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Development of Self-Compacting Concrete Containing Fly Ash As Minneral Addition

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Abstract: The main topic of this paper is to analyze the properties of self-compacting concrete (SCC) containing fly ash, compared with the properties of self-compacting concrete containing limestone filler. The key characteristics of SCC for confirming self-compactability and compressive strength were subject of investigation. The fly ash is a "cheap" waste that costs less than limestone filler. For the purpose of the experimental study the following fixed parameters are set: cement content and volume of fine aggregate. 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. Requirements for self-compactability are fully met for all tested SCC mixtures. In general, obtained results for workability of concrete are in the same class. The performed tests illustrate that fly ash may replace limestone filler as a mineral addition in SCC.

Key words: self-compacting concrete, fly ash, limestone filler, filling ability, passing ability, segregation resistance

1. Introduction

In this experimental research two different mineral additions are used. Fly ash which belongs to type II (pozzolanic or latent hydraulic mineral additions) and limestone filler which belongs to type I (inert or semi-inert mineral additions). 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 usage in concrete composition. Fly ash has pozzolanic activity, produces not only technological and economical benefits, but also operating advantages such as high compressive strength and corrosion resistance [1]. "REK" Bitola produces 1.5 million tons of fly ash annually, which is danger waste for peoples health. Hence, in this paper fly ash with origin from "REK" Bitola was used. 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 has a positive effect on workabillity, compressive strength, durability, sulfate resistance, bleeding, shrinkage, creep, permeability, corrosion activity, carbonation, alkali-silica reaction, modulus of elasticity, reducing the heat of hydration. Also the use of fly ash contributes to reducing required energy and CO_2 emissions during the cement production. In Table 1 granulometric analysis is shown according to EN 933-1 [2], and in Table 2 the particle density according to EN 1097-6 is shown [3].

The parameters for limestone filler are shown in Table 3, granulometric analysis according to EN 933-1, and in Table 4, particle density according to EN 1097-6.

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

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

Table 2 Particle density of fly ash according to EN 1097-6.

Particle density [kg/dm^3]	1.80

Table 3 Granulometric analysis of limestone filler according to EN 933-1.

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

Table 4 Particle density of limestone filler according to EN 1097-6.

Particle density [kg/dm^3]	2.77

All materials used for SCC mixtures were tested in the Central Laboratory Ading (CLA). The following materials were used: fine aggregate (0/4) mm from separation "Goiva" Skopje, crushed limestone aggregate (4/8) mm from quarry "Govrlevo" Skopje, crushed limestone aggregate (8/16) mm from quarry "Govrlevo" Skopje, CEM I 52.5N from cement factory Cementarnica USJE A. D. Skopje–TITAN GROUP, limestone filler (0/0.125) mm from quarry "Brazda"-Granit AD Skopje, fly ash from "REK" Bitola and superplasticizing admixture "Superfluid 21 EKO" from "ADING" AD Skopje. The experimental study included testing of 18-cement pastes, 18-mortars and 18-SCC mixtures.

It is well known that the superplasticizers based on polycarboxylate ether are specially created for SCC as its essential ingredient, and in these experimental testings polycarboxylate superplasticizer "Superfluid 21 EKO" from the product program of ADING AD-Skopje was used. Hence, new generation superplasticizer "Superfluid 21 EKO" will confirm its guaranteed quality for preparation of SCC.

2. Experimental Research

The purpose of this study is to research the impact of fly ash on the properties of SCC, such as key characteristics of SCC for confirming self-compactability and compressive strength. Limestone filler and fly ash were used as mineral additions for necessity of the research. For the purpose of the properties analysis and establishing certain correlations, the following fixed parameters are set: 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 experimental programme consists of three series of SCC mixtures, each serie with different cement content (250 kg/m^3, 350 kg/m^3 and 450 kg/m^3). 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 additions, 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. (40 %, 45 % and 50 %). All tests were performed in accordance with european normatives, such as: EN 12350-8 for slump-flow test [4], EN 12350-9 for V-funnel test [5], EN 12350-10 for L box test [6], EN 12350-11 for sieve segregation test [7], EN 12390-3 [8] for determining compressive strength and EN 12390-7 [9] for determining density of hardened concrete. 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 [10], while in some SCC mixtures part of these recommendations were outside the recommended limits.

3. Cement Pastes

Parameter βp, as known as "zero flow" is the state before the mortar starts to flow. The first step in designing a SCC mixture is to determine the parameter βp. For this task 18 – cement pastes are tested, divided equally with different mineral additions, in this case fly ash or limestone filler. Volume proportion of cement/mineral additions was 70/30, 50/50 and 30/70.

In Fig. 1 are shown results from cement pastes with limestone filler. It is obvious that higher cement percentage leads to higher value of "zero flow" (βp). The highest value of βp = 1.0847 is for V_c/V_F = 70/30, then for V_c/V_F = 50/50, βp = 1.0171, and the smallest value of βp = 0.9744 is for volume proportion V_c/V_F = 30/70. The conclusion is that higher amount of limestone filler reduces the water demand for SCC [11].

Fig. 2 illustrates the results obtained from cement pastes with fly ash. In this case, as for cement pastes with limestone filler, a higher percentage of cement gives higher value of "zero flow" (βp). The highest value of βp = 1.1997 is for V_c/V_{FA} = 70/30, and the smallest value of βp = 1.1484 is for V_c/V_{FA} = 30/70. For the proportion V_c/V_{FA} = 50/50 the value of βp = 1.1653 was obtained. If we compare the parameter βp for cement pastes with limestone filler and cement pastes with fly ash, we can conclude that cement pastes with fly ash have higher value of βp for all volume proportions. This indicates that SCC containing fly ash will have a higher water demand [11].

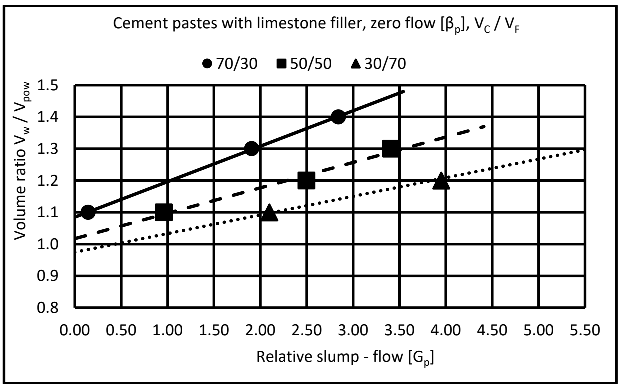

Fig. 1 Cement pastes with limestone filler.

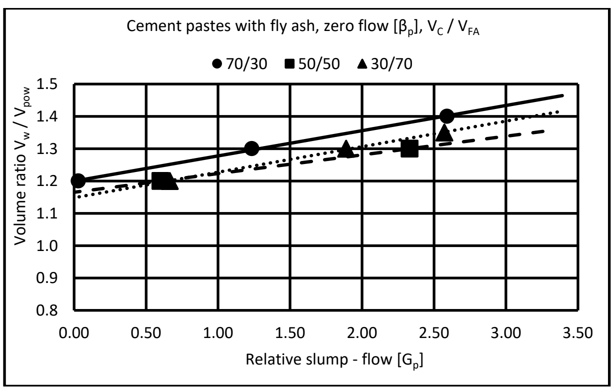

Fig. 2 Cement pastes with fly ash.

4. Mortars

The second step in the designing of SCC mixture is to determine the parameter βm = $V_W/V_{pow.}$ Through mortar testing βm is determined, in order to obtain optimal water/powder ratio and dosage of superplasticizing admixture. Tests with flow cone and V-funnel for mortar are performed at varying water/powder ratios in the range [0.8-0.9] βp and dosages of superplasticizer. Target values are slump-flow of 240 mm to 260 mm and V-funnel time of 7 s to 11 s [12]. And there, as for cement pastes, 18-mortars are tested, 9-mortars containing fly ash and 9-mortars containing limestone filler as mineral addition. The volume proportions of cement/mineral additve are same as for cement pastes. It was found that the relationship between the flowability of mortar and concrete cannot always be unique due to differences in the characteristics of the solid paricles in the mortar, even if the characteristics of the coarse aggregate and its content in concrete are constant [13].

Fig. 3 illustrates the correlation between slump-flow value of mortar and cement content for 40 % volume of fine aggregate. Mortars with fly ash have better value of slump-flow regardless of cement content. It is typical for both mortars with different mineral additions that for the range of cement content (250÷350) kg/m^3 the flow of mortar decreases, but for the range of cement content (350÷450) kg/m^3 the flow of mortar increases [11].

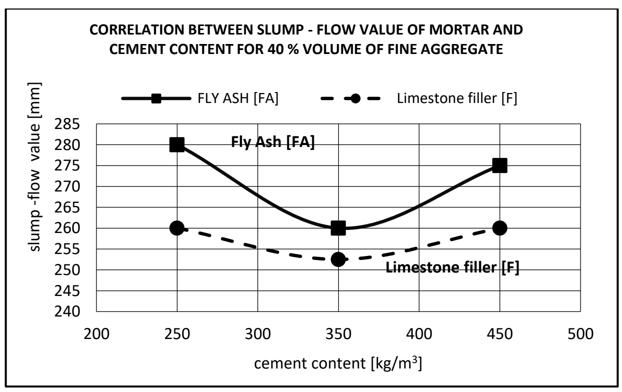

Fig. 3 Correlation between slump-flow value of mortar and cement content for 40 % volume of fine aggregate.

Fig. 4 shows the correlation between slump-flow value of mortar and cement content for 45 % volume of fine aggregate. Mortars with fly ash have a higher value of slump-flow than mortars with limestone filler. For both types of mortars the increase in cement content leads to increase the flow of mortar [11].

Correlation between slump-flow value of mortar and cement content for 50% volume of fine aggregate is illustrated on Fig. 5. In this case the mortars with limestone filler have better flow of mortar than mortars with fly ash, regardless of cement content. Both mortars with different mineral additions have the simillar diagram lines from obtained results. For the range of cement content (250÷350) kg/m^3 the flow of mortar increases, but for the range of cement content (350÷450) kg/m^3 the flow of mortar decreases [11].

5. SCC Mixtures

In this paper 18-SCC mixtures were tested, 9-SCC mixtures containing fly ash and 9-SCC mixtures containing limestone filler as a mineral addition. The main challenge was to determine whether fly ash could replace the limestone filler in SCC composition, by fulfilling the key characteristics of SCC. Also, subject of comparison was the compressive strength**.** Limestone filler is an inert mineral addition that has no effect on the development of compressive strength. Fly ash is a pozzolanic mineral addition that has pozzolanic properties, which increases the compressive strength up to 90 days.

Pozzolans such as fly ash, silica fume, and slag cement are used extensively in conventional concrete to economize mixtures, lower the heat of hydration for mass concrete, reduce chloride permeability, and inhibit alkali-silica reactivity, among other things. In recent years, they have been used to enhance the sustainability and reduce the carbon footprint of concrete by reducing the Portland cement content per cubic meter. These materials can be and are used in SCC for the same purposes [14].

5.1 Key Characteristics

Fig. 6 shows the correlation between slump-flow and cement content for various volume of fine aggregate 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 [11].

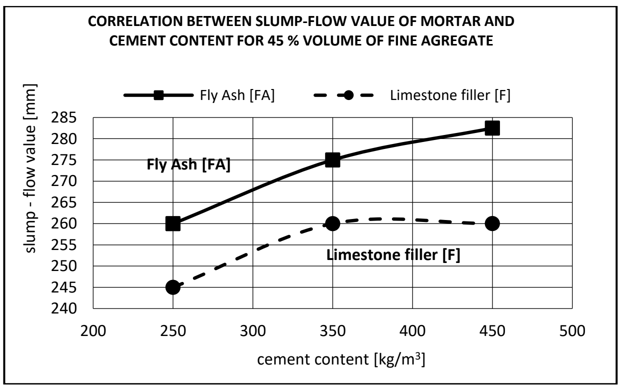

Fig. 4 Correlation between slump-flow value of mortar and cement content for 45% volume of fine aggregate.

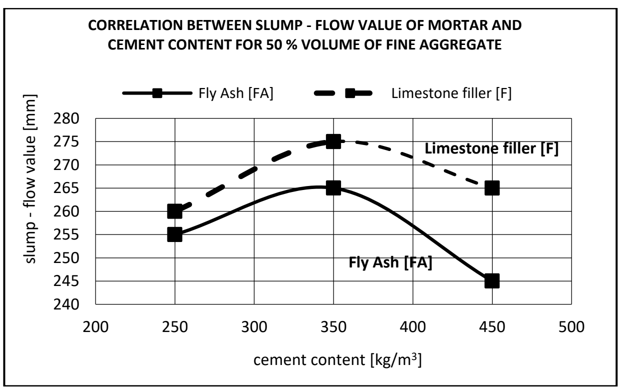

Fig. 5 Correlation between slump-flow value of mortar and cement content for 50 % volume of fine aggregate.

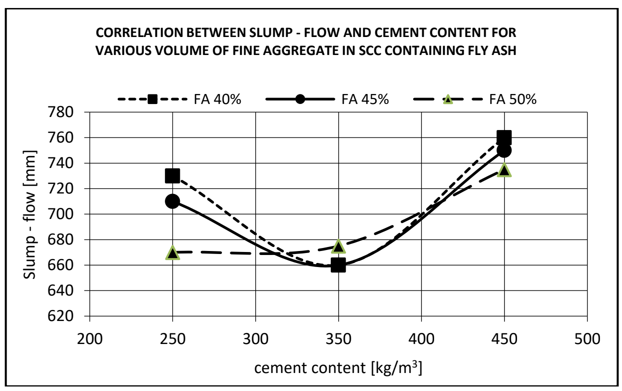

Fig. 6 Correlation between slump-flow and cement for various volume of fine aggregate in SCC containing fly ash.

Fig. 7 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 [11].

From the illustration on Fig. 8 we can conclude that reduction in cement content decreases the V-funnel time, regardless of whether limestone filler or fly ash is used as mineral addition. This indicates that mineral additions (limestone filler and fly ash) improve the viscosity of SCC [11].

Fig. 9 shows that higher volume of fine aggregate decreases the viscosity of SCC, regardless the type of mineral addition. 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 [11].

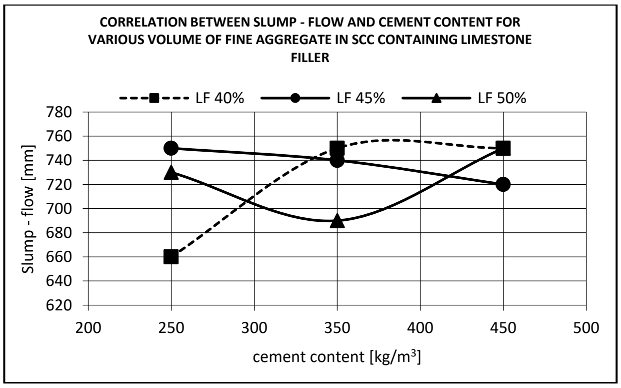

Fig. 7 Correlation between slump-flow and cement for various volume of fine aggregate in SCC containing limestone filler.

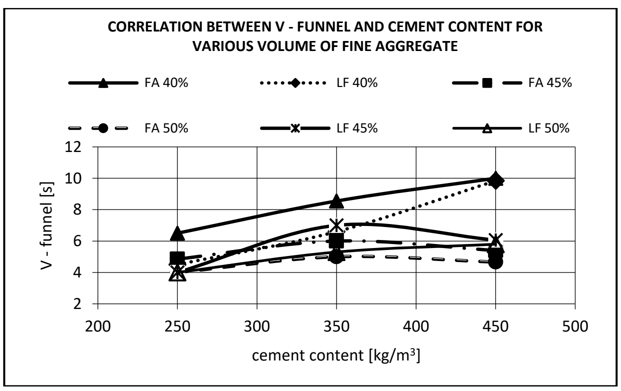

Fig. 8 Correlation between V-funnel and cement content for various volume of fine aggregate.

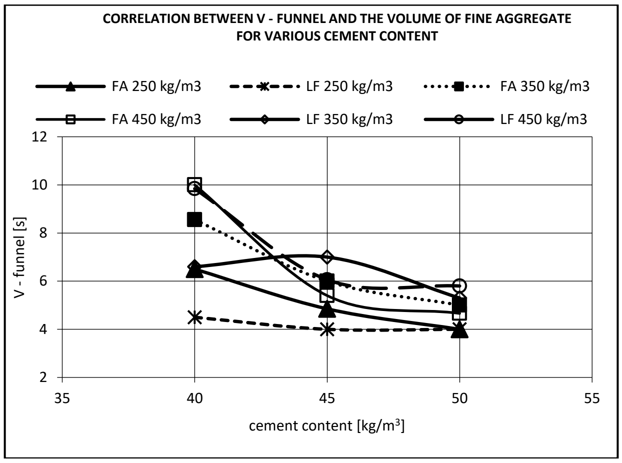

Fig. 9 Correlation between V-funnel and the volume of fine aggregate for various cement content.

Fig. 10 shows 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 [11].

Fig. 11 shows the correlation between 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 additions keep the percentage of segregation under 15%, which conforms to class SR2 [11].

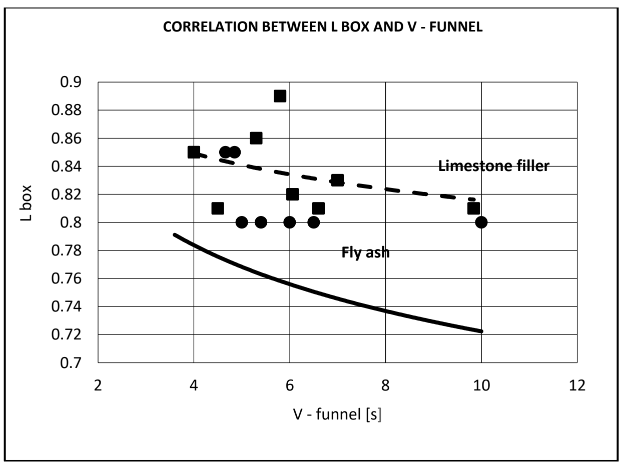

Fig. 10 Correlation between L box and V-funnel.

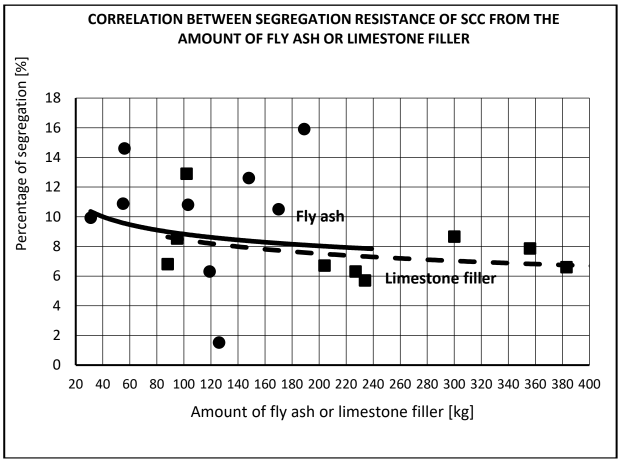

Fig. 11 Correlation between segregation resistance of SCC from the amount of fly ash or limestone filler.

5.2 Compressive Strength

Fig. 12 illustrates the correlation between compressive strength and volume of fine aggregate for various cement content at achieved compressive strength. SCC containing limestone filler achieved compressive strength at the age of 28 days. As a result of the pozzolanic effect of fly ash, SCC containing fly ash achieved compressive strength at the age of 90 days. Compressive strength at the age of 90 days for SCC containing fly ash is similar or higher than compressive strength at the age of 28 days for SCC containing limestone filler [11].

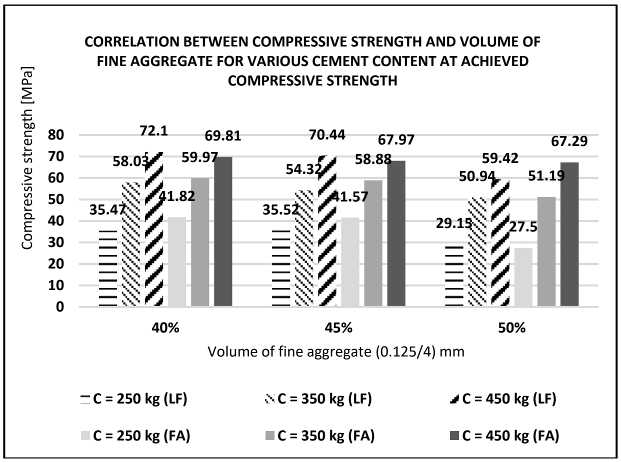

Fig. 12 Correlation between compressive strength and volume of fine aggregate for various cement content at achieved compressive strength.

6. Conclusion

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

- At cement paste tests when determining the parameter β_p as known as “zero flow” for various V_W/V_{pow} correlations, the cement paste containing fly ash has a 14.2% higher water demand than cement paste containing limestone filler.
- The obtained results for slump-flow value of mortars, indicate that mortars containing fly ash with 40% and 45% volume of fine aggregate, don't meet the requirement of EFNARC regardless of cement content. The mortars containing limestone filler and same volume of fine aggregate meet the requirements of EFNARC. At 50% volume of fine aggregate mortar containing fly ash meet the requirement of EFNARC regardless of cement content, while mortar containing limestone filler don’t meet this requirement. This shows that if we use fly ash, the volume of fine aggregate should be higher, but if we use limestone filler, the volume of fine aggregate should be smaller, regardless of cement content.
- In general, fly ash which belongs to type II (pozzolanic or latent hydraulic) mineral additions, can replace the limestone filler which belongts to type I (inert or semi-inert) mineral additions, in the production on SCC according to a general method based on mineral additions 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.
- Increasing the volume of fine aggregate and reducing in cement content leads to decreasing the V-funnel time (viscosity) for SCC, regardless of the used mineral addition (limestone filler or fly ash).
- The higher amount of limestone filler or fly ash in SCC composition increases segregation resistance.
- Increasing in V-funnel time decreases the value of L box. This indicates that increasing the viscosity of SCC leads to decreasing the passing ability.
- SCC containing fly ash has a similar or higher compressive strength at the age of 90 days, compared with SCC containing limestone filler at the age of 28 days, as a result of pozzolanic effect of fly ash. For cement content of 250 kg/m^3 SCC containing fly ash has higher compressive strength than SCC containing limestone filler in the limits of 17% to 17.9%, but for cement content of 350 kg/m^3 this limit is 0.5% to 8.4%.

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