Properties and Leachability of Self-Compacting Concrete Incorporated with Fly Ash and Bottom Ash

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Abstract. The process of combustion in coal-fired power plant generates ashes, namely fly ash and bottom ash. Besides, coal ash produced from coal combustion contains heavy metals within their compositions. These metals are toxic to the environment as well as to human health. Fortunately, treatment methods are available for these ashes, and the use of fly ash and bottom ash in the concrete mix is one of the few. Therefore, an experimental program was carried out to study the properties and determine the leachability of self-compacting concrete incorporated with fly ash and bottom ash. For experimental study, self-compacting concrete was produced with fly ash as a replacement for Ordinary Portland Cement and bottom ash as a replacement for sand with the ratios of 10%, 20%, and 30% respectively. The fresh properties tests conducted were slump flow, t₅₀₀, sieve segregation and J-ring. Meanwhile for the hardened properties, density, compressive strength and water absorption test were performed. The samples were then crushed to be extracted using Toxicity Characteristic Leaching Procedure and heavy metals content within the samples were identified accordingly using Atomic Absorption Spectrometry. The results demonstrated that both fresh and hardened properties were qualified to categorize as self-compacting concrete. Improvements in compressive strength were observed, and densities for all the samples were identified as a normal weight concrete with ranges between 2000 kg/m³ to 2600 kg/m³. Other than that, it was found that incorporation up to 30% of the ashes was safe as the leached heavy metals concentration did not exceed the regulatory levels, except for arsenic. In conclusion, this study will serve as a reference which suggests that fly ash and bottom ash are widely applicable in concrete technology, and its incorporation in self-compacting concrete constitutes a potential means of adding value to appropriate mix and design.

1. Introduction

In a developed country like Malaysia, the growth in production and manufactured sector had lead to increased industrial by-product waste. According to [1], Malaysia had generated approximately 1.1 million metric tons of scheduled waste in the year 2007. Every year, the coal-fired power plants produced large amounts of FA and BA worldwide. Malaysia was not left behind in created of fly ash and bottom ash. Although there was no reported about the production of coal ash every year in
Malaysia, about 10% of the total weight of the coal ash has been contributed [2]. The schedule industrial waste generated in Malaysia in the year 2009 was 1,705,308 metric tons, and the major components of the waste were from dross, slag, clinker, ash, gypsum, oil and hydrocarbon [2, 3, 4]. Both FA and BA disposed of as waste. The landfill has become the primary method of disposal of waste materials. However, dumped the BA and FA in the landfill was not the best sustainable solution [5]. These wastes must adequately manage without caused any harmful environment effects. Alternatively, a better approach in solved and handled of coal combustion by-product should be explored. The FA and BA were effectively used in many applications [6]. The problems that occurred to disposed of coal ash with limited landfill area can be reduced by reuse of FA and BA in the construction industry technology. The used of FA from coal-fired power plants and ground granulated slag from the blast-furnace industry in blended Portland cement was an excellence example of industrial that reduced environmental impact [7, 8].

Previous studies proved that FA and BA could potentially be used as an alternative replacement material for cement and sand in the concrete mix. This research was conducted based on the awareness of the need to utilize the waste product to preserve the environment [9,10] It was also to promote the use of environmentally friendly technology and sources in construction. Therefore, this research was conducted to determine the properties as well as leachability of self-compacting concrete (SCC) incorporating with FA and BA and to formulate the suitable ratio for this waste replacement.

2. Materials and Methods

2.1. Materials

Fly ash and bottom ash were collected from one of the coal-fired power plant located in Peninsula Malaysia. FA and BA were become part of the SCC mix composition by replacing cement and sand in the percentages of 0%, 10%, 20% and 30% respectively. ADVA 181 superplasticizer (SP) that specially formulated to produce high strength concrete with good slump retention was used. According to Table 1, ten design mix proportions were made, which had total binder content of 530 kg/m$^3$ to 550 kg/m$^3$ at water to binder ratio (w/b) of 0.41. The workability of the mix proportions was determined by referring to specification and guidelines for SCC prepared by EFNARC [11]. The size of specimens used throughout this research was 150 mm cubes. Total binder for all the samples was between 530 kg/m$^3$ to 550 kg/m$^3$ respectively. Note that the proportion is for one batch casting (0.0475 m$^3$).

| Mix Design | Total Binder (kg/m$^3$) | Cement (kg/m$^3$) | FA (kg/m$^3$) | CA (kg/m$^3$) | Sand (kg/m$^3$) | BA (kg/m$^3$) | Water (kg/m$^3$) | SP (kg/m$^3$) |
|------------|------------------------|-------------------|--------------|--------------|----------------|--------------|----------------|-------------|
| FA0BA0     | 550                    | 550               | 0            | 593          | 914            | 0            | 228            | 5           |
| FA10BA0    | 550                    | 495               | 55           | 593          | 914            | 0            | 220            | 4           |
| FA20BA0    | 540                    | 432               | 108          | 593          | 914            | 0            | 216            | 4           |
| FA30BA0    | 530                    | 371               | 159          | 593          | 914            | 0            | 212            | 4           |
| FA0BA10    | 550                    | 550               | 0            | 593          | 822            | 67           | 228            | 5           |
| FA0BA20    | 550                    | 550               | 0            | 593          | 731            | 133          | 228            | 5           |
| FA0BA30    | 550                    | 550               | 0            | 593          | 640            | 200          | 228            | 5           |
| FA10BA10   | 550                    | 495               | 55           | 593          | 822            | 67           | 228            | 5           |
| FA20BA20   | 550                    | 432               | 108          | 593          | 731            | 133          | 216            | 4           |
| FA30BA30   | 530                    | 371               | 159          | 593          | 640            | 200          | 212            | 4           |

*CA: Coarse aggregate; SP: super plasticizer

2.2. Methods

Each mixed proportions were tested for their fresh and hardened properties of SCC to classify it at SCC. These tests are the filling ability (slump flow and T$_{500}$ test), passing ability (J-ring test) and segregation resistance (siege segregation test) according to BS EN 12350 respectively [12, 13, and 14]. Curing was done in accordance with BS EN 12390-2 and density, compressive strength and water
absorption at 28 days were determined by referring BS EN 12390 and BS 1881: part 122:1983 [15, 16].

After compressive strength test, the samples were then crushed further using the Aggregate Impact Value (AIV) equipment so as to reduce the solid particles sizes to less than 9.5 mm. Using a sieve with the corresponding size, the crushed fragments were sieved and collected as samples for Toxicity Characteristic Leaching Procedure (TCLP) [17].

TCLP was used as a set of instructions to prepare extracted samples of concrete samples for leaching analysis to be done. As SCC cubes were solid samples, the procedure of extraction had to be done under the category for sample containing more than 0.5% dry solid. The pH of each solid sample was checked in order to determine the suitable extraction fluid to be used. It was found that the pH of all samples exceeded 5.0; hence extraction fluid No.2 was prepared and used to extract the samples.

Extraction fluid No.2 was prepared by diluting 5.7 mL glacial acetic acids (CH₃CH₂OOH) with distilled water to a volume of 1 litre. A total of 50 g sample was prepared and placed into a 2 liter extraction bottle, and the extraction fluid was poured in after. Fixing the extraction bottle to a rotary agitation apparatus, it was left to rotate from end to end for 18 hours. The solutions within the extraction bottle were then filtered to dispel the solid particles. The fluid portion of the sample was preserved to a pH less than 2.0 and stored in a refrigerator at 5 °C for leachate determination analysis using AAS, which was performed using Perkin Elmer AAnalyst 800.

3. Result and Discussion

4. 3.1. Fresh properties of SCC. Figure 1 showed the result of filling ability by using slump flow test of ten different percentages FA and BA in SCC. Generally, diameters of the spread for all the mixes were recorded higher than the minimum requirement of the SCC, which is 500 mm. 4 mixes come out with result below 600 mm which is control, FA10BA0, FA20BA0, and FA30BA0 of SCC samples with diameter of spread 565 mm, 553 mm, 580 mm and 518 mm respectively. The other six mixes were recorded higher than 600mm diameter of the spread. A slump flow value ranging from 500 to 700 mm for a concrete to be self-compacting was suggested by Liu [20]. At slump flow higher than 700 mm, the concrete might segregate, and at lower than 500 mm, the concrete might have insufficient flow to pass through highly congested reinforcement. The time spread of t₅₀₀ for the samples was recorded as shown in Figure 2. The red line in the figures indicates the permissible line to recognized the concrete as SCC.

Meanwhile, Figure 3 showed the result of passing ability by using J-ring test. According to the result, all the design mix proportions have fulfilled the requirement of the J-ring test. Those samples showed the ability to pass the height of spread ≤ 2cm and distance from spread end to t₅₀₀ ≤ 10 cm. The highest reading for the height of spread for J-ring test was recorded by the sample FA30BA30 with 1.025cm while the sample FA30BA0 recorded the height of spread for J-ring test with 2.08cm.
Based on the sieve segregation test result from Figure 4, all the design mix proportions have achieved the target of the test that was conducted to determine the ability to remain homogeneous in composition during transport and placing of the SCC. The segregated portion ≤ 20% was the requirement need to be obtained by the samples. The lowest value of segregated portion, 3.33% was recorded by the sample FA0BA30 and the highest values of segregated portion are from the control (FA0BA0) sample with 15.85%.

3.2 Hardened properties of SCC

3.2.1 Density

The density of SCC incorporated with FA and BA was determined by weighing the cube samples before conducting the compressive strength test. For accuracy, the average density is calculated for each concrete mix design and the results as tabulated in Table 2. According to Table 2, FA30BA30 samples achieved the lowest density which is 2170 kg/m³. Meanwhile the highest density of SCC samples was recorded by FA10BA0 and FA20BA0 samples with 2304 kg/m³. It shows that with the replacement of FA up to 20% in the samples, the density was recorded higher compared to the samples with BA alone. Nevertheless, all the samples were comparable with BS EN 206: 2013 as a normal weight concrete with the range between 2000 kg/m³ and not exceed 2600 kg/m³. Other than that, [18] suggested that density of hardened mortar or concrete varies, depending on the amount and density of the aggregate, the amount of air voids that is entrained or entrapped and the water and cement contents.

| Sample     | Average (kg/m³) |
|------------|-----------------|
| FA0BA0     | 2189            |
| FA10BA0    | 2304            |
| FA20BA0    | 2304            |
| FA30BA0    | 2274            |
| FA0BA10    | 2244            |
| FA0BA20    | 2289            |
| FA0BA30    | 2244            |
| FA10BA10   | 2296            |
| FA20BA20   | 2207            |
| FA30BA30   | 2170            |
3.2.2 Water absorption

Water absorption is used to determine the amount of water absorbed under specified conditions which indicate the degree of porosity of material [19]. This test was conducted according to BS 1881: 2011 on 28 days to determine the water absorption of SCC incorporated FA and BA. The results for water absorption of SCC samples were tabulated in Table 3. According to Table 3; it shows that with the increase of BA only to the samples, the water absorption decreased slightly for FA0BA10 sample with 1.08 %, FA0BA20 sample with 1.02% and FA0BA30 sample with 0.67%. It is suggested by Siddique [19] that incorporating of BA in concrete resulted in low absorption characteristic that is less than 10% of absorption. The same patterns are also demonstrated for the incorporation of FA and combination of FA and BA. For samples with FA only, the results are 1.10%, 0.66% and 0.53% with the addition of 10%, 20% and 30% of FA respectively. For the samples incorporated with FA and BA, the results are 0.79%, 0.55% and 0.46% for FA10BA10, FA20BA20 and FA30BA30 respectively. According to the result, it showed that the more percentage of FA and BA added to the samples, the lower the percentages of water absorption recorded. It was supported by Liu [20] that this could because the FA is finer than the cement. Therefore it fills the voids in the samples and leading to lower porosity. It is noticeable that all SCC mixes samples had low absorption characteristic (less than 10%).

| Sample     | Water Absorption (%) |
|------------|-----------------------|
| FA0BA0     | 0.97                  |
| FA10BA0    | 1.10                  |
| FA20BA0    | 0.66                  |
| FA30BA0    | 0.53                  |
| FA0BA10    | 1.08                  |
| FA0BA20    | 1.02                  |
| FA0BA30    | 0.67                  |
| FA10BA10   | 0.79                  |
| FA20BA20   | 0.55                  |
| FA30BA30   | 0.46                  |

3.2.3 Compressive Strength

In terms of mechanical properties, the compressive strength of the cube samples with a size of (150x150x150) mm was tested at the age of 7 days, 14 days and 28 days. The compressive strength was determined accordingly to BS EN 12390-3:2009. All the SCC incorporated with FA and BA obtained compressive strengths with similar range but higher than normal concrete. By referring to BS EN 206: 2013, compressive strength classes for the samples were range from class C45 to C70 at 28 days and meets the requirement to be categorized as normal-weight and heavy-weight concrete. Figure 5a, 5b, and 5c show the comparison of compressive strengths between control sample (FA0BA0) and samples with various percentages of FA and BA replacement in SCC.

Figure 5a shows the compressive strength at various FA contents in SCC samples. At various replacement of OPC with 0%, 10%, 20%, and 30% of FA, strengths were observed to be in the range of 30 MPa to 42 MPa at seven days, 41 MPa to 59 MPa at 14 days and 49 MPa to 69 MPa respectively. All the samples incorporated with FA were higher than control sample which is FA0BA0. It shows that replacement of FA has improved the compressive strength of the SCC. The highest strength was recorded from FA10BA0 sample with 68.79 MPa at 28 days. The increase in strength of fly ash concrete may be attributed to continuous hydration and the filling of pores with Calcium Silicate Hydrated gel formed due to pozzolanic action of coal fly ash [21].
Meanwhile, for compressive strength with a various replacement of sand with 10%, 20%, and 30% of BA, the results are shown in Figure 5b. It shows that strengths were observed to be in the range of 33 MPa to 50 MPa, 41 MPa to 57 MPa, and 49 MPa to 59 MPa at 7, 14 and 28 days respectively. SCC incorporated with BA gained higher strength at early ages of the SCC ranging from 47 MPa to 49 MPa but slowly increased at 14 days and 28 days with the highest value recorded was from FA0BA10 sample with 58.01 MPa.

Figure 5c shows the compressive strength with various replacements of FA and BA (10%, 20%, and 30%) replacing cement and sand in SCC. Again, the result showed that SCC incorporated with FA and BA were higher than control samples with a range of 33 MPa to 46 MPa, 38 MPa to 53 MPa, and 46 MPa to 58 MPa at 7, 14 and 28 days respectively. However, only FA30BA30 recorded lower value than the control sample. Therefore, the reduction in strength was observed up to 30% replacement of the fine aggregate of FA and BA. It was supported by [22] that increasing in percentages of BA will decrease the compressive strength of SCC.
3.2.4 Morphology Analysis

Morphology analysis using Scanning Electron Microscope (SEM) was done in order to determine to investigate the surface changes in the SCC samples and also its porosity with 1000x magnification as illustrated in Figure 6a to Figure 6j. In addition, SEM is one of the most versatile instruments available for the examination and analysis of the microstructure characteristics of solid objects SEM observation was carried out on the surface of control SCC sample, samples incorporated with FA only, samples incorporated with BA only and samples incorporated with both FA and BA samples. As can be seen, the majority of the FA and BA particles are spherical. This ash consists of a series of spherical vitreous particles of different sizes (diameters ranging from 200 µm to 10 µm). The morphology of the particles was similar to the control sample. The spheres seem to be almost intact or appear within other spheres, depending on the percentages of the FA in the samples. Finer particles with higher density, which have the appearance of metallic lustre in SEM images, can be seen on larger particles. Observation also revealed that there are significant changes in the growth of pore size with the incorporation of BA compared to control (FA0BA0) sample. This is because BA has a larger size to be compared to FA. The mechanical performance of the concrete can be related to morphological changes on the surfaces. Apart from that, the uses of bottom ash as replacement of natural sand in self-compacting concrete, the number of fines and irregular shaped, rough textured and porous particles increases and thereby increasing the inter-particles friction. The increased inter-particle friction hinders the flow characteristics of fresh concrete [23].
3.3 Toxicity Characteristic Leaching Procedure (TCLP) result

From the results of the TCLP test in Table 4, it shows that there are insignificant levels of heavy metals leached out from the samples. The results were then compared to United States Environmental Protection Agency regulatory levels.

Element concentrations in all the samples in TCLP were below the permissible limit set by USEPA except for arsenic. In addition, samples with replacement of FA alone and samples with a combination of FA and BA resulted in the higher leaching of As to be compared with samples with BA alone. The highest leaching of As was recorded by sample FA30BA30 with 18.576 mg/L. Arsenic has gained considerable attention due to the fact that it is mobile throughout a wide pH range. Arsenic releases from acidic solution increase with pH, whereas in alkaline solution, this trend is reversed [24]. The difference in leaching is caused by the Ph dependent of most heavy metals elements [25]. Another study by [24] showed that the types of FA are also a factor in leaching of As. It is because FA consists aluminum oxide and iron hydroxide that are common sorbents for As adsorption.
Table 4: Leachability of heavy metals in SCC samples in TCLP

| Heavy metals | Concentration (mg/L)* | Samples |
|--------------|-----------------------|---------|
| As           | 5                     | 12.060  |
| Cr           | 5                     | 0.112   |
| Pb           | 5                     | 0.447   |
| Zn           | NA                    | 0.173   |
| Cu           | 100                   | 0.026   |
| Ni           | NA                    | 0.167   |
| Fe           | NA                    | 0.095   |
| Mn           | NA                    | ND      |
| FA0BA0       | 14.705                |
| FA10BA0      | 14.895                |
| FA20BA0      | 15.370                |
| FA30BA0      | 13.640                |
| FA0BA10      | 13.675                |
| FA0BA20      | 14.640                |
| FA0BA30      | 16.510                |
| FA10BA10     | 18.200                |
| FA20BA20     | 18.576                |
| FA30BA30     |                       |

Where,
As = Arsenic      Pb = Lead              Cr = Chromium  Zn = Zinc  Cu = Copper  Ni = Nickel
Fe = Ferum        Mn = Manganese

* US Environmental Protection Agency, USEPA (1996); NA – Not Available; ND – Not Detected

4. Conclusion
As a conclusion, it was observed that fly ash and bottom ash have potential to been used as replacement in SCC. All the samples incorporated with these waste materials showed the fresh properties within the ranges specified to be categorized as SCC. As for compressive strength, it shows that compressive strength increased from day 7 up to day 28. By referring to BS EN 206: 2013, compressive strength classes for the samples were range from class C45 to C70 at 28 days and met the requirement to be categorized as normal-weight and heavy-weight concrete. From water absorption, it shows that with the increase of BA only to the samples, the water absorption decreased slightly for FA0BA10 sample with 1.08%, FA0BA20 sample with 1.02% and FA0BA30 sample with 0.67%. SEM images for SCC incorporated with FA shows the morphology of the particles were similar to the control sample. The spheres seem to be almost intact or appear within other spheres, depending on the percentages of the FA in the samples. Leachability of heavy metals of SCC incorporated with FA and BA was determined using TCLP. As environmental concerns is a top priority, the uses of FA and BA are not only could reduce the amount of these wastes materials sent to the landfill, but it is also will serve better in concrete technology in terms of economic-viability as a low-cost replacement materials.

5. References
[1] Ahmaruzzaman, M., (2010). A review on the utilization of fly ash. Progress in Energy and Combustion Science, Vol. 36(3), pp.327–363.
[2] Kadir A. A., Hassan M. I. H.,(2014) “An Overview of Fly Ash and Bottom Ash Replacement in Self Compaction Concrete” Key Engineering Materials Vols. 594-595 pp 465-470.
[3] Naganathan, S., (2012). Development of Brick Using Thermal Power Plant Bottom Ash and Fly Ash. Asian Journal of Civil Engineering (Building and Housing), 13(1), pp.275–287.
[4] B. Kim, M. Prezzi, & R. Salgado (2005), “Geotechnical properties of fly and bottom ash mixtures for use in highway embankments.” *Journal of Geotechnical, Geo-environment Engineering*, 131(7), 914–924.

[5] Siddique, R., Paratibha, A., Yogesh, A., (2012) “Influence of water/powder ratio on strength properties of self-compacting concrete containing coal fly ash and bottom ash”, *Construction and Building Materials* 29 pp. 73–81.

[6] Syahrul, M., Muftah F., Muda Zulkifli (2010). The Properties of Special Concrete Using Washed Bottom Ash (WBA) as Partial Sand Replacement. *International Journal of Sustainable Construction Engineering & Technology*, 1(December 2010), pp.65–76.

[7] Prajapati K, Chandak R. and Dubey S.K., (2012) “Development and Properties of Self Compacting Concrete Mixed with Fly Ash”, *Research Journal of Engineering Sciences* Vol. (3), 11-14.

[8] Muhardi, A., (2010). Engineering characteristics of Tanjung Bin coal ash. *Electronic Journal of Geotechnical Engineering*, Vol. 15, pp.1117–1129.

[9] Sarode, D.B.,Jadhav R. N.,Khatik V. A., Ingle S. T., Attarde S.B., (2010). Extraction and leaching of heavy metals from thermal power plant fly ash and its admixtures. *Polish Journal of Environmental Studies*, 19(6), pp.1325–1330.

[10] Kadir, A and Mohajerani, A (2012), 'Leachability of heavy metals from fired clay bricks incorporated with cigarette butts', *Proceedings from the 8th International Symposium on Lowland Technology*, pp. 1-7.

[11] EFNARC, (2002), “Specifications and Guidelines for Self-Compacting Concrete”, (www.efnarc.org), pp 1-32.

[12] British Standards Institution (2010). Testing fresh concrete – Part 8: Self-compacting concrete – Slump-flow test. London. BS EN 12350-8.

[13] British Standards Institution (2010). Testing fresh concrete – Part 11: Self-compacting concrete – Sieve segregation test. London. BS EN 12350-11.

[14] British Standards Institution (2010). Testing fresh concrete – Part 12: Self-compacting concrete – J-ring test. London. BS EN 12350-12.

[15] British Standards Institution (2000). “Testing hardened concrete – part 2: making and curing specimens for strength tests, BS EN 12390-3: 2000,

[16] BS 1881-122:1993, Testing concrete. Method for determination of water absorption.

[17] TCLP. Toxicity Characteristic Leaching Procedure. (1992). US Environmental Protection Agency, Method 1311.

[18] Wongkeo, W., Thongsanitgarn P., Ngamjarurojana A., Chaipanich A., (2014) Compressive strength and chloride resistance of self-compacting concrete containing high level fly ash and silica fume. *Materials & Design*, Vol. 64, pp.261–269.

[19] Siddique, R., (2013)Properties of self-compacting concrete containing class F fly ash, Material and Design 32 1501–1507.

[20] Liu, M., (2010). Self-compacting concrete with different levels of pulverized fuel ash. *Construction and Building Materials*, Vol. 24 (7), pp.1245–1252.

[21] Siddique, R., (2010) “Utilization of coal combustion by-products in Sustainable Construction materials, resources, conservation and recycling, Vol. 54, *Construction and Building Materials*, pp. 1060-1066.

[22] Kasemchaisiri, R. & Tangtermsirikul, S., (2008). Properties of Self-Compacting Concrete in Corporating Bottom Ash as a Partial Replacement of Fine Aggregate. *ScienceAsia* 34, pp.87–95.

[23] Singh, M. & Siddique, R., (2015). Properties of concrete containing high volumes of coal bottom ash as fine aggregate. *Journal of Cleaner Production*, 91, pp.269–278.

[24] Kosson, D.S. (2014). pH-dependent leaching of constituents of potential concern from concrete materials containing coal combustion fly ash. *Chemosphere*, Vol. 103, pp.140–7.

[25] Kim B., Prezzi M., Salgado R. & Lee J. (2005). Mechanical properties of Class F fly and bottom ash mixtures for embankment application. *Indian Geotechnical Conference*. pp. 239 – 242.