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Leachability of Self-Compacting Concrete (SCC) Incorporated With Fly Ash and Bottom Ash by Using Toxicity Characteristic Leaching Procedure (TCLP)

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Abstract. The process of combustion in coal fired power plant generates ashes, namely fly ash (FA) and bottom ash (BA). In addition, coal ash generated from coal combustion generally contains heavy metals within their compositions. These metals are toxic to the environment as well as to the human health. Fortunately, treatment methods are available for these ashes and the use of FA and BA in concrete mix is one of the few. As such, this study presents the work in determining the leachability of self-compacting concrete (SCC) incorporated with FA and BA. The ashes were obtained from Kapar Energy Ventures power plant in Kapar, Selangor. SCC mixtures incorporated with 10%, 20% and 30% FA (replacing cement) and BA (replacing sand) respectively was formulated and casted. The samples were then crushed to be extracted using Toxicity Characteristic Leaching Procedure (TCLP) and heavy metals content within the samples were identified accordingly using Atomic Absorption Spectrometry (AAS). From the results, it was found that incorporation up to 30% of the ashes were safe as the leached heavy metals concentration did not exceed the regulatory levels, except for arsenic (As). On the other hand, incorporation of 20% FA and BA each in SCC provided the most economically viable product, with high strength and low leachate concentrations. In conclusion, this study will serve as a reference which suggests that FA and BA are widely applicable in concrete technology and its incorporation in SCC constitutes a potential means of adding value with appropriate mix and design.

Introduction

Fly ash (FA) and bottom ash (BA) are some of the residues produced from the combustion process in an incineration plant. Generally, the total amount of FA and BA produced accounts for 80% of the total residues produced from incineration, as well as air pollution control (APC) residues [1]. The residue weighs differently from 5% to 30% before combustion depending on the composition, combustion temperature and time [2]. Basically, FA may consist of fine particles with a large amount of heavy metals, organic compounds and chlorides [3]. BA on the other hand, can be explained as heterogeneous particles that consist of various elements such as glass, metals, mineral, ceramics and unburned materials [4]. In short, FA and BA both contain a variety of hazardous elements such as easily leachable heavy metals, soluble salts and organic compounds. This must be acknowledged as a concerning threat to the environment as well as its jeopardizing impact on life.

Researchers Chang and Wey (2006), and also Aubert, Husson and Vaquier (2004) described the diminishing effect of landfill application for FA and BA disposal in Taiwan and France respectively [5, 6]. Hence, the matter resulted in incineration of the solid wastes to reduce the volume of disposal, which in turn created the ashes as combusted by-products. The leachability of heavy metals of untreated FA and BA remained as the only flaw in this alternative.

BA had already been reused mainly as ingredients for roads and as aggregate or sand material in concrete. Meanwhile, due to the high content of heavy metals in FA, the ashes had very limited usage and were mostly disposed at landfills. However, in recent years, FA has been proven to be potentially applicable as a replacement of cement in concrete industries due to its cementitious properties. During cement hydration process, ettringite, a complex mineral, can be found and it turned out to be advantageous towards strength growth of the end product.

As such, the aim of this research was to incorporate the contaminated ashes, FA and BA, into the application of SCC as building materials. Most researches were dedicated in finding the direct effects from the incorporation of wastes into their subject of study based on changes in mechanical and chemical properties, durability and strength variations before this. Environmental effects however, were either omitted or less elaborated. Therefore in this paper, both compressive strength and leachability effects from the incorporation were determined, analyzed and presented.

Experimental Programs

Materials. The ashes were obtained from a thermal plant known as Kapar Energy Ventures (KEV) located at Kapar, Selangor. KEV generates about 2420 MW, contributing around 15% of the country's demand for energy.

The material characterization of FA and BA were carried out through X-ray fluorescence (XRF) test, performed using Bruker AXS S4 PIONEER. FA and BA samples used for the test were prepared in the forms of pellets, abiding a sample to wax ratio of 8:2, according to Pressed Pellet Technique. The chemical compositions of the ashes are shown in Table 1.

Table 1: Average chemical composition of FA, BA and Ordinary Portland Cement (OPC)

Inorganic elements / Chemical compounds	Formula	Concentration (mg/L)		
		FA	***BA***	***OPC***
Chromium	Cr	228	176	54
Manganese Oxide	MnO	900	800	800
Iron (III) Oxide	Fe_2O_3	41600	52600	30200
Nickel	Ni	107	88	19
Copper	Cu	101	38	26
Zinc	Zn	52	31	164
Arsenic	As	38	12	37
Lead	Pb	62	18	60

Among all of the elements and compounds in the ashes detected by XRF, only the metal elements detectable by Atomic Absorption Spectrometry (AAS) are listed in Table 1.

Aggregate and sand used in SCC manufacture generally complied with the requirements of EN 206-1 [7]. For aggregates, sizes from 14-20 mm were prepared by sieving method. OPC was used in accordance to EN 197-1 [8] whereas admixtures were checked to comply with EN 943-2.

Mix Proportions. A total number of 10 specimens including control SCC with 0% of ashes incorporation were prepared and studied in this research. Total binder for all the specimens were between 530kg/m^3 to 550 kg/m^3 respectively. FA was replacing the cement in the percentages of 10%, 20% and 30% meanwhile BA was replacing the sand with the same percentages. Standard moulds of 150 mm^3 according to BS EN 12390-1 [9,10] were used to contain the fresh SCC prepared.

Testing of the specimens. After compressive strength test, the fractured cubes were crushed using a steel hammer to obtain smaller fragments of the specimens. The fragments 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) [11].

TCLP was used as a set of instructions to prepare extracted samples of concrete specimens in order for leachate analysis to be done. As SCC cubes were solid specimens, 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 samples were checked in order to determine the suitable extraction fluid to be used. It was found that the pH for all samples exceeded 5.0; hence extraction fluid #2 was prepared and used to extract the samples.

Extraction fluid #2 was prepared by diluting 5.7 mL glacial acetic acid (CH_3COOH) with distilled water to a volume of 1 L. A total of 50 g sample was prepared and placed into a 2 L 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 solution within the extraction bottle was then filtered to dispel the solid particles. 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.

Result and Discussions

Characteristics of the Materials. From Table 1, it was seen that majority of the concentrations of elements in FA were much higher than that in BA, where OPC only had small amounts as compared to FA. This is because BA comprise mostly of inert and non-combustible fractions of the solid waste which consist of lower concentrations of heavy metals. More reactive elements are often burnt and reduced to ashes, cumulated as FA, while inert and non-combustible materials are swept down the furnace and collected as BA. Thus, FA naturally possesses a higher risk in leaching hazardous heavy metals.

Leachability of heavy metals. The obtained data of leachate concentrations are tabulated in Table 2 whereby it compares the results with the concentration limits of each heavy metal detected respectively.

The data displays that the concentrations of all the heavy metals in leachate from FA only incorporated concrete was less than the allowable concentration except for As which was the only heavy metal that leached in large amounts even in the control specimen. Similarly, BA incorporated concrete and also FA and BA incorporated concrete both exhibited the same behaviour. The reason for the high amount of As leaching is due to the direct effect of the extraction fluid used. The TCLP extraction fluid was acidic with a pH of 2.88, hence causing As to had continuously leached out under acidic conditions during the extraction process.

The leaching behaviour of As in each specimen is way above the limit of 5 mg/L allowed by USEPA. However, this does not necessarily represent the nature of the leachates excreted by crushed SCC. As mentioned earlier, low pH causes this metal to leach out more. Therefore, if given normal undisturbed conditions, the crushed SCC may not leach out such a high amount of As. The trends suggest that As leaching is more influenced by the increment of FA volume in SCC since As leaches the least when BA volume is the highest. Indirectly, it also points out that acid reacts more readily with FA than BA

Table 2: Result for heavy metals in SCC specimens using TCLP

Heavy metal	Concentration level* (mg/L)	Concentration level** (mg/L)	Leachate concentration (mg/L)									
			Control	FA10BA0	FA20BA0	FA30BA0	FA0BA10	FA0BA20	FA0BA30	FA10BA10	FA20BA20	FA30BA30
As	5	2.8	26.52	23.89	25.19	25	27.82	26.94	24.8	23.51	24.49	27.47
Cr	5	0.8	0.033	-	-	-	-	-	-	-	-	-
Pb	5	4	0.447	0.578	0.646	0.695	0.783	0.847	0.909	0.94	1.028	1.024

Zn	500	1200	0.173	0.173	0.202	0.222	0.145	0.144	0.16	0.172	0.177	0.181
Cu	100	800	0.026	0.029	0.026	0.031	0.03	0.03	0.031	0.033	0.034	0.035
Ni	1.34	88	0.135	0.187	0.211	0.221	0.26	0.132	0.064	0.287	0.061	-
Fe	-	-	0.095	0.074	0.083	0.083	0.053	0.034	0.017	0.136	0.037	-
Mn	-	-	0.033	0.027	0.105	1.235	0.007	-	-	-	-	-

*United States Environmental Protection Agency (USEPA, 1996) [12]
**EPAV (2005) [13]

The standard allowable leaching limit of Cr is 5 and 0.8 mg/L and the specimens leachate complied with the maximum concentration permitted. Similar to Cr, Mn leaching concentration practically recorded zero for all specimens too, except for FA30BA0, which had a value of 1.235 mg/L. This value is considered small and insignificant. On the other hand, it is seen that Pb concentration demonstrated an almost linearly increasing trend in the figure. This adheres to logic, whereby the more ashes incorporated into the concrete mix; the more amount of Pb leaches out from its crushed state. In addition, it is also clearly seen that Pb leaches out in higher amount from BA. The highest concentration detected was 1.028 mg/L in 20% FA and BA incorporated SCC. However, given that the concentration limit of Pb in leachate is 5 and 4 mg/L, the former number seems irrelevant.

Zn also displayed and inclining trend in leachate concentrations, but the amounts are still way below the threshold of 500 and 1200mg/L. On a different note, Cu recorded an inclining creep in SCC incorporated with BA, and both FA and BA as well, except for a fluctuated trend in FA incorporated specimens. This irregular pattern is relatively difficult to interpret without substantial data and further distinct analysis. It is claimed that the speciation of Cu contained in BA does not change while only the release of Cu from FA is affected by the S/S process. Indirectly, it explains the rather constant trend of Cu leaching behaviour in SCC incorporated with BA only. Nevertheless, leaching concentrations of Cu is still below the regulatory level which is 100 and 800 mg/L. The allowable maximum concentration for Ni is 1.34 and 88 mg/L, which is not exceeded by any specimen's leachate as well. Fe leaching behaviour is similar to Ni, but with much smaller amounts of concentrations.

Overall, incorporation up to 30% of FA and BA each or both ashes together in SCC in this research did not produce a leachate concentration which will serve as a threat to the environment and its surroundings when crushed.

Conclusions

In conclusion, the outcome of this research achieved the aims of this study successfully. In order to determine the characteristics of FA and BA, raw samples of the ashes were obtained and analyzed using XRF. Again, it was found that concentrations of elements in FA were generally higher than that in BA. Secondly, in order to incorporate different percentages of the ashes into SCC separately and combined as well, trial mixes were formulated and casted up to a total of 60 specimens. Leachability of heavy metals of SCC incorporated with FA and BA was determined using TCLP. Based on the results, incorporation up to 30% of the ashes was still acceptable as the relative leachate concentrations were far below the concentration limits. Apart from As, the rest of the described metals were leached in a very low amount of concentration. As environmental concerns is a top priority, it was concluded that FA20BA20 mixture will serve better in concrete technology in terms of economic-viability as it also provide a good strength. 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 thoughtful towards the environment and sustainably productive for construction purposes.

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