CSCE Annual Conference
Growing with youth – Croître avec les jeunes

Laval (Greater Montreal)
June 12 - 15, 2019

SEGREGATION RESISTANCE OF SELF-CONSOLIDATING CONCRETE INCORPORATING PALM OIL FUEL ASH

Md. A. Salam[1], Md. Safiuddin[2,3,5*] and Mohd Z. Jumaat[4]
[1] Department of Civil Engineering, Dhaka University of Engineering and Technology, Gazipur-1700, Dhaka, Bangladesh
[2] Angelo DelZotto School of Construction Management, George Brown College, 146 Kendal Avenue, Toronto, ON M5T 2T9, Canada
[3] Department of Civil Engineering, Ryerson University, 350 Victoria Street, Toronto, ON M5B 2K3, Canada
[4] Department of Civil Engineering, University of Malaya, Kuala Lumpur 50603, Malaysia
[5] msafiuddin@georgebrown.ca; safiq@yahoo.com

Abstract: This study presents the segregation resistance of SCC incorporating palm oil fuel ash (POFA). Twenty SCC mixtures were produced based on the water/binder (W/B) ratios of 0.25-0.40 and incorporating 0-30% POFA by weight of cement. The segregation resistance of the SCC mixtures was examined by sieve and column segregation tests with respect to segregation index and segregation factor, respectively. In both tests, the effects of W/B ratio and POFA content on the segregation resistance of SCC were observed. Test results revealed that the segregation index varied from 9% to 18.9%. The lowest segregation index was obtained for the SCC produced with 0.40 W/B ratio and 0% POFA content and the highest segregation index was achieved for the SCC prepared with 0.25 W/B ratio and 30% POFA content. Furthermore, the segregation factor varied from 8% to 21.8%. The lowest segregation factor was found for the SCC mixture produced with 0.35 W/B ratio and 0% POFA content whereas the highest segregation factor was achieved for the SCC mixture prepared with 0.25 W/B ratio and 30% POFA content. Higher segregation index and segregation factor indicate a lower segregation resistance for SCC. The recommended maximum limit for segregation index is 18% and the acceptable maximum limit of segregation factor is 20%. The overall test results showed that W/B ratio and POFA content significantly affect the segregation resistance of SCC. However, all concretes of this study passed the requirements of segregation resistance, except the concrete mixture produced with 0.25 W/B ratio and 30% POFA content.

1 INTRODUCTION

Self-consolidating concrete (SCC) is a special concrete that can flow easily through congested reinforcement to fill all spaces in the formwork, and gets consolidated without any aid of vibration (Khayat 1999). If designed properly, it possesses superior filling ability into concrete formwork, excellent passing ability through reinforcing bars, and good segregation resistance during and after placement.

SCC becomes more prone to segregation because of its highly fluid nature, unless it is designed adequately to get a cohesive concrete mixture. Different forms of segregation such as bleeding, mortar halo, and coarse aggregate settlement may occur in SCC (EFNARC 2002). The segregation resistance of

SCC is influenced by the volume concentrations of cementing materials and coarse aggregates (Safiuddin 2008). The water/binder (W/B) ratio of SCC might be decreased to get higher binder content as well as lower aggregate content. In addition, high-range water reducer (HRWR) should be added adequately to increase the flowing ability (filling ability and passing ability) of SCC. In fact, W/B ratio and HRWR make it possible to produce SCC with the desired filing ability, passing ability, and segregation resistance. However, excessive HRWR dosage and high W/B ratio may reduce the cohesiveness of concrete, thus leading to segregation of concrete. Therefore, the balanced use of W/B ratio and HRWR dosage is required to enhance the flowing ability of SCC without a substantial reduction in cohesiveness (Khayat 1999). Viscosity modifying admixture (VMA) can be used to improve the segregation resistance of SCC (Okamura and Ozawa 1994). On the other hand, the use of one or more suitable supplementary cementing materials (SCMs) may be an option to produce SCC with good flowing ability and adequate segregation resistance. Certain SCMs can decrease bleeding and enhance the segregation resistance of SCC (Safiuddin 2008, Safiuddin et al. 2009). It has been observed that SCMs are often used in concrete mixtures to reduce cement content, improve flowing ability and segregation resistance, increase strength, and to enhance durability through hydraulic or pozzolanic activity (CAN/CSA A3001 2003, Siddique and Khan 2011, Safiuddin 2008, Safiuddin et al. 2009).

SCMs are categorized as natural and industrial by-product materials based on the sources (Safiuddin 2008). In addition, some SCMs can be obtained from agro-industrial wastes such as rice husk ash and palm oil fuel ash (POFA). Several SCMs (fly ash, silica fume, ground granulated blast-furnace slag, rice husk ash, etc.) obtained from industrial and agriculture sources have already been used to produce SCC (Cyr and Mouret 2003, Kim et al. 1997, Okamura and Ozawa 1995, Safiuddin 2008). Likewise, POFA, which is an agro-industrial waste generated in palm oil plants can be used as a suitable SCM to produce SCC with good flowing ability and adequate segregation resistance. POFA is generally dumped in open field near palm-oil mills without profitable return, causing environmental pollution and human health hazard (Sumadi and Hussin 1995, Tonnayopas et al. 2006). Many researchers have recognized that POFA can be used as an SCM to produce various types of concrete including SCC (Safiuddin et al. 2011a, Alsubari et al. 2014, Alsubari et al. 2015, Salam et al. 2015, Ofuyatan et al. 2015, Mohammadhosseini et al. 2015, Ranjbar et al. 2016). However, very few studies have been performed to examine the segregation resistance of SCC including POFA. Alsubari et al. (2015) prepared different SCC mixtures replacing 0%, 10%, 20%, 30%, and 50% of cement by treated POFA and studied several fresh properties such as slump flow, T_{50} spread time, V-funnel flow time, J-ring flow, L-box, and segregation index. Mohammadhosseini et al. (2015) presented the experimental results of some fresh and hardened properties of the SCC mixtures prepared with 30% and 60% POFA at different W/B ratios of 0.4, 0.45 and 0.5. The filling ability, passing ability and segregation resistance of SCC along with strength properties were determined in their study. Ranjbar et al. (2016) produced a number of SCC mixtures by using 10, 15 and 20% POFA by weight as a partial replacement of Portland cement for the W/B ratio of 0.35 and investigated their fresh properties such as slump flow, T_{50} spread time, V-funnel flow time, J-ring flow, L-box flow, and segregation index. The aforementioned three studies determined the segregation resistance of SCC by visual inspection, sieve test, and V-funnel flow test (after 5 min rest). None of these studies used column segregation test to examine the segregation resistance of SCC.

The present study produced various SCC mixtures using 0-30% POFA contents with the W/B ratios of 0.25-0.40 to examine the segregation resistance by sieve and column segregation tests. These two tests are usually used to examine the segregation resistance of SCC. In this study, sieve and column segregation tests were conducted to determine the segregation index and segregation factor of the SCC mixtures, respectively. In both tests, the effects of W/B ratio and POFA content on the segregation resistance of SCC were observed.

2 MATERIALS AND METHODOLOGY

2.1 Materials

Crushed granite stone coarse aggregate (CA) with a nominal maximum size of 19 mm was used in this study. The specific gravity of CA was 2.62, the absorption capacity was 0.55 wt.%, and the oven-dry based bulk density was 1510 kg/m^3. The mining sand with a maximum size of 4.75 mm was used as fine aggregate (FA). Its specific gravity was 2.69, absorption capacity was 1.32 wt.%, fineness modulus was 2.88 and, oven-dry based bulk density was 1700 kg/m^3. Ordinary (ASTM Type I) Portland cement (OPC) was used as the main cementing material. The relative density of OPC was 3.16, the median particle size was 14.6 µm, and the Blaine specific surface area was 351 m^2/kg. POFA was used as an SCM to partially replace OPC. The raw POFA collected from a local palm oil mill was ground in the Los Angeles abrasion machine using steel bars to pass 95% through 45-µm wet sieve. The median particle size, relative density, Blaine specific surface area, and strength activity index of POFA was 9.51 µm, 2.48, 775 m^2/kg, and 105%, respectively. The silica content of ground POFA was 62.3%. Normal tap water (W) was used in preparing the concretes. In addition, a polycarboxylate-based HRWR was used to maintain high flowing ability in the SCC mixtures. The solid content and relative density of HRWR was 30 wt.% and 1.05, respectively.

2.2 Concrete Mixture Proportions

In total, twenty SSC mixtures were produced with different W/B ratios and POFA contents. OPC was substituted with 0%, 10%, 20%, 25% and 30% POFA by weight. The lower W/B ratios of 0.25, 0.30, 0.35, and 0.40 were used to produce various SCC mixtures. The amount of water was selected based on the guideline given in ACI 211.4R-08 (2008) and the amount of cement was calculated based on the selected W/B ratios. The optimum sand/aggregate (S/A) ratio leading to maximum bulk density was 0.50, which was determined by measuring the bulk density of various aggregate blends. The HRWR dosage for an SCC was fixed to obtain high flowing ability with a slump flow higher than 600 mm. The detailed mixture proportions of various SSC mixtures along with their designations are shown in Table 1.

Table 1: Mixture proportions of various SCCs

SCC designation	W/B ratio	CA (kg/m^3)	FA (kg/m^3)	OPC (kg/m^3)	POFA (wt.% of B*)	POFA (kg/m^3)	W (kg/m^3)	HRWR (wt.% of B*)
SCC25P0	0.25	780.0	779.7	705.9	0	0	176.5	1.8
SCC25P10	0.25	772.0	771.4	635.3	10	70.6	176.5	1.845
SCC25P20	0.25	763.0	761.0	564.7	20	141.2	176.5	1.875
SCC25P25	0.25	758.0	757.9	529.4	25	176.5	176.5	2.0
SCC25P30	0.25	754.0	752.1	494.1	30	211.8	176.5	2.1
SCC30P0	0.30	834.0	833.2	588.2	0	0	176.5	1.5
SCC30P10	0.30	827.0	825.6	529.4	10	58.8	176.5	1.575
SCC30P20	0.30	819.0	817.1	470.6	20	117.6	176.5	1.8
SCC30P25	0.30	815.0	813.3	441.2	25	147.1	176.5	1.875
SCC30P30	0.30	811.0	809.9	411.8	30	176.5	176.5	1.925
SCC35P0	0.35	872.0	871.4	504.2	0	0	176.5	1.2
SCC35P10	0.35	867.0	865.3	453.8	10	50.4	176.5	1.225
SCC35P20	0.35	860.0	858.5	403.4	20	100.8	176.5	1.25
SCC35P25	0.35	856.0	855.5	378.2	25	126.1	176.5	1.5
SCC35P30	0.35	853.0	851.9	352.9	30	153.3	176.5	1.575
SCC40P0	0.40	901.0	899.5	441.2	0	0	176.5	1.0
SCC40P10	0.40	895.0	894.9	397.1	10	44.1	176.5	1.05
SCC40P20	0.40	890.0	888.2	352.9	20	88.2	176.5	1.2
SCC40P25	0.40	887.0	885.9	330.9	25	110.3	176.5	1.225
SCC40P30	0.40	884.0	882.1	308.8	30	132.4	176.5	1.4

*OPC+POFA

2.3 Preparation and Testing of Concretes

A revolving pan-type concrete mixer was used to prepare the SCC mixtures. At first, coarse and fine aggregates were charged into the mixer and then mixed with one third of the mix water for 1 min. Thereafter, the mixer was stopped, the binder (OPC alone or with POFA) was added, and the mixing was continued for additional 2 min with another one third of the mix water. Then the mixer was stopped and allowed for a 3 min rest. To minimize the evaporation of water during the rest period, a piece of wet burlap was used to cover the mixer. After the rest period, the final one third of the mix water blended with the HRWR dosage was added and the mixing was continued for further 3 min to produce the fresh SCC mixtures. Immediately after the completion of mixing, the flowing ability of the fresh concretes was examined by determining the slump flow of concrete in accordance with ASTM C 1611/C 1611M-09a (2009). Then the technique depicted in Safiuddin et al. (2009) was followed to conduct the sieve segregation test. A 300 mm diameter sieve along with a pan was used to conduct the sieve segregation test for all SCC mixtures. The concrete sample was poured onto the sieve and left for 5 minutes rest to allow a fraction of the mortar to pass through the sieve. After that, the sieve and pan assembly including the concrete was weighed (Figure 1(a)). The weights of the sieve and pan were subtracted to get the weight of the concrete sample. Then the pan along with the mortar fraction passed was weighed (Figure 1(b)), and the weight of the mortar was determined by subtracting the weight of the pan. Thereafter, the concrete on sieve was washed and the aggregates obtained thereby were made surface-dry by absorbent cloths. The aggregates were weighed and subtracted from the concrete weight to get the amount of mortar contained in the concrete sample.

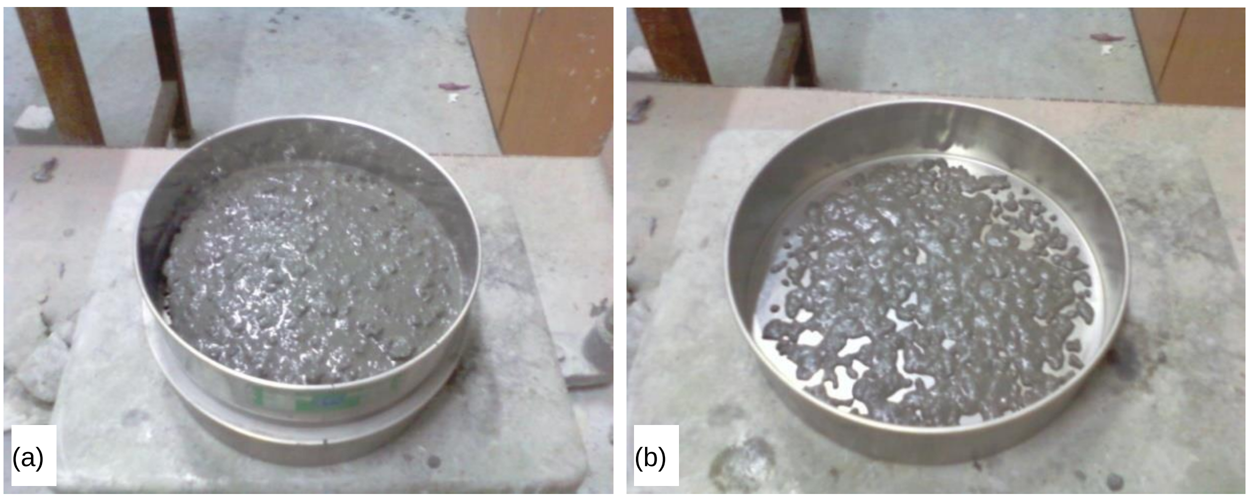

Figure 1: Sieve segregation test

The segregation index (SI) was determined from the sieve segregation test to examine the segregation resistance of SCC mixtures. At first, the amounts of mortar passing the sieve and contained in freshly mixed concrete sample were measured. Then the segregation index for each SCC was computed using the following equation.

$$S_I = \frac{M_p}{M_c} \times 100\% \qquad (1)$$

Where,
S_I = Segregation index (wt.%)
M_p = Weight of the mortar that passed the sieve (kg)
M_c = Weight of the mortar contained in concrete sample (kg)

The column segregation test was performed for all SCC mixtures using the apparatus developed by Safiuddin (2008). A circular steel column of size 150 mm diameter (D) × 600 mm height (H) was used to measure the segregation resistance of SCC. There are three sections in the column apparatus; the bottom and top sections are 150 mm D × 150 mm H whereas the middle section is 150 mm D × 300 mm H. Before testing, the top, middle and bottom sections were attached accordingly. The fitted three-section column apparatus was filled with concrete in one layer within 2 min by using scoop without any compaction (Figure 2(a)). The concrete was allowed to stand undisturbed in the column mould for 15±1 min. Thereafter, the top section of the column mould was separated and the concrete from the top section was collected in the collector plate to put onto a No. 4 (4.75 mm) sieve. A similar process was applied to collect the concrete portion from the middle section; this portion was discarded. The remaining concrete portion from the bottom section was also placed onto a No. 4 sieve. The concrete portions from the top and bottom sections were washed to separate the aggregates (Figure 2(b)). The separated aggregates were made surface-dry by using absorbent cloths.

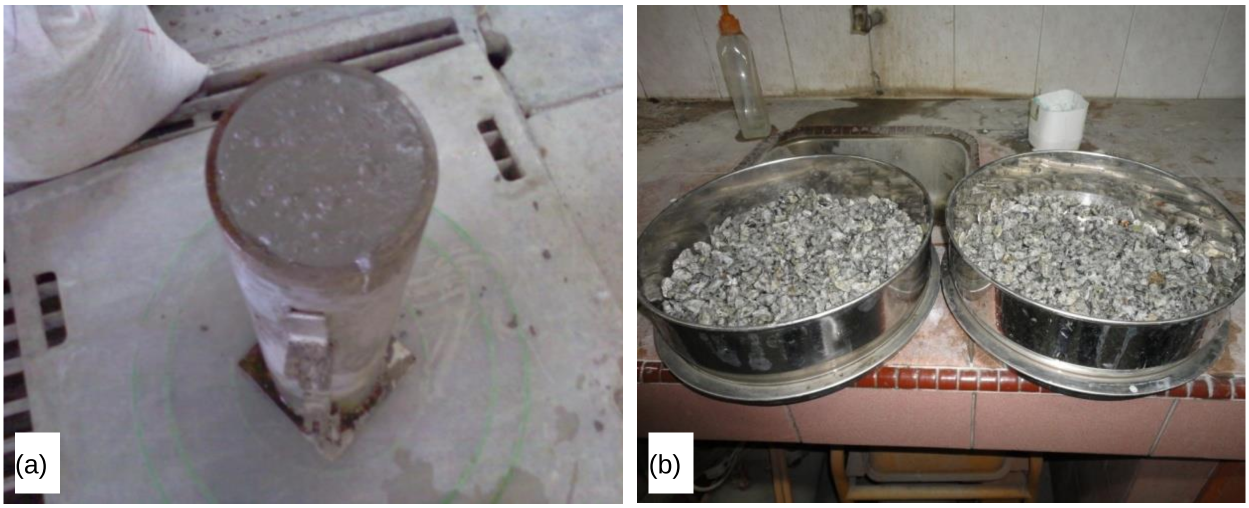

Figure 2: Column segregation test

The segregation factor was determined from the column segregation test to express the segregation resistance of SCC. At first, the amounts of coarse aggregates in top and bottom sections of the column apparatus were measured. Then the segregation factor for each SCC was quantified using the following equation.

$$S_F = 2\left[\frac{(CA_B - CA_T)}{(CA_B + CA_T)}\right] \times 100\% \quad (2)$$

Where,
S_F = Segregation factor (wt.%)
CA_B = Weight of coarse aggregate in the bottom section of the column apparatus (kg)
CA_T = Weight of coarse aggregate in the top section of the column apparatus (kg)

3 RESULTS AND DISCUSSION

The concretes were highly flowable and fulfilled the requirement of SCC, as the slump flow varied in the range of 605–720 mm in this study (Table 2). According to SCCEPG (2005), SCC must provide a slump flow greater than 550 mm. In this study, the SCC mixtures with a lower W/B ratio and a higher POFA content needed a larger HRWR dosage for the desired flowing ability with regard to slump flow. Nevertheless, the detailed discussion on the flowing ability of different SCC mixtures is not provided in this paper. The focus of this paper is the segregation resistance of SCC. The segregation resistance results of various SCC mixtures have been discussed below.

3.1 Segregation Index from Sieve Segregation Test

Sieve segregation test yields segregation index to quantify the segregation resistance of SCC. This segregation parameter is particularly suitable to judge the segregation resistance of an SCC mixture that spreads horizontally in shallow sections, such as sidewalk, pavement, floor, balcony, and flat roof. The segregation indices of various SCC mixtures are shown in Figure 3.

In this study, the segregation index ranged from 9% to 18.9%. The SCC mixture with 0.40 W/B ratio and 0% POFA content (SCC40P0) had the lowest segregation index. In contrast, the SCC mixture with 0.25 W/B ratio and 30% POFA content (SCC25P30) possessed the highest segregation index. The recommended maximum limit of segregation index for SCC mixtures is 18% (Parez et al. 2002). Hence, the sieve segregation test results reveal that all SCC mixtures, except SCC25P25 and SCC25P30, showed good or satisfactory segregation resistance.

Table 2: Slump flow results of various SCC mixtures

Concrete type	Slump flow (mm)	Concrete type	Slump flow (mm)	Concrete type	Slump flow (mm)	Concrete type	Slump flow (mm)
SCC25P0	660	SCC30P0	640	SCC35P0	630	SCC40P0	605
SCC25P10	680	SCC30P10	655	SCC35P10	640	SCC40P10	620
SCC25P20	705	SCC30P20	670	SCC35P20	665	SCC40P20	630
SCC25P25	710	SCC30P25	680	SCC35P25	670	SCC40P25	635
SCC25P30	720	SCC30P30	700	SCC35P30	675	SCC40P30	645

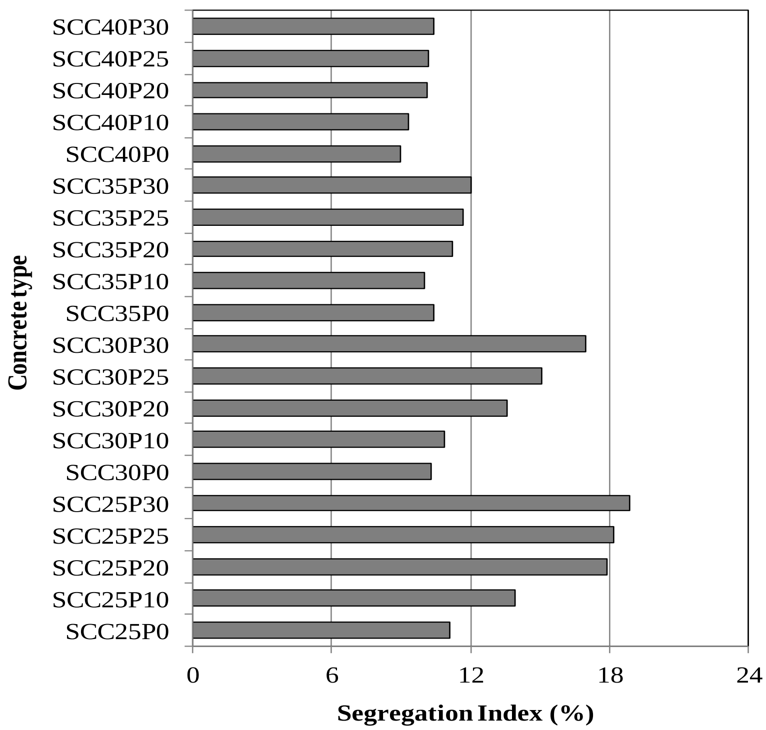

Figure 3: Sieve segregation test results of various SCC mixtures

It was also observed that an SCC mixture provided a higher segregation index when it possessed a greater slump flow (Table 2, Figure 3). The greater slump flow intensified concrete spread on the sieve. As a consequence, more mortar passed through the sieve openings and hence an increased segregation index indicating a reduced segregation resistance was obtained. The previous research studies on SCC incorporating limestone powder and fly ash (Rols et al. 1997), ground granulated blast-furnace slag and fly ash (Lachemi et al. 2003), and rice husk ash (Safiuddin 2008) reported similar findings.

3.2 Segregation Factor from Column Segregation Test

Column segregation test yields segregation factor to measure the segregation resistance of SCC. This segregation parameter is particularly suitable to judge the segregation resistance of an SCC placed vertically in deep sections, such as column, deep beam, foundation wall, retaining wall, and deep footing. The segregation factors of various SCC mixtures are presented in Figure 4.

The segregation factor for various SCC mixtures ranged from 8% to 21.8%. A higher segregation factor indicates a lower segregation resistance (Safiuddin et al. 2011b). For SCC mixtures, the recommended maximum limit of segregation factor is 20% (Safiuddin 2008). Hence, the SCC mixture with 0.25 W/B ratio and 30% POFA (SCC25P30) possessed inadequate segregation resistance as it had a segregation factor > 20%. This SCC mixture showed a lower segregation resistance mainly due to non-uniform distribution of coarse aggregates. Also, the heterogeneity occurring along the height of concrete column during and after placement may lead to an increase in segregation factor (Safiuddin et al. 2011c).

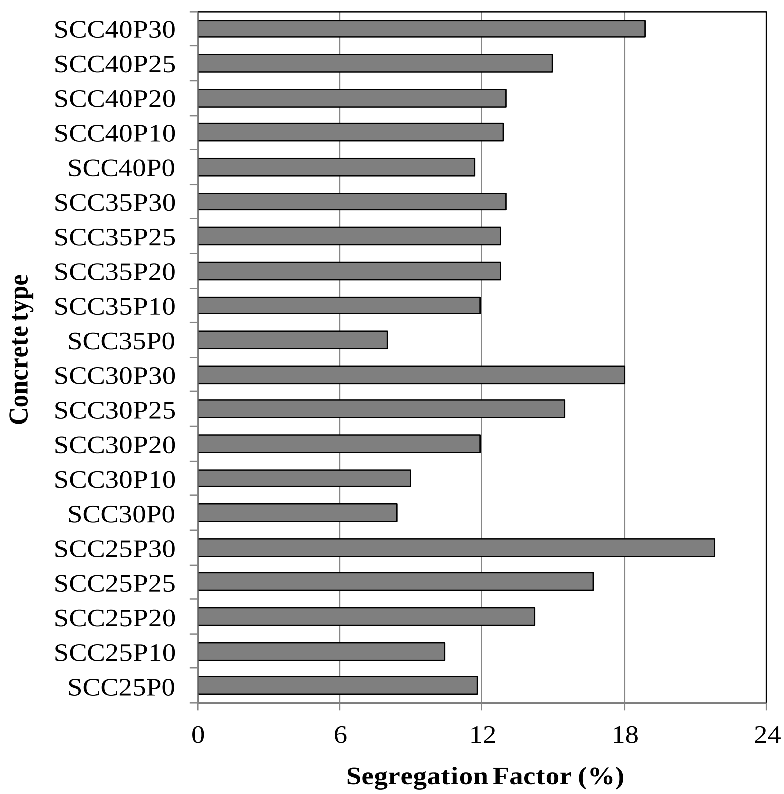

Figure 4: Column segregation test results of various SCC mixtures

3.3 Effects of W/B Ratio and POFA Content

The segregation resistance of SCC was influenced by the W/B ratio and POFA content. The segregation index of SCC, measured by sieve segregation test, increased with lower W/B ratio and higher POFA content, as can be seen from Figure 5. The slump flow results (Table 2) indicate that concrete spread was higher with lower W/B ratio and higher POFA content due to a greater paste or mortar fluidity. However, the increased paste or mortar fluidity in concrete intensifies the phase separation of mortar in the form of mortar halo (Bailey 2005, Safiuddin et al. 2012). For that reason, the quantity of mortar passing through the sieve openings increased and thus a higher segregation index indicating a lower segregation resistance was obtained.

The segregation factor of SCC, measured by column segregation test, mostly increased with higher POFA content, as can be seen from Figure 6. This finding is also linked with the greater paste or mortar fluidity of concrete. For an SCC with higher POFA content, a higher HRWR dosage was added (Table 1) to achieve the required flowing ability by increasing the fluidity of paste or mortar component. But the increased paste or mortar fluidity intensifies the settlement of coarse aggregates in SCC (Bailey 2005, Safiuddin et al. 2012). Therefore, an SCC with higher POFA content had a higher segregation factor indicating a lower segregation resistance.

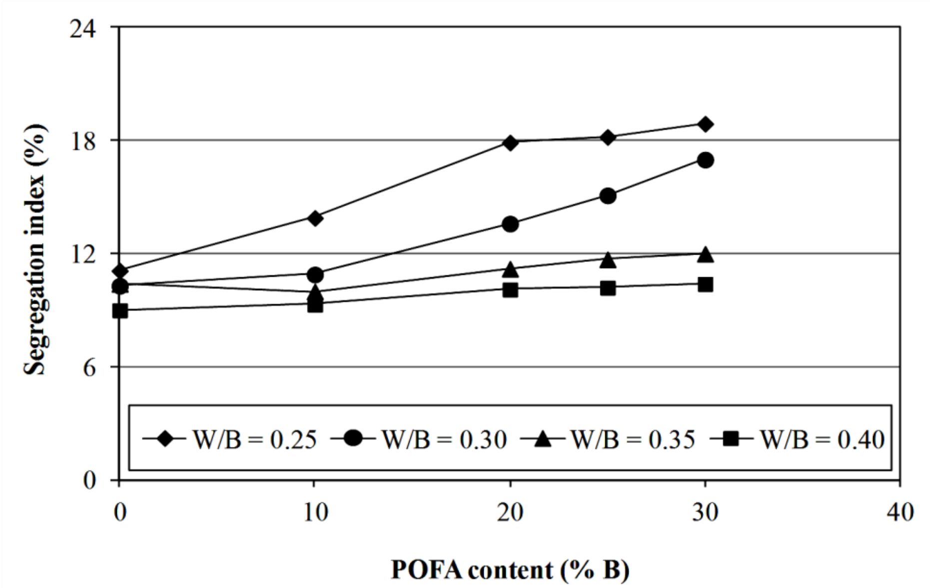

Figure 5: Effect of W/B ratio and POFA content on the segregation index of SCC

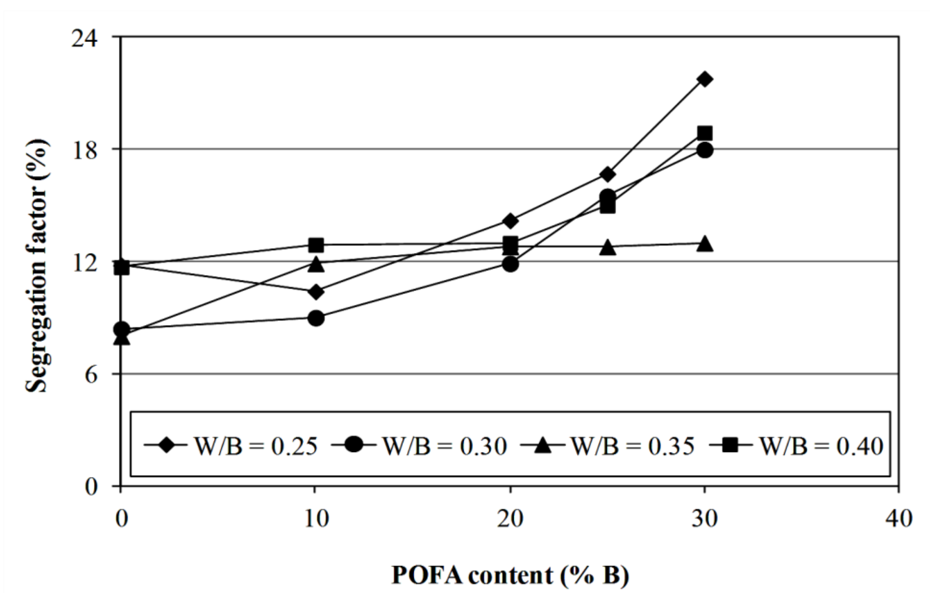

Figure 6: Effect of W/B ratio and POFA content on the segregation factor of SCC

The segregation factor did not vary systematically with the W/B ratio of concrete, as can be seen from Figure 6. This is perhaps due to the variation in the HRWR dosage used for different SCC mixtures as well as their aggregate content. For example, the SCC mixture prepared with a W/B ratio of 0.25 required a relatively high dosage of HRWR (Table 1) to obtain the desired flowing ability that substantially intensified the concrete fluidity, which is obvious from its higher slump flow (Table 2). As a consequence, the settlement rate of coarse aggregates increased in this SCC mixture, leading to a higher segregation factor. Furthermore, the fluidity of SCC mixture prepared with a W/B ratio of 0.40 was comparatively low (Table 2). This SCC mixture needed a lower HRWR dosage but its coarse aggregate content became substantially higher due to an increased W/B ratio (Table 1). The increased aggregate content intensifies the degree of aggregate settlement (Bonen and Shah 2005, Saak et al. 2001). Therefore, a relatively high segregation factor was found for the SCC mixture produced with a W/B ratio of 0.40, as can be seen in Figure 6.

4 CONCLUSIONS

The segregation resistance of SCC was influenced by the W/B ratio and POFA content of concrete. The following conclusions are drawn based on the findings of the present study:

a) The SCC mixture with lower W/B ratio and higher POFA content possessed higher segregation index and thus exhibited lower segregation resistance as the increased amount of mortar passed through the sieve due to a greater concrete spread.
b) The W/B ratio of SCC affected its segregation factor depending on the HRWR dosage and aggregate content of concrete mixture. Higher HRWR dosage and increased aggregate content contributed to increase the segregation factor of SCC for a given W/B ratio.
c) The increase in POFA content enhanced the settlement rate of coarse aggregates in an SCC mixture. This is because the increased POFA content required a higher HRWR dosage, which enhanced the paste or mortar fluidity in SCC. Consequently, the SCC mixture with greater POFA content possessed lower segregation resistance and thus provided higher segregation factor.
d) The SCC mixtures including 0-25% POFA contents fulfilled the performance criteria for segregation resistance. However, the SCC mixtures incorporating 20% POFA content exhibited the best segregation resistance performance.
e) The overall research findings suggest that segregation-resistant SCC can be produced incorporating a reasonable amount of POFA into concrete.

Acknowledgements

The authors thankfully acknowledge the financial support through the research grant (RG050-09AET) from the University of Malaya, Kuala Lumpur, Malaysia. The authors are also grateful to Jugra Palm Oil Mill Sdn. Bhd., Banting, Selangor Darul Ehsan, Malaysia for the supply of palm oil fuel ash.

References

ACI 211.4R-08. 2008. Guide for Selecting Proportions for High-Strength Concrete Using Portland Cement and Other Cementitious Materials. *ACI Manual of Concrete Practice.* Part 1, American Concrete Institute, Farmington Hills, Michigan, USA.

Alsubari, B., Shafigh, P., Jumaat, M.Z. and Alengaram, U.J. 2014. Palm Oil Fuel Ash as a Partial Cement Replacement for Producing Durable Self-Consolidating High-Strength Concrete. *Arabian Journal of Science and Engineering*, **39**(12): 8507–8516.

Alsubari, B., Shafigh, P. and Jumaat, M.Z. 2015. Development of Self-Consolidating High Strength Concrete Incorporating Treated Palm Oil Fuel Ash. *Materials*, **8**(5): 2154-2173.

ASTM C 1611/C 1611M-09. 2009. Standard Test Method for Slump Flow of Self-Consolidating Concrete. *Annual Book of ASTM Standards*. American Society for Testing and Materials, Philadelphia, USA.

Bailey, J.D. 2005. *An Evaluation of the Use of Self-Consolidating Concrete (SCC) for Drilled Shaft Applications*. Master's thesis, Auburn University, Alabama, USA.

Bonen, D. and Shah, S.P. 2005. Fresh and Hardened Properties of Self-Consolidating Concrete. *Progress in Structural Engineering and Materials*, **7**(1): 14-26.

CAN/CSA A3001. 2003. Cementitious Materials for Use in Concrete. *Cementitious Materials Compendium*. Canadian Standards Association, Etobicoke, Ontario, Canada.

Cyr, M. and Mouret, M. 2003. Rheological Characterization of Superplasticized Cement Pastes Containing Mineral Admixtures: Consequences on Self-Compacting Concrete Design. *Seventh CANMET/ACI International Conference on Superplasticizers and Other Chemical Admixtures in Concrete*, American Concrete Institute, Berlin, Germany, **ACI SP-217**: 241-256.

EFNARC. 2002. *Specifications and Guidelines for Self-Consolidating Concrete*. European Federation of National Associations Representing for Concrete (EFNARC), Surrey, UK.

Khayat, K.H. 1999. Workability, Testing, and Performance of Self-Consolidating Concrete. *ACI Materials Journal*, **96**(3): 346-353.

Kim, H., Park, Y.-D., Noh, J., Song, Y., Han, C. and Kang, S. 1997. Rheological Properties of Self-Compacting High-Performance Concrete. *Proceedings of the Third CANMET/ACI International Conference*, American Concrete Institute, Kuala Lumpur, Malaysia, **ACI SP-172**: 653-668.

Lachemi, M., Hossain, K.M.A., Lambros, V. and Bouzoubaâ, N. 2003. Development of Cost-Effective Self-Consolidating Concrete Incorporating Fly Ash, Slag Cement, or Viscosity-Modifying Admixtures. *ACI Materials Journal*, **100**(5): 419-425.

Mohammadhosseini, H., Awal, A.S.M.A. and Ehsan, A.H. 2015. Influence of Palm Oil Fuel Ash on Fresh and Mechanical Properties of Self-Compacting Concrete. *Sadhana*, **40**(6): 1989-1999.

Ofuyatan, T., Olutoge, F. and Olowofoyeku, A. 2015. Durability Properties of Palm Oil Fuel Ash Self Compacting Concrete. *Engineering, Technology & Applied Science Research*, **5**(1): 753-756.

Okamura, H. and Ozawa, K. 1994. Self-Compactable High-Performance Concrete in Japan. *Proceedings of the International Workshop on High-Performance Concrete*, American Concrete Institute, Bangkok, Thailand, **ACI SP-159**: 31-44.

Okamura, H. and Ozawa, K. 1995. Mix Design for Self-Compacting Concrete. *Concrete Library of JSCE*, **25**: 107-120.

Parez, N., Romero, H., Hermida, G. and Cuellar, G. 2002. Self-Compacting Concrete, on the Search and Finding of an Optimized Design. *Proceedings of the First North American Conference on the Design and Use of Self-Consolidating Concrete*, Hanley-Wood LLC, Chicago, Illinois, USA: 101-107.

Ranjbar, N., Behnia, A., Alsubari, B., Birgani, P.M. and Jumaat, M.Z. 2016. Durability and Mechanical Properties of Self-Compacting Concrete Incorporating Palm Oil Fuel Ash. *Journal of Cleaner Production*, **112**(1): 723-730.

Rols, S., Ambroise, J. and Pera, J. 1997. Development of an Admixture for Self-Levelling Concrete. *Proceedings of the Fifth CANMET/ACI International Conference on Superplasticizers and Other Chemical Admixtures*, American Concrete Institute, Rome, Italy, **ACI SP-173**: 493-510.

Saak, A.W., Jennings, H.M. and Shah, S.P. 2001. New Methodology for Designing Self-Compacting Concrete. *ACI Materials Journal*, **98**(6): 429-439.

Safiuddin, Md. 2008. *Development of Self-Consolidating High Performance Concrete Incorporating Rice Husk Ash*. PhD thesis, University of Waterloo, Waterloo, Ontario, Canada.

Safiuddin, Md., West, J.S. and Soudki, K.A. 2009. *Self-Consolidating High Performance Concrete with Rice Husk Ash: Components, Properties, and Mixture Design.* 1st ed., VDM Publishing House Ltd., Saabruecken, Germany.

Safiuddin, Md., Salam, M.A. and Jumaat, M.Z. 2011a. Utilization of Palm Oil Fuel Ash in Concrete: a Review. *Journal of Civil Engineering and Management*, **17**(2): 234-247.

Safiuddin, Md., Isa, M.H.M. and Jumaat, M.Z. 2011b. Fresh Properties of Self-Consolidating Concrete Incorporating Palm Oil Fuel Ash as a Supplementary Cementing Material. *Chiang Mai Journal of Science*, **38**(3): 389-404.

Safiuddin, Md., Salam, M.A. and Jumaat, M.Z. 2011c. Effects of Recycled Concrete Aggregate on the Fresh Properties of Self-Consolidating Concrete. *Archives of Civil and Mechanical Engineering*, **11**(4): 1023-1041.

Safiuddin, Md., West, J.S. and Soudki, K.A. 2012. Properties of Freshly Mixed Self-Consolidating Concretes Incorporating Rice Husk Ash as a Supplementary Cementing Material. *Construction and Building Materials*, **30**: 833-842.

Salam, M.A., Safiuddin, Md. and Jumaat, M.Z. 2015. Non-Destructive Evaluation of Self-Consolidating High-Strength Concrete Incorporating Palm Oil Fuel Ash. *British Journal of Applied Science and Technology*, **11**(4): 1-13.

SCCEPG. 2005. *The European Guidelines for Self-Compacting Concrete: Specification, Production and Use.* Self-Compacting Concrete European Project Group (SCCEPG), European Federation of Concrete Admixtures Associations, Brussels, Belgium.

Siddique, R. and Khan, M.I. 2011. *Supplementary Cementing Materials*. Part of the Engineering Materials Book Series, Vol. 37. Springer, New York, USA.

Sumadi, S.R. and Hussin, M.W. 1995. Palm Oil Fuel Ash (POFA) as a Future Partial Cement Replacement Material in Housing Construction. *Journal of Ferrocement*, **25**(1): 25-34.

Tonnayopas, D., Nilrat, F., Putto, K. and Tantiwitayawanich, J. 2006. Effect of Oil Palm Fiber Fuel Ash on Compressive Strength of Hardening Concrete. *Proceedings of the 4th Thailand Materials Science and Engineering*, Pathumthani, Thailand:1-3.