Investigation on Leaching Behaviour of Fly Ash and Bottom Ash Replacement in Self-Compacting Concrete

Aeslina Abdul Kadir1,2, Mohd Ikhmal Haqeeem Hassan1 & Mohd Mustafa Al Bakri Abdullah3

1Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat Johor, Malaysia
2Center of Excellence Geopolymer & Green Technology (CeGeoGTech), School of Material Engineering, Universiti Malaysia Perlis (UniMAP), Perlis Malaysia
3Faculty of Engineering Technology, Universiti Malaysia Perlis (UniMAP), Perlis, Malaysia

Email: aeslina@uthm.edu.my, mohd.ikhmal.haqeem@gmail.com & mustafa_albakri@unimap.edu.my

Abstract. Fly ash and bottom ash are some of the waste generated by coal-fired power plants, which contains large quantities of toxic and heavy metals. In recent years, many researchers have been interested in studying the properties of self-compacting concrete incorporated with fly ash and bottom ash but there was very limited research from the combination of fly ash and bottom ash towards the environmental needs. Therefore, this research was focused on investigating the leachability of heavy metals of SCC incorporated with fly ash and bottom ash by using Toxicity Characteristic Leaching Procedure, Synthetic Precipitation Leaching Procedure and Static Leaching Test. The samples obtained from the coal-fired power plant located at Peninsula, Malaysia. In this study, the potential heavy metals leached out from SCC that is produced with fly ash as a replacement for Ordinary Portland Cement and bottom ash as a substitute for sand with the ratios from 10% to 30% respectively were designated and cast. There are eight heavy metals of concern such as As, Cr, Pb, Zn, Cu, Ni, Mn and Fe. The results indicated that most of the heavy metals leached below the permissible limits from the United States Environmental Protection Agency and World Health Organization limit for drinking water. As a conclusion, the minimum leaching of the heavy metals from the incorporation of fly ash and bottom ash in self-compacting concrete was found in 20% of fly ash and 20% of bottom ash replacement. The results also indicate that this incorporation could minimize the potential of environmental problems.

1. Introduction
Malaysia is one of the thriving economies and a well-developing country in the world. Because of that, economic growth has contributed to the increase in the demand for electricity primarily that was produced by coal-fired plants. It will lead to the increment in coal utilization by the power plants thus will generate waste such as fly ash (FA) and bottom ash (BA) to landfills [1,2]. These wastes needed to manage appropriately and disposed of without causing any harmful environmental effects. There are about 10% total weights of the coal burned produces ash [3] with very high environmental risk. FA can be recognized as a fine grey powder consisting mostly of spherical in shape, and their surfaces
appeared to be smooth [4]. On the other hand, BA is coarse, with grain sizes spanning from fine sand to fine gravel ranging between 10 mm to 0.075mm and typically grey to black in color [5, 6]. At present, the utilization of FA and BA from power stations includes in road construction, brick making and the production of cement and concrete. Fly ash is the famous type of cement replacement material to replace a certain amount of cement content in the concrete and increased the workability properties of SCC mix. The cementitious compound in FA may produce when siliceous material reacts with calcium hydroxide in the presence of water at ordinary temperature. Meanwhile, many investigations found that the BA has some cementitious properties in which may increase the strength and long-term than concrete with natural sand [7, 8]. Even though the utilization of FA and BA have been practiced in worldwide with positive results, but weathering and erosion over time will ultimately cause the heavy metal contents have a tendency to leached out, and a diversely would affect human and environmental health [9]. Therefore, this research was conducted to determine the leachability of SCC incorporated with fly ash and bottom ash by using Toxicity Characteristic Leaching Procedure (TCLP), Synthetic Precipitation Leaching Procedure (SPLP) and Static Leaching Test (SLT).

2. Materials and Methods

2.1. Materials

The fly ash and bottom ash were obtained from a power plant located at Peninsula, Malaysia. The material characterization of FA, BA and OPC were carried out through X-ray fluorescence (XRF) test, performed using Bruker AXS S4 Pioneer. Fly ash and bottom ash samples used for the test were prepared in the forms of pellets, abiding a sample to a wax ratio of 8:2 using Pressed Pellet Technique. The chemical compositions of the materials are shown in Table 1. A total of 26 chemical compounds or elements were detected in FA, BA, and OPC. By considering the constraint of laboratory apparatus, only selected parameter were considered to be tested by using Atomic Absorption Spectrometry (AAS). Henceforth, the analysis of the leachability of SCC incorporated with FA and BA is narrowed down to these few specific heavy metals. The heavy metals selected are As, Cr, Pb, Zn, Cu, Ni, Mn, and Fe.

Table 1: Heavy metals of FA, BA, and OPC

| Heavy metals | Formula | FA | BA | OPC |
|--------------|---------|----|----|-----|
| Chromium     | Cr      | 217| 145| 69  |
| Manganese Oxide | MnO    | 900| 700| 700 |
| Iron (III) Oxide | Fe₂O₃ | 38800| 48700| 29600 |
| Nickel       | Ni      | 99 | 74 | 17  |
| Copper       | Cu      | 94 | 42 | 20  |
| Zinc         | Zn      | 50 | 30 | 132 |
| Arsenic      | As      | 35 | 12 | 33  |
| Lead         | Pb      | 54 | 14 | 41  |

2.1.1. Mix Proportions of SCC Incorporated with fly ash and bottom ash

The mix design of SCC incorporating with FA and BA are presented. Ten mixtures were designed for control sample with 0% FA and BA and mixture with various percentages of FA and BA (10%, 20%, 30% of FA and BA). The different percentages of FA and BA designed by considering in minimizing heavy metals leachability that can leach out from leaching testing under the regulatory level. Total binder for all the samples was between 530 kg/m³ to 550 kg/m³ respectively. Fly ash was replacing the cement in the percentages of 10%, 20% and 30% meanwhile bottom ash was replacing the sand with the same percentages. The details of the mix design for this research as tabulated in Table 2. Note that the proportion is for one batch casting (0.0475 m³).
2.2. Methods

2.2.1. Toxicity Characteristic Leaching Procedure (TCLP)

The Toxicity Characteristic Leaching Procedure (TCLP) was adopted by the USEPA in 1990 to replace the Extraction Procedure (EP) as the USEPA regulatory method for classifying wastes as hazardous based on toxicity [10]. This method is designed to determine the mobility of both organic and inorganic contaminants present in liquid, solid and multiphase wastes. In this research, the cube concrete sample was crushed into four portions finer than 9.5 mm for the analysis. The extraction fluid used for the extraction depends on the alkalinity of the waste material. Very alkaline waste materials are leached with a fixed amount of glacial acetic acid (CH₃CH₂OOH) with distilled water while other waste materials are leached with glacial acetic acid, distilled water and sodium hydroxide (NaOH). There were two types of extraction fluid as described in TCLP namely Extraction Fluid No.1 and Extraction Fluid No.2. After the determination of the extraction fluid has been done, the samples were prepared in screw-capped polyethylene bottles which were filled with crushed concrete samples and leaching fluid at the ratio of 1:20. The bottles were agitated at 30 rpm for 18 hours in an end-over-end manner (Figure 1). The leachate collected was then filtered using 0.7 μm glass fiber filters, preserved the sample before being analyzed using Atomic Absorption Spectrometry to determine the dissolved metals.

2.2.2. Synthetic Precipitation Leaching Procedure (SPLP)

The Synthetic Precipitation Leaching Procedure (SPLP) is an agitated extraction that is used to provide information on the mobility (leachability) of organic and inorganic constituents from liquids, soils, and wastes [11]. This procedure is similar to the TCLP but instead of the acetic acid mixture used with the TCLP to simulate landfill leachate, nitric and sulfuric acids are utilized to simulate the acid rain resulting from airborne nitric and sulfuric oxides. For sites east of the Mississippi River, the leaching fluid is a solution of 60% of sulfuric acid and 40% of nitric acid in distilled water until the pH 4.2. For sites west of the Mississippi River, a solution of sulfuric acid and nitric acid in distilled water, pH 5.0, is used as the leaching fluid. If the sample is a waste or wastewater, the extraction fluid employed is the pH 4.2 solution. For this research, extraction fluids with pH 4.2 solution were used. The next procedure is same with TCLP that has been described earlier.

Table 2: Mix proportions of SCC mixes incorporated with FA and BA

| Mix Design | Total Binder (kg/m³) | Cement (kg/m³) | FA (kg/m³) | CA (kg/m³) | Sand (kg/m³) | BA (kg/m³) | Water (kg/m³) | SP (kg/m³) |
|------------|---------------------|---------------|-----------|-----------|-------------|-----------|---------------|-----------|
| 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        | 220           | 4         |
| FA20BA20   | 540                 | 432           | 108       | 593       | 731         | 133       | 216           | 4         |
| FA30BA30   | 530                 | 371           | 159       | 593       | 640         | 200       | 212           | 4         |

*CA: Coarse aggregate; SP: super plasticizer
2.2.3. Static Leaching Test (SLT)

Another leaching testing used in this research was Static Leaching Test (SLT). A modified and simplified method from American Nuclear Society for solidified a low-level radioactive waste which is conducted for long term duration was considered in this research [12]. Static leaching methods are used to evaluate the release of an element from a material that typically exists as a massive solid and are frequently used to characterize the release of pollutants from stabilized waste materials [13]. The release element is a function of the exposed surface area as opposed to the mass. In SLT, a regular particle geometry and known surface area are immersed in a volume of leaching solution. The same leaching solution is sampled with no renewal of the solution to ensure leachate concentration is not interrupted by leachate renewal process. Also, the main objective of this test is to study long-term leaching behavior and to determine optimum quantity of heavy metals that leached out from FA and BA. In this test, ten whole solid concrete samples, containing 0% (control), 10%, 20%, 30% FA and BA was prepared. The whole concrete samples were suspended in a closed container for up to 200 days. The static leaching test was conducted as shown in Figure 2.

3. Result and Discussion

3.1. Toxicity Characteristic Leaching Procedure (TCLP) result

From the results of the TCLP test in Table 3, 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. Explanations of the results were discussed further according to Figure 3a, 3b, and 3c.

Table 3: Leachability of heavy metals in SCC samples in TCLP

| Samples | FA0BA0 | FA10BA0 | FA20BA0 | FA30BA0 | FA0BA10 | FA0BA20 | FA0BA30 | FA10BA10 | FA20BA20 | FA30BA30 |
|---------|--------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| As      | 12.060 | 14.705  | 14.895  | 15.370  | 13.640  | 13.675  | 14.640  | 16.510  | 18.200  | 18.576  |
| Cr      | 0.112  | 0.128   | 0.132   | 0.140   | 0.143   | 0.154   | 0.170   | 0.174   | 0.184   | 0.207   |
| Pb      | 0.447  | 0.783   | 0.847   | 0.909   | 0.578   | 0.646   | 0.695   | 0.940   | 1.024   | 1.028   |
| Zn      | 0.173  | 0.145   | 0.202   | 0.222   | 0.145   | 0.144   | 0.160   | 0.172   | 0.177   | 0.181   |
| Cu      | 0.026  | 0.030   | 0.030   | 0.031   | 0.029   | 0.026   | 0.031   | 0.033   | 0.034   | 0.035   |
| Ni      | 0.167  | 0.065   | 0.066   | 0.069   | 0.065   | 0.071   | 0.075   | 0.062   | 0.063   | 0.077   |
| Fe      | 0.095  | 0.074   | 0.083   | 0.083   | 0.053   | 0.034   | 0.017   | 0.136   | 0.037   | 0.000   |
| Mn      | ND     | ND      | ND      | ND      | ND      | ND      | ND      | ND      | ND      | ND      |

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

According to Figure 3a, the results showed the comparison of heavy metals concentrations for control sample which is FA0BA0 sample with samples incorporated with different percentages of FA. The As concentrations in FA0BA0, FA10BA0, FA20BA0 and FA30BA0 (12.060 mg/L, 14.705 mg/L, 14.895 mg/L, 15.370 mg/L respectively) was the highest leaching among other heavy metals. In fact, only Arsenic leached higher than the regulatory level set by USEPA (5 mg/L). Several factor which affect leaching potentials is type of extraction fluid, solid to liquid ratio, the number of extraction and the length of test duration. This is also explained by [14] in his research, whereby the metals leachate concentration is directly affected by the pH of the solution. The Cr, and Pb, concentrations in FA30BA0 (0.170 mg/L, 0.695 mg/L, and 0.202 mg/L respectively) were slightly higher than control
sample (FA0BA0) (0.112 mg/L, 0.447 mg/L and 0.173 mg/L respectively). In comparison to USEPA, these heavy metals were far below the regulatory level. The Cu and Ni concentrations were also recorded with similar trends of leaching. The highest leached of Cu and Ni concentration value were from the FA30BA0 sample with 0.031 mg/L and the lowest was from control sample (0.026 mg/L). The Ni concentration was recorded highest from the control sample with 0.167 mg/L and the lowest was from FA10BA0 sample with 0.065 mg/L while Fe and Mn concentrations were marginally low throughout the TCLP test.

Figure 3b: Comparison of heavy metal concentrations for control sample (FA0BA0) with samples incorporated with BA (FA0BA10, FA0BA20, and FA0BA30) using TCLP

Figure 3b shows the comparison of heavy metal concentrations for the control sample (FA0BA0) with samples incorporated with BA only (FA0BA10, FA0BA20, and FA0BA30) by using TCLP method. From the observation at different percentage of BA, it shows that the As leaching are the highest even in control (FA0BA0) samples. The highest peak of As leaching was recorded from FA0BA30 sample with 14.640 mg/L followed by FA0BA20 (13.675 mg/L), FA0BA10 (13.640 mg/L) and the lowest from the control sample (12.060 mg/L). Zn and Ni concentrations were recorded the highest value in the control sample (0.173 mg/L and 0.167 mg/L respectively) without the mixture of BA in it. Other heavy metals such as Cr, Pb, Cu, Fe and Mn concentrations were slightly low in all the samples and still in allowable value when compared to USEPA except Arsenic. Arsenic releases from acidic solution increase with pH, whereas in alkaline solution this trend is reversed [15].

Figure 3c: Comparison of heavy metal concentrations for control sample (FA0BA0) with samples incorporated with FA and BA (FA10BA10, FA20BA20 and FA30BA30) using TCLP

As can be seen in Figure 3c, Arsenic leaching was the major heavy metals leached from the samples. As such, the highest value for As was recorded from FA30BA30 sample with 18.576 mg/L. It is because the percentage of FA and BA in this sample was the highest to be compared to other samples.
heavy metal such as Cr, Pb, Zn and Cu concentrations in the 30% replacement of FA and BA in SCC (0.207 mg/L, 1.024 mg/L, 0.181 mg/L, and 0.035 mg/L respectively) were slightly higher than the control sample (FA0BA0) with (0.112 mg/L, 0.447 mg/L, 0.173 mg/L and 0.026 mg/L respectively). It shows that the results recorded higher concentration with the increasing of FA and BA replacement in the samples.

3.2 Synthetic Precipitation Leaching Procedure (SPLP) result
The leaching fluid for this test is a solution of 60% sulfuric acid and 40% of nitric acid in distilled water until the pH is 4.2. Table 4 summarizes the results determined for heavy metals by using the SPLP method. Further results were then explained according to Figure 4a, 4b, and 4c.

Table 4: Leachability of heavy metals in SCC samples in SPLP

| Samples          | FA0BA0 | FA10BA0 | FA20BA0 | FA30BA0 | FA0BA10 | FA0BA20 | FA0BA30 | FA0BA10 | FA20BA20 | FA30BA30 |
|------------------|--------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Concentration (mg/L) | 0.01   | 12.060  | 14.705  | 14.895  | 15.370  | 13.640  | 16.510  | 18.200  | 18.576  |
| As = Arsenic      | 0.05   | 0.112   | 0.128   | 0.132   | 0.140   | 0.143   | 0.154   | 0.170   | 0.174   |
| Cr = Chromium     | 0.01   | 0.447   | 0.783   | 0.847   | 0.909   | 0.578   | 0.646   | 0.695   | 0.940   |
| Pb = Lead         | 0.07   | 0.167   | 0.065   | 0.066   | 0.069   | 0.065   | 0.071   | 0.075   | 0.062   |
| Zn = Zinc         | 0.095  | 0.074   | 0.083   | 0.083   | 0.053   | 0.034   | 0.017   | 0.136   | 0.037   |
| Cu = Copper       | 0.4    | ND      | ND      | ND      | ND      | ND      | ND      | ND      | ND      |
| Ni = Nickel       | 0.8    | ND      | ND      | ND      | ND      | ND      | ND      | ND      | ND      |
| Fe = Ferum        | 0.4    | ND      | ND      | ND      | ND      | ND      | ND      | ND      | ND      |
| Mn = Manganese    | 0.4    | ND      | ND      | ND      | ND      | ND      | ND      | ND      | ND      |

* US Environmental Protection Agency, USEPA (1996); NA – Not Available; ND – Not Detected
**Guideline values for chemicals that are of health significance in drinking-water, WHO (2006) [16]

Figure 4a: Comparison of heavy metal concentrations for control sample (FA0BA0) with samples incorporated with FA (FA10BA0, FA20BA0, and FA30BA0) using SPLP

Referring to Figure 4a, the results demonstrated the comparison of heavy metals concentrations for control sample which is FA0BA0 sample with samples incorporated with different percentages of FA using SPLP. The As concentrations in FA0BA0, FA10BA0, FA20BA0 and FA30BA0 with 8.349 mg/L, 7.216 mg/L, 7.477 mg/L, and 7.868 mg/L respectively were the highest leaching concentrations
among other heavy metals. In fact, only the As reached higher than the regulatory level set by USEPA (5 mg/L) and WHO (0.01 mg/L). The second greatest heavy metal in the SPLP samples was Pb ranging from 0.266 mg/L to 0.436 mg/L. Meanwhile, heavy metals such as Ni, Fe, and Mn concentrations were not detected in the samples used in SPLP method. Other than that, Pb, Zn, Cr, and Cu were leached in very low concentrations. In comparison to USEPA (1996), all the heavy metals were recorded below the concentrations level except for As. The concentration of As and Pb were higher than WHO level for all the samples.

From Figure 4b, the results had shown different leaching level with different percentages of BA in the samples. From the observation, it shows that As is the highest heavy metals that leached out followed by Pb, Zn, Cr, and Cu. Meanwhile, for Ni, Fe, and Mn, the results were not detected in the samples incorporated with BA. As was recorded the highest with 8.349 mg/L and the lowest for As was 6.376 mg/L from FA0BA10 sample. Meanwhile Pb is the second largest heavy metals that leached out was ranging from 0.266 mg/L to 0.667 mg/L. From the observation, only As was exceeded the permissible limit given by USEPA. On the other hand, the concentration of As and Pb were slightly higher than WHO regulatory level but still considered as low concentration as well.

Figure 4c shows heavy metal concentrations for control samples with samples incorporated with BA using SPLP. As can be seen, the trend was similar to samples incorporated with FA only and samples incorporated with BA only. It shows that highest heavy metal concentration was Arsenic. The Arsenic concentration for control sample is 8.349 mg/L. Meanwhile, for samples incorporated with FA and BA which is FA10BA10 (8.133 mg/L), FA20BA20 (8.213 mg/L) and FA30BA30 (8.415 mg/L).
mg/L) of As concentration. It shows that higher percentages of FA and BA in the samples produce higher heavy metal concentrations. Another observation has been made for heavy metals such as Ni, Fe, and Mn. The result shows that these three heavy metals were not detected in SPLP samples. Meanwhile for Cr, Pb, Zn and Cu, the results were leached in low concentration. However, As and Pb concentrations were once again over the WHO limit and did not fulfill the requirements.

3.3 Static Leaching Test (SLT) result

Static Leaching Test (SLT) test was tested to simulate weathering for continuous exposure to acid rain. Hence, the leaching fluid used in this SLT test used the same leaching fluid for SPLP. The concentrations of selected heavy metals element such as As, Mn, Cu, Cr, Zn, Ni, Fe, and Pb along the period of 4, 8, 12, 36, 40, 60, 80, 100, 120, 140, 160,180 and 200 days were measured using AAS. Figures 5a to 5j summarized the results of heavy metal concentrations at the specified sampling periods.
The concentration of selected heavy metals (As, Mn, Cu, Cr, Zn, Ni, Fe, and Pb) in the synthetic acid rain leachate collected from the SCC specimens were significantly lower than the limit specified by the USEPA (1996) [17]. The results produced slightly lower values than TCLP and SPLP due to the differences in the types of samples and the leachant used. Even though SLT were carried out after 200 days, the results revealed that all the elements were leached in small value compared to the TCLP.
and SPLP results. As a whole samples (without crushing), these observations indicate that the cement chemistry of the hydrated cement paste in each concrete controls the leaching concentration of most materials at alkaline condition [15]. As for a comparison with WHO guidelines, elements such as As, Pb, and Ni in most cases have exceeded the guidelines. However, these elements were detected in low concentration in SLT test. Much of this variability can be explained by differences in the compositions of the coal combustion products which is in this case FA and BA [18].

The materials of FA and BA maybe bound up in the SCC due to the lack of heavy metals concentration leach from the specimens. The concentrations of heavy metals in the leachate were lower than the detection limit is due to the solidification/stabilization process that takes place when to apply cement binders. Besides that, the immobilization of heavy metals is believed to be caused by chemical changes like pozzolanic reactions incorporate into a solid matrix during the process of solidification take place [19].

4. Conclusion
The concentration of heavy metals elements such as Cr, Mn, Cu, Zn, As and Pb showed that FA contained the highest concentration value compared to OPC and BA. From TCLP, As leaching was the only heavy metals that leached out from the samples and exceeded the limit set by USEPA. Meanwhile for SPLP, once again the results show that that the highest heavy metal concentration that leached out from the samples was As. The Arsenic concentrations for control sample are 8.349 mg/L. For samples incorporated with FA and BA, which is FA10BA10 (8.133 mg/L), FA20BA20 (8.213 mg/L) and FA30BA30 (8.415 mg/L) of As concentration. The important factor that effects the leaching of heavy metals concentrations is the pH value of the leachant. TCLP results show higher value compared to SPLP result because the leaching is more acidic compared to SPLP. Meanwhile for SLT results, it revealed that heavy metals concentrations in all the samples were leached in low concentration even the test has been conducted up to 200 days. From these three results, it indicated that 20% of FA and BA (FA20BA20) in SCC are recommended since it leached less heavy metal. As environmental concerns is a top priority, it was concluded that FA20BA20 sample will serve better in concrete technology regarding economic-viability as it also provides a good strength. All in all, FA and BA are both man-generated wastes that are steadily accumulating every year. Hence, a proper sustainable and safe way of reusing such waste materials as in this research is useful towards the environment and sustainability for construction purposes.

5. References

[1] 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.
[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] Kim, B, Prezzi, M., and Salgado R.,(2005), “Geotechnical properties of fly and bottom ash mixtures for use in highway embankments.” *Journal of Geotechnical Geo-environment Engineering*. 131(7), 914–924.
[4] 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.
[5] Muhardi, A., (2010). Engineering characteristics of Tanjung Bin coal ash. *Electronic Journal of Geotechnical Engineering*, Vol. 15, pp.1117–1129.
[6] USEPA, (United State Environmental Protection Agency). Wastes – Resource Conservation – Reduce, Reuse, Recycle – Industrial Materials Recycling. Available online http://www.epa.gov/epawaste/conserve/rrr/imr/ccps/flyash.htm (accessed on 12th April 2010).
[7] 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.

[8] Sua-Iam, G. & Makul, N., (2015). Utilization of coal- and biomass-fired ash in the production of self-consolidating concrete: A literature review. *Journal of Cleaner Production*, 100, pp.59–76.

[9] 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.

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

[11] SPLP. Synthetic Precipitation Leaching Procedure. (1994). US Environmental Protection Agency, Method 1312.

[12] American Nuclear Society (2003). ANSI/ANS.16.1:2003. Measurement of the Leachability of Solidified Low-Level Radioactive Wastes by a Short-Term Test Procedure.

[13] 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.

[14] Garrabrants, A.C., Kosson D., DeLappa, R., van der Sloot H., (2014). Effect of coal combustion fly ash use in concrete on the mass transport release of constituents of potential concern. *Chemosphere, Vol.* 103, pp.131–9.

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

[16] World Health Organization (WHO) (2006). Guidelines for Drinking Water Quality.

[17] USEPA Environmental Protection Agency, United States (1996). Hazardous wastes characteristics (scoping study).

[18] Jones, K, Leslie F, and Sharon M. (2012). “Leaching of Elements from Bottom Ash, Economizer Fly Ash, and Fly Ash from Two Coal-Fired Power Plants” *International Journal of Coal Geology*, Vol 94 pp 337–348.

[19] Gines, O., Chimenos, J. M., Vizcarro, A., Formosa, J. &Rosell, J. R., (2009). Combined use of MSWI bottom ash and fly ash as aggregate in concrete formulation: Environmental and mechanical considerations. *Journal of Hazardous Materials, Vol.* 169, pp. 643 – 650.