluid 21 EKO	Slump-flow	Slump-flow class	t_{500}	VS class	V-funnel	V – funnel class	L box (with 3 bars)	L box class	Segregation resistance	Segregation resistance class
	[kg/m^3]	[kg/m^3]	[kg/m^3]	[kg/m^3]	[kg/m^3]	[kg/m^3]	[kg/m^3]	[mm]	/	[s]	/	[s]	/	(PL)	/	(%)	(%)
1.2.1	189	734	435	359	254	248	3.82	730	SF2	1:90	VS1	6:50	VF1	0.80	PL2	15.9	SR1
1.2.2	170	919	333	275	254	250	3.54	710	SF2	1:80	VS1	4:85	VF1	0.85	PL2	10.5	SR2
1.2.3	148	1151	199	164	252	268	4.30	670	SF2	1:90	VS1	4:00	VF1	0.62	/	12.6	SR2
2.2.1	125	691	477	395	352	229	4.39	660	SF2	1:80	VS1	8:55	VF1	0.56	/	1.52	SR2
2.2.2	119	861	373	309	348	235	4.88	660	SF2	2:00	VS2	6:00	VF1	0.80	PL2	6.30	SR2
2.2.3	103	1076	260	215	349	238	4.87	675	SF2	2:00	VS2	5:00	VF1	0.80	PL2	10.8	SR2
3.2.1	56	657	524	433	452	222	5.44	760	SF3	1:70	VS1	10:00	VF2	0.80	PL2	14.6	SR2
3.2.2	55	827	422	349	449	220	5.39	750	SF2	1:60	VS1	5:40	VF1	0.80	PL2	10.9	SR2
3.2.3	31	1036	308	254	449	236	5.78	735	SF2	1:80	VS1	4:66	VF1	0.85	PL2	9.93	SR2

According to the used test methods, SCC mixtures can belong to the following classes:

1. slump – flow

- SF1 (550÷650) mm – for unreinforced or slightly reinforced concrete structures that are cast from the top. (e.g. housing slabs). Casting by a pump injection system (e.g. tunnel linings), sections that are small enough to prevent small horizontal flow (e.g. piles and some deep foundations)
- SF2 (660÷750) mm – is suitable for many normal application of SCC (e.g. walls, columns.)
- SF3 (760÷850) mm – is used for vertical applications in very congested structures, structures with complex shapes, or for filling under formwork. SF3 will often give better surface finish than SF2 for normal vertical applications but segregation resistance is more difficult to control.

2. t_{500} and V – funnel

- VS1 / VF1 (VS1 < 2.0 s; VF1 < 9 s) – good filling ability even with congested reinforcement. It is capable of self-levelling and generally has the best surface finish. However, it is more likely to suffer from bleeding and segregation
- VS2 / VF2 (VS2 ≥ 2.0 s; VF2 = 9÷25 s) – limiting the formwork pressure or improving segregation resistance. Negative effects may be experienced regarding surface finish (blow holes) and sensitivity to stoppages or delays between successive lifts

3. L box

- PL1 (≥ 0.80 with 2 reinforcing bars) – housing, vertical structures
- PL2 (≥ 0.80 with reinforcing bars) – civil engineering structures

4. sieve segregation test

- SR1 (< 20 %) – is generally applicable for thin slabs and for vertical applications with a flow distance of less than 5 meters and a confinement gap greater than 80 mm
- SR2 (< 15 %) – is preferred in vertical applications if the flow distance is more than 5 meters with a confinement gap greater than 80 mm in order to take care of segregation during flow

The obtained results for slump – flow illustrates that the value of slump – flow is in class SF2, regardless of whether limestone filler or fly ash are used as a mineral additive. The obtained results for V – funnel have been in class VF1 with both mineral additives. With the slump – flow test according to EN 12350-8 [8] and V – funnel according to EN 12350-9 [9] filling ability has been tested. The passing ability was simulated in accordance to EN 12350-10 [10], the obtained class for all mixtures was PL2, except for mixture 1.2.3 and 2.2.1 where the test was unsuccessful. The L box improves with increasing the volume of fine aggregate. Segregation resistance were confirmed with sieve segregation test according to EN 12350-11 [11]. All 18 – SCC mixtures were resistant to segregation, and conform to class SR2.

Diagram 1 shows the correlation between slump – flow and cement content for various volume of fine aggregate (V_{fa}) in SCC containing fly ash. It is obvious that slump – flow value is higher when the cement content is 250 kg/m^3 or 450 kg/m^3 for various volume of fine aggregate, i.e. when fly ash has a minimum or maximum presence. [13]

Diagram 2 gives a graphic display of the correlation between slump – flow and cement content for various volume of fine aggregate (V_{fa}) in SCC containing limestone filler. At 40 % volume of fine aggregate, the increase in cement content increases the value of slump – flow, while at 45 % volume of fine aggregate, increasing the cement content decreases the value of slump-flow. At 50 % volume of fine aggregate the highest value of slump – flow is for 250 kg/m^3 or 450 kg/m^3. [13]

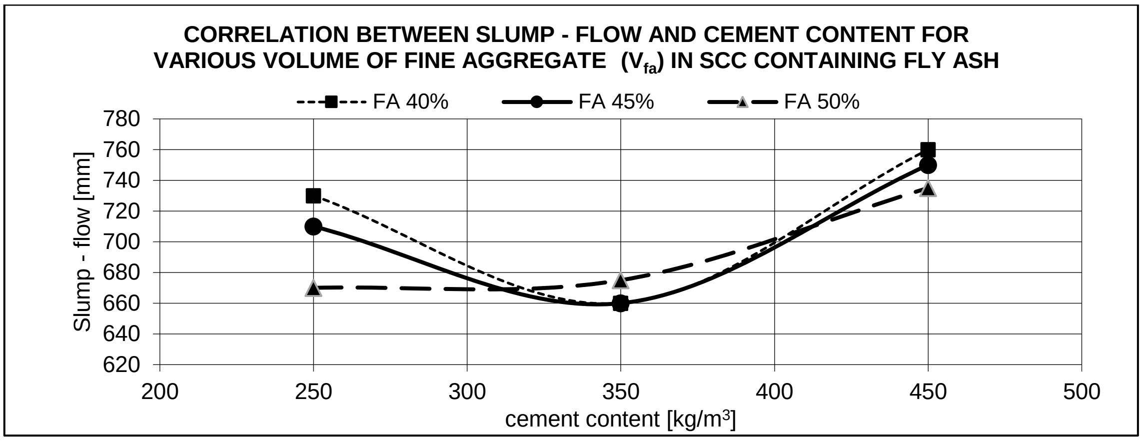

Diagram 1 – Correlation between slump – flow and cement content for various volume of fine aggregate (V_{fa}) in SCC containing fly ash

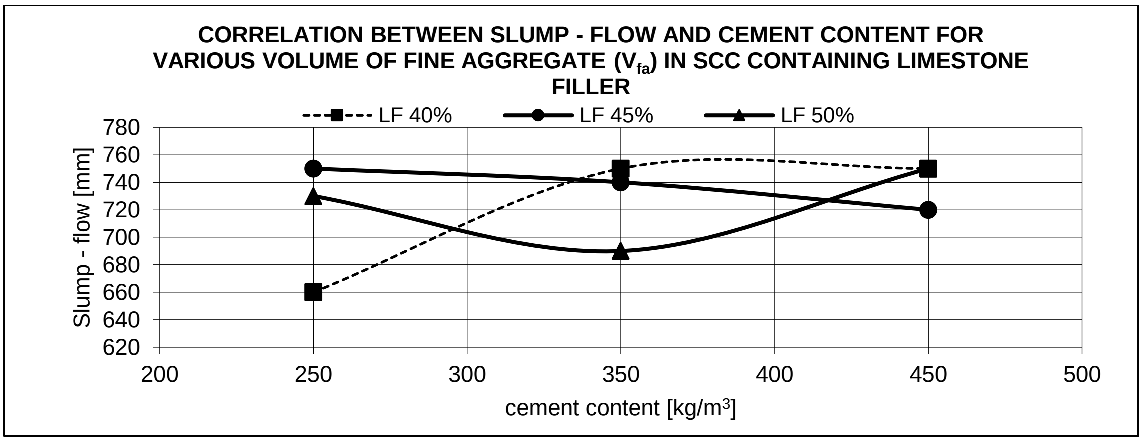

Diagram 2 – Correlation between slump – flow and cement content for various volume of fine aggregate (V_{fa}) in SCC containing limestone filler

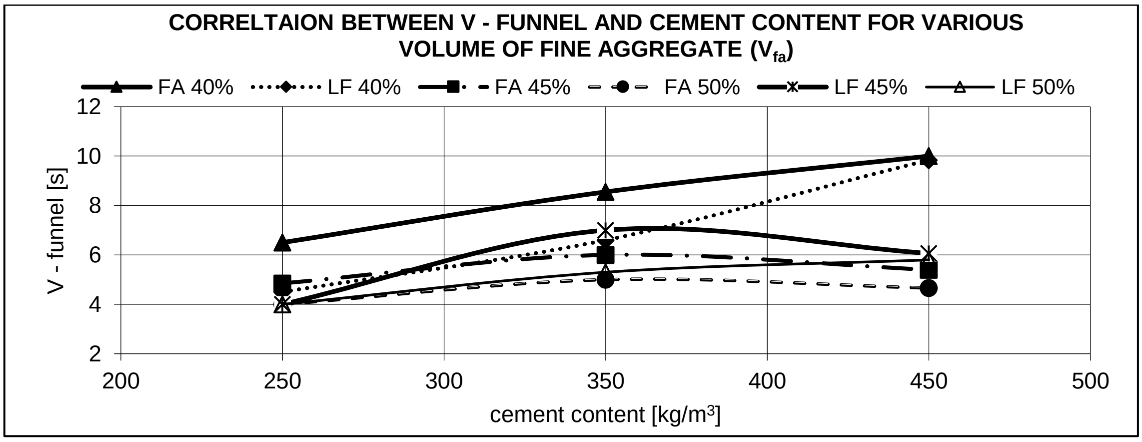

Diagram 3 – Correlation between V – funnel and cement content for various volume of fine aggregate (V_{fa})

From the illustration on Diagram 3 we can conclude that reduction in cement content decreases the V – funnel time, regardless of whether limestone filler or fly ash are used as mineral additive. This indicates that mineral additives (limestone filler and fly ash) improve the viscosity of SCC. [13]

Diagram 4 shows that higher volume of fine aggregate decreases the viscosity of SCC, regardless the type of mineral additive. The shortest time on V – funnel or the lowest viscosity of SCC is at 50 % volume of fine aggregate, which indicates that higher volume of fine aggregate decreases viscosity of SCC. [13]

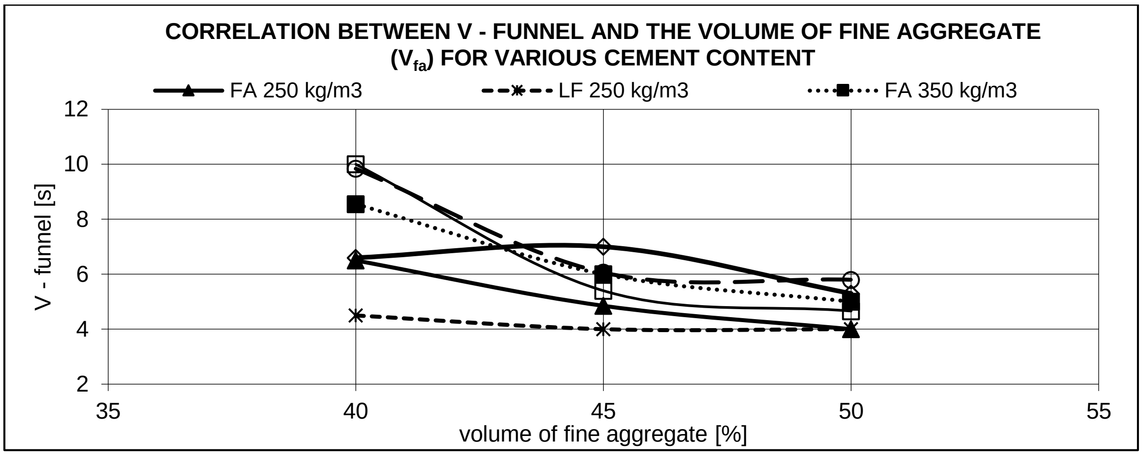

Diagram 4 – Correlation between V – funnel and the volume of fine aggregate (V_{fa}) for various cement content

From Diagram 5 can be concluded that the increase in V – funnel time decreases the value of L box. This indicates that increasing the viscosity of SCC leads to decreasing the passing ability. [13]

Diagram 6 shows the segregation resistance of SCC from the amount of fly ash or limestone filler. The increase in amount of fly ash or limestone filler leads to better segregation resistance. Both used mineral additives keep the percentage of segregation under 15 %, which conforms to class SR2. [13]

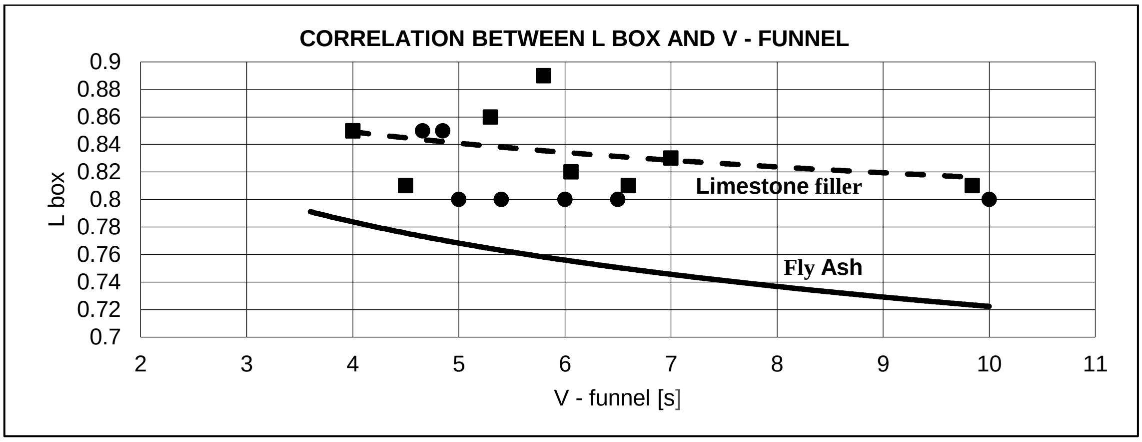

Diagram 5 – Correlation between L box and V – funnel

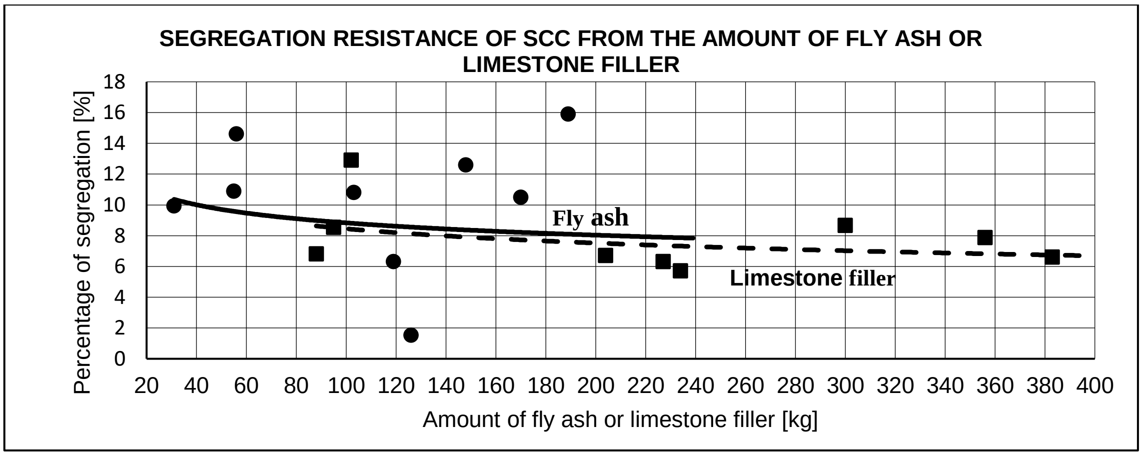

Diagram 6 – Segregation resistance of SCC from the amount of fly ash or limestone filler

6. CONCLUSION

Based on the conducted research and obtained results for the key characteristics of self–compacting concrete (SCC) in fresh state, where fly ash and limestone filler were used as mineral additives, the following conclusions can be drawn:

- In general, fly ash which belongs to type II (pozzolanic or latent hydraulic) mineral additives, can replace the limestone filler which belongs to type I (inert or semi-inert) mineral additives, in the production on SCC according to a general method based on mineral additives for confirming self – compactability and key characteristics on SCC.
- SCC containing fly ash and SCC containing limestone filler in fresh state meet the requirements for: filling ability, passing ability and segregation resistance, regardless of the cement content and volume of fine aggregate in SCC.
- The same classes of workability were obtained from performed tests for SCC containing fly ash and SCC containing limestone filler, regardless of whether fly ash or limestone filler was used.
- Increase the volume of fine aggregate and reduction in cement content leads to decreasing the V – funnel time (viscosity) for SCC, regardless the used mineral additive (limestone filler or fly ash).
- The higher amount of limestone filler or fly ash in SCC composition increasing segregation resistance.
- Increase in V – funnel time decreases the value of L box. This indicates that increasing the viscosity of SCC leads to decreasing the passing ability.

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