International Journal of GEOMATE, Feb., 2020, Vol.18, Issue 66, pp. 24-29
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2020.66.9138
Geotechnique, Construction Materials and Environment

EFFECTS OF MINERAL AND CHEMICAL ADMIXTURES ON THE RHEOLOGICAL PROPERTIES OF SELF COMPACTING CONCRETE

* Nolan C. Concha[1] and Melito A. Baccay[2]

[1]Faculty, FEU-Institute of Technology, Philippines; [2]Faculty, Technological University of the Philippines, Philippines

*Corresponding Author, Received:24 June 2019, Revised: 27 Nov. 2019, Accepted: 30 Dec. 2019

ABSTRACT: One of the most significant innovations on the workability of concrete that was achieved in recent years is self-compacting concrete (SCC). This desirable performance can be attained through the addition of admixtures to enhance its properties. In this study, superplasticizers were blended with fly ash and air entraining admixtures and were tested for Slump Flow, V-Funnel, L-Box, U-Box, and Screen Stability tests based on the European Federation of National Associations Representing for Concrete (EFNARC) specifications and guidelines for SSC. Based on the results of the study, Fly ash with spherical smooth texture enhances the lubrication between the concrete particles while the air-entrainer provides microscopic bubbles acting as ball bearings between aggregates. The best result was obtained in the specimens containing 5.0% superplasticizers due to its dispersibility effect and reduced flow resistance. In general, the air entraining agent blended with 3.7% superplasticizer exhibited the best performance in all workability test conducted.

Keywords: Viscosity; Yield stress; Self-compacting concrete; Rheology; Dispersibility

1. INTRODUCTION

The introduction of chemical and mineral admixtures in the fundamental components of self-compacting concrete (SCC) has been used to enhance further the desirable properties of the freshly mixed concrete. SCC is a special concrete mixture exhibiting superior material homogeneity and workability requiring less to no form of external compaction [1]. Even without the aid of a compactor, a concrete would be able to pass through corners of forms through its own mass. Such condition is essential in developing designs of SCC mixture. However, there is a limited number of studies as to this area of concrete technology and thus require further research to completely describe the behaviour of SCC [2]. In the preparation of SCC, the material proportions of the mix are an essential component [3-6]. The compactness of concrete attributed by well distributed aggregates imparts strength to the concrete. The efficiency of the concrete in flowability is affected much by tuning the coarse aggregates spacing that depends on sizes and volume of cement in the mixture.

The rheological performance of SCC is much affected by the proportioning of the material components in the preparation of the mixture [7]. All normal concrete fine aggregates including crushed or rounded either siliceous or calcareous fine aggregates can be used in SCC. In order to develop a self compacting concrete of desirable quality, the moisture content of sand must be carefully checked and must be regarded into account. The volume of sand less than 0.125 mm must be taken as powder and is essential for the consistency of SCC. The small quantity of accumulated powders, resulting from the binders and the used of fine aggregates, must be achieved to avoid segregation with a recommended value of 500-600 kg/m3 [8]. Almost every type of coarse aggregates is appropriate for the production SCC, where the angular coarse aggregates develop the mechanical interlocking performance of the particles resulting to better strength, whilst rounded aggregates enhanced the flowability attributed by the lesser build-up of frictional stresses. The average largest aggregate size is normally 16-20 mm but particle sizes of 40 mm and up have been utilized in SCC. Well-graded aggregates are of vital importance in the production of SCC, while gap graded aggregates may exhibit more internal resistance and provide flow reduction. The volume content of the coarse aggregates usually varies between 50 to 60% of the total volume of solids in concrete [9]. When the amount of coarse aggregates in concrete go beyond the recommended limit (50-60%), the chance between aggregate particle contact or collision develop quickly and may result in higher susceptibility to blockage when the concrete move through gaps between rebars [10]. Mineral admixtures were incorporated as well in the SCC mix to further enhance the desirable properties of concrete. Rice husk ash can improve the resistance to segregation and plastic viscosity of the mixture [11]. The concrete also exhibited chloride ion resistance and drying shrinkage with the addition of ground granulated furnace slag in the design mix [12]. The use of waste marble powder of up to 0.60 in ratio with cement produced better workability and compressive strength in the development of eco-efficient SCC [13].

To investigate the effects of blending admixtures on the rheology of self-compacting concrete, various concrete mixtures with different dosages of admixtures were prepared. The results can be used as baseline information for the identification of the most appropriate proportion for self-compacting concrete, decrease the duration of construction, and minimizes the use of external vibrators.

2. EXPERIMENTAL PROGRAM

The primary objective of this research is to measure the rheological properties of self-consolidating concrete using the EFNARC criteria and examine the influence of added admixture in the concrete mix. All locally available concrete materials were tested to meet the structural standards established by the American Society for Testing and Materials (ASTM). In order to meet the requirements for SCC, superplasticizer was added to the concrete mix in gradual amounts. Adjustments as recommended by the EFNARC trouble shooting guide was carried out correspondingly to develop the desired SCC mix. The workability performance of the freshly mixed concrete having 3.7 % and 5.0% superplasticizers blended binary with Fly ash, Retarding, and Air-entraining admixtures were tested for V-Funnel, Slump Flow, L-Box, U-Box, and Screen Stability tests. Two SCC proportions with different amounts of superplasticizers was derived using the recommended material design proportions provided by the American Concrete Institute (ACI). These design mixes were used as benchmark proportions to investigate the influence of various admixtures when blended with superplasticizers. Using the general criteria for self-compacting concrete, test specimens with varied admixture dosages were designed and tested in three trials for viscosity and flowability performance. Linear regression analysis was considered in order to develop various linear models describing the correlation of the variation of mineral and chemical admixtures on the workability of concrete.

3. EXPERIMENTAL RESULTS

3.1 Rheological Tests of Blended Superplasticizer and Fly Ash

Typical quantity of fly ash ranging from 15-25% was used to partially replace the cement in the concrete mixture. This amount is found to be sufficient without providing undesirable effects in the mechanical properties of hardened concrete. Various experimental tests were carried out to evaluate the performance of the samples in passing, filling, and resistance to segregation abilities with the results reflected in Table 1. The design proportions in the table contains an increasing volume of fly ash and it is apparent from the measured values that the greater the quantity of this additive in the design proportion, the better will be the filling ability of the resulting SCC mix. Fig. 1 shows a direct correlation between fly ash volume and the flow spread of freshly mixed concrete. The addition of fly ash in the mixed resulted to better flowability performance of SCC.

Table 1 Test Results of SCC with Blended Fly Ash

Fly Ash (kg/m^3)	FILLING ABILITY				PASSING ABILITY				SEGREGATION RESISTANCE	
	Slump Flow (550-850 mm)		V-Funnel (0-8 sec)		L-Box (0.8-1.0)		U-Box (0-30mm)		Screen Stability (0-15%)	
	SCC1	SCC2	SCC1	SCC2	SCC1	SCC2	SCC1	SCC2	SCC1	SCC2
20.20	561	591	6.25	6.08	0.81	0.90	27.0	21.5	12.11	13.47
24.24	577	608	6.15	6.01	0.81	0.91	27.0	19.5	12.65	13.11
28.28	569	615	6.15	6.05	0.83	0.94	27.5	19.0	12.33	14.00
32.32	583	611	5.92	5.54	0.84	0.91	27.0	21.0	12.73	13.94
36.36	579	619	5.83	5.21	0.85	0.93	26.0	20.0	13.00	14.02
40.40	589	622	5.58	4.89	0.83	0.93	26.0	20.0	12.95	15.31
44.44	596	629	5.41	5.13	0.85	0.92	26.0	20.5	13.44	14.88
48.48	600	623	5.38	4.56	0.88	0.93	25.5	19.0	13.63	15.22
52.52	598	638	5.44	4.78	0.89	0.93	25.0	19.5	13.94	16.35
56.56	612	631	5.39	4.45	0.89	0.95	23.5	18.5	13.79	15.93
60.60	620	645	5.33	4.33	0.91	0.94	22.5	18.0	13.86	16.12

Legend: ■ - Passed ■ - Failed

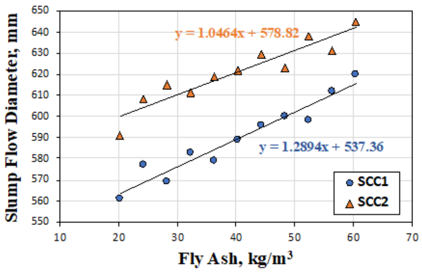

Fig. 1 Fly Ash vs Slump Flow

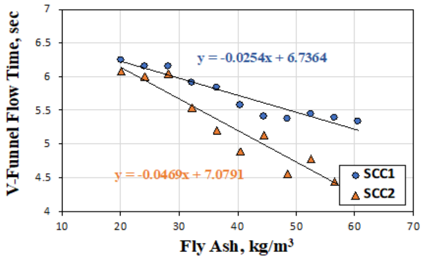

Fig. 2 Fly Ash vs V-Funnel

All samples satisfactorily met the minimum standard flow of 550 mm with SCC2 having the highest amount of fly ash registered the highest flow diameter. This observation is being justified by the time-based parameter considering a decrease in time of the concrete to move in the V-Funnel test. It is also evident and important to note that under the V-Funnel test, each SCC proportion consistently provides a declining flow time values having a strong correlation coefficient as shown in fig. 2. The dominating rounded structure of the particles of fly ash associated with mainly glassy texture and composition of its surface as shown in fig. 3 has significantly affected the flow time values of the concrete containing fly ash. Fly ash in rounded and particulate geometry can enhance flowability by its ball bearing effect between aggregate particles [14]. The increased ball bearing effect of the particle imparts better lubrication and reduces the cohesion between particles allowing it to flow freely and provides lesser recorded time.

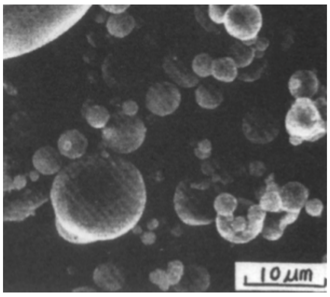

Fig. 3 Fly Ash under Scanning Electron Micrograph [14]

Ouchi et al. [15] had established the correlation between the flowing ability of fresh concrete and the amount of superplasticizer. It has been reported that the ratio of flow diameter and V-Funnel flow time could be an index of dispersibility of the concrete components. The dispersibility values of the samples tested increases with the amount of fly ash introduced in the mix with a remarkable correlation coefficient.

The particulate form of the fly ash has glassy texture and are charged negatively. With this, it has lesser capacity in absorption relative to the particles of Portland cement. The quantity of adsorbed superplasticizer in the cement mixed with fly ash varies largely on the substituted fraction of the Portland cement with fly ash [16]. Superplasticizers tend to increase the dispersing effect between solid particles and since fly ash is weak to adsorb it, the adsorption effect has been given to the cement particles allowing a higher dispersibility. Fly ash can also reduce the water requirement of the mortar mixtures since porous particles can be attributed to the absorption of water. This property has a substantial effect on the behavior of the fresh concrete.

The coarse aggregates sizes were limited to a maximum of 20 mm in diameter to improve the passing ability of the mixture. Each passing ability test showed impressive results indicating a well-achieved self-compacting concrete proportion. Fig. 4 shows the behavior of the design mixes in relation with L-box and U-box tests and both regression lines demonstrate a consistent concrete behaviour in the two sample groups. As the distance between the particles decreases, the potential for blocking increases due to the particle collisions and internal stresses. The presence of excess water developed in the mixture due to the amount of fly ash and the considerable powder content maintained sufficient gap between aggregates thereby reducing interparticle interaction and build up. The aggregates in the samples having the least amount of fly ash developed a less spaced particle that is highly susceptible to collision, thus obtaining the most undesirable values.

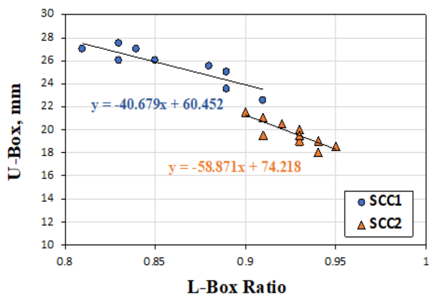

Fig. 4 L-Box vs U-Box

The viscosity of concrete dictates its segregation resistance and the more viscous the resulting mixture, the lesser will be the likelihood of its components to segregate. Fig. 5 shows a picture of the behavior of the mixture when tested using the screen stability. The given data evidently established correlation between the values obtained and the quantity of fly ash blended in the concrete. Most of the calculated percentages in the mixtures indicates a susceptible chance to material segregation. Consistency is essentially related on the thickness and cohesiveness of the mixture of concrete. These properties can be enhanced by lessening the excess amount water and increasing the volume of cement. The SCC samples having the greatest amount of fly ash excessively increased the free water content and reduced cohesiveness of the mixture.

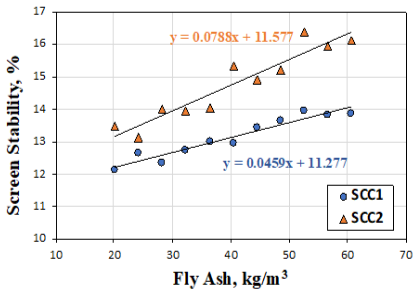

Fig. 5 Fly Ash vs Screen Stability

3.2 Rheological Tests of Blended Superplasticizer and Air Entraining Admixtures

This section discusses the final set of SCC designed samples with the addition of varying amounts of air entraining admixtures. Similar proportions of concrete components and superplasticizer were prepared and tested for filling ability, passing ability, and segregation resistance requirements as shown in table 2. The mixture in each SCC design contains an increasing amount of air entraining admixture. In the slump flow test, the spread of the concrete in each sample satisfactorily met the acceptance criteria and this shows that the blending promotes better and smooth horizontal free flow of the mixture. As observed in the table, the increasing amount of air entrainer corresponds to a better slump flow result and is consistently exhibited in the two SSC design groups as shown in fig. 6. Stabilizing the air void system in the fresh concrete would permit relatively free motion of fresh concrete in shear. The drastic change in the air bubbles as contributed by the increase in the air-entraining dosage resulted to a desirable effect on the flow efficiency of SCC. The entrained air also increases the paste volume and tends to increase the distances between solid particles. This in turn reduced the interparticle friction and interaction allowing the fresh concrete to flow easily in the slump flow test.

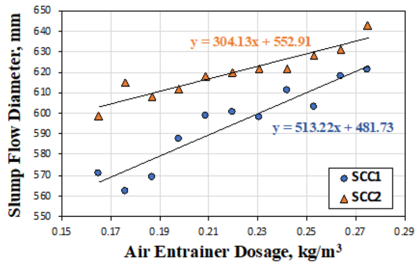

Fig. 6 Air Entrainer vs. Slump Flow

With the low results in the recorded data of the time-based V-Funnel test, the samples displayed better fluidity and efficient flow ability. Fig. 7 shows the declining flow time with the increasing dosage of air entrainer. This implies that the fresh concrete was able to flow easily due to low flow resistance and minimal frictional stresses developed between concrete particles.

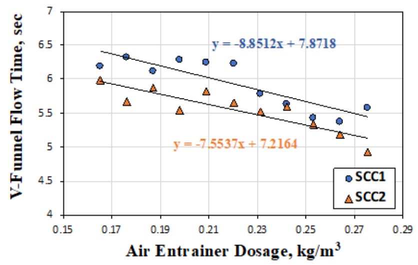

Fig. 7 Air Entrainer vs V-Funnel

The entrained bubbles in the mixture considerably modified the flow characteristics of the mixture yielding a well-performed SCC. It can be seen in fig. 8 the relationship between the increased dosage of the admixture and the dispersibility of the mixture. The addition of superplasticizers in the mixture as well imparts dispersion effect in the particles creating a significant dispersibility results. The entrained bubbles allowed deformation under compression and slippages of neighboring particles offering smooth translation of the concrete particles.

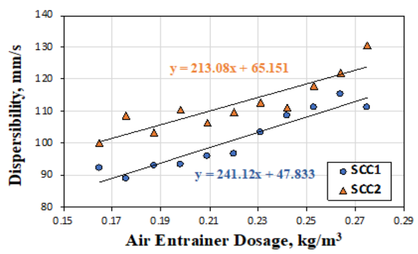

Fig. 8 Air Entrainer vs. Dispersibility

Table 2 Test Results of SCC with Air Entraining Admixture

Air Entrainer (kg/m^3)	FILLING ABILITY				PASSING ABILITY				SEGREGATION RESISTANCE	
	Slump Flow (550-850 mm)		V-Funnel (0-8 sec)		L-Box (0.8-1.0)		U-Box (0-30mm)		Screen Stability (0-15%)	
	SCC1	SCC2	SCC1	SCC2	SCC1	SCC2	SCC1	SCC2	SCC1	SCC2
0.165	571	599	6.19	5.99	0.71	0.78	28.50	24.50	10.56	13.32
0.176	562	615	6.33	5.67	0.74	0.84	27.00	22.50	11.88	13.56
0.187	569	608	6.11	5.88	0.80	0.71	23.00	27.50	11.72	13.12
0.198	588	612	6.29	5.54	0.79	0.87	24.00	22.50	12.12	14.00
0.209	599	618	6.24	5.81	0.83	0.90	22.44	20.00	12.45	14.19
0.220	601	620	6.22	5.66	0.83	0.90	21.50	21.50	12.47	14.33
0.231	598	622	5.78	5.53	0.85	0.89	22.50	22.00	12.63	14.55
0.242	611	622	5.63	5.59	0.83	0.93	21.00	18.50	13.33	14.22
0.253	603	628	5.43	5.33	0.87	0.88	22.50	20.50	13.71	14.67
0.264	618	631	5.37	5.18	0.87	0.92	19.00	19.50	13.12	14.51
0.275	621	643	5.58	4.92	0.89	0.94	20.50	20.00	13.75	14.73

Legend: ■ - Passed ■ - Failed

When the entrained air content is increased, the effect of further increased in the electrostatic attraction between the cement and other small particles was counteracted by greater reduction in the mechanical interlocking due to the lubricating effect of the bubbles. The group of samples was also tested for passing ability requirements. According to Chia [1] entrained air bubbles were able to perform effectively as deformable and elastic ball bearings, reducing internal friction in the fresh concrete. It can be seen that the samples having the highest amount of air entrainer registered the best results among the samples. The augmented ball bearing behavior of the bubbles imparts better lubrication and reduces the friction between particles allowing it to flow freely and pass over the apparatus. The impressive ability of the concrete to flow over complex forms is described by the results in the L-box and U-box tests depicted in Fig. 9. Again, the lubrication and minimal development of friction due to the ball bearing behaviour of the entrained bubbles enable the freshly mixed concrete to flow and pass successfully over the L-Box and U-Box apparatus.

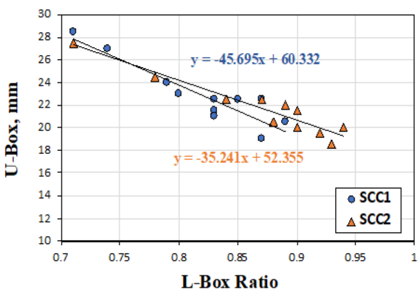

Fig. 9 L-Box vs. U-Box

Fig. 10 presents the increasing values in the screen stability test with the amount of air entrainers mixed in the concrete. This has been regularly observed in each SCC design groups. It can be noted that a less stable distribution in the composition of concrete was provided by the corresponding increase in the dosage of the admixture. Among the design proportions prepared, SCC2 having the most amount of air entrainer showed possible chance to segregation.

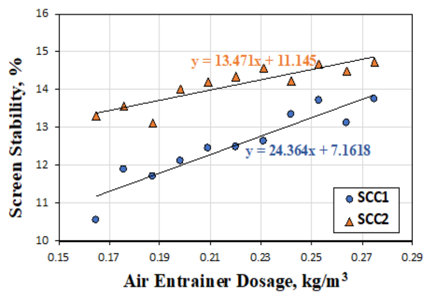

Fig. 10 Air Entrainer vs Screen Stability

4. CONCLUSIONS

The blending of fly ash and superplasticizer showed a remarkable performance in the filling ability and passing ability of the self-compacting concrete. This is due to the roller bearing effect of the smooth spherical surface of the fly ash. Most of the tests conducted for these workability parameters were fulfilled, hence, establishing a concrete with high flowability. Consequently, the blending significantly reduced the viscosity of the mixture producing a concrete that is susceptible to segregation. It is advisable to blend these two admixtures at their minimum recommended amounts to maintain the overall workability performance of SCC.

To produce SCC having a uniform material distribution, one of the two admixtures is sufficient for the purpose. With the increasing amount of air entrainer in the production of self-compacting concrete, the design mixes performed efficiently in the three workability parameters. The blending of air entraining admixture and superplasticizer significantly enhanced the ability of the concrete in passing, filling and resistance to segregation. The blending should be done such that the proportions of each admixture fall within the middle range of the recommended dosage.

6. REFERENCES

[1] Seng CK. Workability and stability of lightweight aggregate concrete from rheology perspective (Doctoral dissertation).

[2] Ozawa K. Evaluation of self-compactability of fresh concrete using the funnel test. InProceedings of Japan society of Civil Engineers 1995 (Vol. 25, pp. 59-75).

[3] Shi C, Wu Z, Lv K, and Wu L. A review on mixture design methods for self-compacting concrete. Construction and Building Materials. 2015 Jun 1;84:387-98.

[4] Concha N and Oreta AW. A model for time-to-cracking of concrete due to chloride induced corrosion using artificial neural network. InIOP Conference Series: Materials Science and Engineering 2018 Oct (Vol. 431, No. 7, p. 072009). IOP Publishing.

[5] Concha NC and Oreta AW. Bond Strength Prediction Model of Corroded Reinforcement in Concrete Using Neural Network. International Journal Of Geomate. 2019 Feb 1;16(54):55-61.

[6] Concha N and Oreta AW. A model for time-to-cracking of concrete due to chloride induced corrosion using artificial neural network. InIOP Conference Series: Materials Science and Engineering 2018 Oct (Vol. 431, No. 7, p. 072009). IOP Publishing.

[7] Le HT, Müller M, Siewert K, and Ludwig HM. The mix design for self-compacting high performance concrete containing various mineral admixtures. Materials & Design. 2015 May 5;72:51-62.

[8] Poppe AM and De Schutter G. Influence of the Nature and the Grading Curve of the Powder on the Rheology of Self-Compacting Concrete. Special Publication. 2001 Jun 1;200:399-414.

[9] Santamaría A, Orbe A, Losañez MM, Skaf M, Ortega-Lopez V, and González JJ. Self-compacting concrete incorporating electric arc-furnace steelmaking slag as aggregate. Materials & Design. 2017 Feb 5;115:179-93.

[10] Saak AW, Jennings HM, and Shah SP. New methodology for designing self-compacting concrete. Materials Journal. 2001 Nov 1;98(6):429-39.

[11] Le HT and Ludwig HM. Effect of rice husk ash and other mineral admixtures on properties of self-compacting high performance concrete. Materials & Design. 2016 Jan 5;89:156-66.

[12] Zhao H, Sun W, Wu X and Gao B. The properties of the self-compacting concrete with fly ash and ground granulated blast furnace slag mineral admixtures. Journal of Cleaner Production. 2015 May 15;95:66-74.

[13] Alyamac KE, Ghafari E, and Ince R. Development of eco-efficient self-compacting concrete with waste marble powder using the response surface method. Journal of cleaner production. 2017 Feb 15;144:192-202.

[14] Nawa T. State-of-the-art report on materials and design of self-compacting concrete. InProc. of the International Workshop on Self-Compacting Concrete 1999 (pp. 160-190).

[15] Ouchi CW. Flowability of fresh mortar in self-compacting concrete using fly ash. InPRO 42: 1st International RILEM Symposium on Design, Performance and Use of Self-Consolidating Concrete-SCC'2005, China 2005 (Vol. 42, p. 261). RILEM Publications.