CHEMICAL ENGINEERING TRANSACTIONS

VOL. 56, 2017

A publication of AIDIC
The Italian Association
of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Jiří Jaromír Klemeš, Peng Yen Liew, Wai Shin Ho, Jeng Shiun Lim

ISBN 978-88-95608-47-1; **ISSN** 2283-9216

DOI: 10.3303/CET1756074

Workability, Compressive Strength and Leachability of Coal Ash Concrete

Mahdi Rafieizonooz*[,a], Mohd Razman Salim[b], Mohd Warid Hussin[c], Jahangir Mirza[c], Salmiati Muhd Yunus[b], Elnaz Khankhaje[a]

[a]Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor Bahru, Malaysia
[b]Centre for Environmental Sustainability and Water Security, Faculty of Civil Engineering, Universiti Teknologi Malaysia
[c]UTM Construction Research Centre (UTM CRC), Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor Bahru, Malaysia
mahdirafiei1982@yahoo.com

One of the essential steps for planning solid waste management towards sustainable development is to reuse solid waste in the construction industry. Coal is one of the world's most important sources of energy, fueling almost 40 % of electricity worldwide. Malaysia is commonly producing electricity through burning millions of tonnes of coal. This process generates around 8.5 Mt of coal ash, which comprised of 80 % Fly Ash (FA), and 20 % Bottom Ash (BA) as waste. The study aims to investigate the workability, compressive strength and leachability of concrete containing BA and FA as replacement of sand and cement. Cement was substituted with 20 % of FA by mass and fine aggregate was replaced with BA at 0, 20, 50, 75 and 100 % in the concrete mix. The results show that the percentage sum of SiO_2, Al_2O_3 and Fe_2O_3 (the main chemical composition in coal ash) in FA and BA are about 78.82 % and 83.24 %. The leaching test showed that the heavy metal concentrations in leachates are much lower than recommended in the USEPA SW 846. Workability of concrete was reduced by increasing BA content as a sand replacement in the concrete mixture. After 91 d and 180 d curing periods, the compressive strength of both the experimental and control samples of concrete were roughly comparable. It can be concluded that BA and FA can be used as a replacement of sand and cement in normal concrete without any environmental problem.

1. Introduction

High production of industrial wastes, as well as excessive consumption of natural resources have resulted in negative impacts on the environment. Reduction in the utilisation of raw materials and energy can lead to resource efficiency enhancement in addition to reduced environmental problems. Subsequently, the increase in resource efficiency would enable a sustainable development. Previous researches have shown that it is possible to produce durable concrete utilising industrial waste materials such as red mug aggregates, silica fume, blast furnace slag, coal fly ash (FA) and coal bottom ash (BA). Decreasing the utilisation of construction materials through the application of industrial by-products wastes in manufacturing concrete is a right step towards a sustainable development (Khankhaje et al., 2015).

According to ST (2014), it is predicted that by the year 2024 the production of electricity will be based on usage of coal and gas (58 % and 25 %). This prediction shows that the production of electricity by burning coal will be increased from 43 % in 2014 to 58 % in 2024. It is clear that by increasing the amount of coal, the volume of coal ash will increase so does its environmental problems.

In general, two types of ash, fly ash (FA) and bottom ash (BA) are produced at coal power plant (80 % - 20 %). The majority of these kind of ash are being abandoned as the waste materials near the factory. It might result in lots of environmental and disposal problems due to a large space of dump yard is required. The production of electricity in Malaysia resulted in huge amount of BA some 1.7 Mt and FA around 6.8 Mt, generated annually. Even though FA is being used in production of concrete and blended cement, BA is not usually used at all.

Please cite this article as: Rafieizonooz M., Salim M.R., Hussin M.H., Mirza J., Yunus S.M., Khankhaje E., 2017, Workability, compressive strength and leachability of coal ash concrete, Chemical Engineering Transactions, 56, 439-444 DOI:10.3303/CET1756074

Several researches have studied the characteristics of concrete containing BA as a fine aggregate replacement (Jang et al., 2016). However, the combined utilisation of FA as partial replacement of OPC and BA as partial or total replacement of sand has been studied by few researches (Rafieizonooz et al., 2016). There is not enough study about leachability of concrete containing BA and FA as sand and cement replacement.

Cheriaf et al. (1999) investigated the pozzolanic characteristic of coal ash concrete and found that BA has pozzolanic property and is appropriate to be used in concrete production. Kim and Lee (2011) reported that BA can be utilised as replacement of river sand in the manufacturing of high-strength concrete. Singh and Siddique (2013) stated that BA is a potential substitute waste for fine aggregate in concrete. Singh and Siddique (2015) also studied the characteristics of concrete containing a high volume of BA as a substitute of fine aggregate. Aggarwal and Siddique (2014) studied the microstructure and characteristics of concrete incorporating BA and waste foundry sand as a substitute of fine aggregate in the production of concrete.

There are several researches documenting heavy metal concentrations and leaching in coal ash concrete from different countries such as Australia (Jankowski et al., 2006), USA (Heidrich et al., 2013), India (Prasad and Mondal, 2008), South Africa (Musyoka et al., 2013) and Zimbabwe (Gwenzi and Mupatsi, 2016). The majority of this researches concentrate on leaching behaviour of heavy metals from unbound coal ash. The findings of these literature are in contrast with each other: Some researcher (Sushil and Batra, 2006) stated that some heavy metals could be leached out from coal ash; whereas other (Gwenzi and Mupatsi, 2016) reported that the leaching of mentioned elements from coal ash was unimportant. These conflicting findings might be due to differences in leaching method and procedures, variability in type and origin of coal burned, types of boiler, the degree of coal pulverization, firing conditions in the furnace, ash handling practice and processing technologies used in thermal power stations.

The objectives of this study were to evaluate the influences of the utilisation of BA and FA as partial or total replacement of fine aggregates and cement on concrete compressive strength and workability as well as to investigate leaching of heavy metals in coal ash concrete.

2. Materials and methods

2.1 Materials

Ordinary Portland Cement (OPC) used in this research is in accordance with ASTM C150 (2007). A single source of BA and FA was obtained from Tanjung Bin coal power plant located in Johor, Malaysia. The chemical properties of cement, FA and BA are shown in Table 1. Cement and FA used in this study had a Fineness modulus, specific gravity, and soundness of 3,990 and 3,450 cm^2/g, 3.15 and 2.45, 1.0 mm. Moreover, BA was sieved through 4.75 mm sieve before use as a replacement of fine aggregate in this research.

Table 1: Chemical properties of OPC, FA and BA

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	SO_3	BaO	LOI
OPC	20.4	5.20	4.19	62.3	1.55	-	0.01	-	2.11	-	2.36
FA	47.6	23.8	7.42	10.7	1.50	2.16	1.68	2.92	0.76	0.15	-
BA	45.3	18.1	19.84	8.70	0.97	-	2.48	3.27	0.35	0.31	-

River sand was obtained from Sungai Sayong quarry located in Johor, Malaysia. The river sand used in this study was graded in accordance with the ASTM C33 / C33M (2013). The coarse aggregate was collected from Bukit Namu quarry. The maximum size of crushed stone coarse aggregate was 20 mm. The results of physical properties (specific gravity, water absorption and fineness modulus) of BA, River sand and coarse aggregate are presented in Table 2.

Table 2: Physical characteristics of BA, sand and coarse aggregate

Material	BA	Sand	Coarse aggregate
Specific gravity	1.88	2.62	2.69
Water absorption (%)	11.61	7.4	0.61
Fineness modulus	3.44	2.67	6.48

2.2 Mix proportion and casting

Concrete cubes of 100 mm × 100 mm × 100 mm sizes with 20 % of FA as cement replacement and 0, 25, 50, 75 and 100 % of BA as a fine aggregate were cast to evaluate the workability and compressive strength. Saturated Surface Dry (SSD) BA and sand were utilised in all of the concrete specimens. The BA was utilised by mass in concrete as a substitute of fine aggregate. The water-cement ratio (w/c) was 0.55 for all concrete samples. The constant amount of cement (375 kg/m^3) and the range of slump (6–18 cm) were the same for all produced concretes. The British (DOE) (BS EN 206 2013) method was utilised to evaluate the mixture ratios. In addition, after compressive strength test, crushed concrete was collected for leaching test.

2.3 Compressive strength and workability

Compressive strength of concrete samples was evaluated at 7 d, 28 d, 91 d and 180 d ages of curing in accordance with BS EN 12390-03 (2009). The 3,000 kN compression testing machine was used for applying constant force with the rate of 5.0 kN/s on SSD cubes. Slump test was done for calculating the workability of concrete mixtures.

2.4 Leaching Test

Toxicity Characteristics Leaching Procedure (TCLP) which was carried out by some researcher (Yilmaz 2015) was used in this study. According to TCLP method 1311 (U.S. EPA 2015), liquid-to-solid (L:S) ratio is 20:1. Therefore in this research, crushed concrete was collected and sieved through 2 mm sieve. After sieving, 50 g of the mentioned sample was added into HDPE (high density polyethylene) bottles. Then, 1 L of leaching solution (reagent water with acetic acid and acetic acid-NaOH) was added to the bottles to achieve the initial pH of 2.88 ± 0.05 and 4.93 ± 0.05. Afterwards, the bottles were rotated at 30 ± 2 rpm in a Rotary Agitation Apparatus for around 18 h in 20 ± 2 °C. After rotating, the pH of the eluates wwas recorded subsequently. After all, the eluates were filtered by vacuum filtration using glass filter with a 0.45 µm filter holder and acidified with HNO_3 (nitric acid) to a pH lower than 2 and kept in the refrigerator in temperature less than 4 °C. the concentration of elements in samples were evaluated by Inductively coupled plasma mass spectrometry (ICP-MS).

3. Results and Discussion

3.1 Workability

Using industrial waste materials in concrete as replacement of fine aggregate by BA combined with a replacement of cement by FA could influence on the workability of coal ash concrete (CAC) mixtures. The slump is a one of the main measurement that is indicating the workability of concrete. Table 3 indicates the mix proportion and the result of slump test on CAC and control concrete mixtures. It is clear that by increasing the content of BA in CAC mixtures, the slump value decreased. According to Table 3, the slump values of control mix C0, CAC1, CAC2, CAC3 and CAC4 were 7.3 cm, 9.2 cm, 7.6 cm, 5.3 cm and 3.7 cm. The water absorption of BA (11.61 %) is higher than river sand (7.4 %) and it could be the reason for decreasing workability of CAC mixtures by increasing the amount of BA. On the other hand, replacement of OPC by FA, caused an increase in slump value and the combination of BA and FA in CAC mixtures result in a different range of slump. Up to 50 % substitute level of BA, CAC mixtures CAC1 and CAC2 presented more increase in a slump when compared to that of normal concrete mix C0. Instead, by increasing BA content in CAC mixtures CAC3 and CAC4, considerable reduction happened in a slump when compared to C0 normal concrete mix. The outcomes of this study are comparable to those stated by Singh and Siddique (2014b).

Table 3: Workability and Mix proportion of concrete mixtures

Codes	Cement		Fine aggregate		w/c	Slump (cm)
	FA	Cement	BA	Sand		
Control	0	100	0	100	0.55	7.3
CAC1	20	80	25	75	0.55	9.2
CAC2	20	80	50	50	0.55	7.6
CAC3	20	80	75	25	0.55	5.3
CAC4	20	80	100	0	0.55	3.7

3.2 Compressive Strength

The results of compressive strength test are shown in Figure 1. The compressive strength development pattern for CAC mixtures during the entire curing period is nearly the same as that of normal concrete. At the early age of curing (7 d), the compressive strength of CAC mixtures decreased with increase in BA volume as replacement of fine aggregate. By increasing the curing time, the compressive strength of CAC mixtures increased at a higher rate than the normal concrete. At 28 d curing age, CAC mixtures CAC1, CAC2, CAC3 and CAC4 achieved 85.38 %, 84.86 %, 80.62 % and 79.26 % of the compressive strength of the normal concrete mix C0. At the curing age of 91 d, the compressive strength of CAC mixtures CAC1, CAC2, CAC3 and CAC4 were 33.44 MPa, 34.55 MPa, 34.20 MPa and 33.85 MPa as compared to 34.48 MPa of the normal concrete specimen. Rapid increase in compressive strength of CAC mixtures could be attributed to the pozzolanic activity of BA and FA. Previous study (Singh and Siddique, 2015) found that the utilisation of by-product BA results in pozzolanic action and it was notable between 28 d and 91 d.

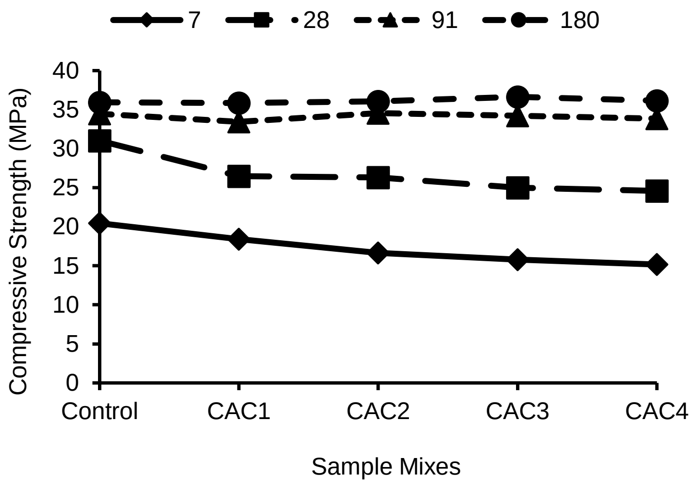

Figure 1: Compressive strength of concrete mixtures versus time

At curing period of 91 d and 180 d, the expansion of Calcium Silicate Hydrate (C-S-H) gel and creation of extra C-S-H gel occurred because of utilisation of portlandite by the pozzolanic action of BA and FA particles leads to higher compressive strength of CAC mixtures. At 180 d of the curing period, the compressive strength of CAC mixtures CAC1, CAC2, CAC 3 and CAC4 were 35.85 MPa, 36.04 MPa, 36.64 MPa and 36.12 MPa as compare to 35.95 of the normal concrete mixture. The results of this study are in agreement with the finding by Singh and Siddique (2014a), Kim and Lee (2011) and Ghafoori and Bucholc (1997). They also reported that there is no considerable change in compressive strength with the utilisation of BA as a substitute of fine aggregate in concrete.

3.3 Leaching Test

Concentrations of the selected components (As, Ba, Be, Cd, Cr, Co, Cu, Pb, Hg, Ni, Se, Ag, Ti, V, Zn) in both eluates with two different initial pH (2.88 and 4.93) obtained from TCLP method were measured by ICP-MS. Table 4 indicates the result of TCLP method on CAC4 mixture particles (for rest of elements, the amount of leaching were not detected). The maximum amount of BA (100 %) as replacement of fine aggregate is applied for the CAC4 mixture, then CAC4 mix was selected for leaching test. All of the elements showed much lower leaching results than standard regulation as mentioned by US EPA SW-846.

All of the elements, except Co and Zn, were leached at higher proportions with initial pH of 2.88. It is clear that on the acetic environment, most of the elements were leached at higher proportion. Due to the acidic environment, the permeability of concrete particles increased and because of increasing in permeability of concrete particles, heavy metals could be released faster and simpler. However, it can be concluded that, there is no significant leaching for TCLP method for both initial pH of 2.88 and 4.93.

The results of this research are in agreement with the findings by Drakonaki et al. (1998); Beard (2002) and Gwenzi and Mupatsi (2016). They also found that the leaching of heavy metals from coal ash concrete was insignificant and did not need to be considered.

Table 4: Leaching test results and Standard limitation (US EPA) (mg/L)

Symbol	Ba	Cr	Co	Pb	Ni	Zn
Initial pH: 2.88	0.57	0.03	0.01	0.02	0.02	0.02
Initial pH: 4.93	0.43	0.02	0.01	0.01	0.01	0.03
Standard Limit (mg/L)	100	5.0	80	5.0	20	250

4. Conclusions

Influences of the utilising BA and FA as a substitute of fine aggregate and OPC on workability, compressive strength and leaching of coal ash concrete were studied. The following results can be taken from this study:

1. The workability of CAC mixtures were decreased because of using of BA as replacement of river sand in concrete. In fact, use of BA as a sand substitute, increase the concrete's structure with many more porous particles, fine-shaped and irregular. Therefore, it increases the particles friction which is the main reason for preventing the flow of fresh concrete.
2. The performance of CAC mixture in relation to the compressive strength at similar curing period was almost comparable to that of the normal concrete. At the curing period of 28 d the compressive strength of normal concrete was higher than that of the coal ash concrete specimens. Nevertheless, by increasing in curing time, the compressive strength of the CAC specimens increased with a higher rate than normal concrete. At the curing time of 91 d, the compressive strength of CAC mixtures was almost close to the normal concrete and after 180 d of curing age, it surpassed the figures obtained by the normal concrete.
3. Generally leaching was higher in the high acidic media (pH 2.88) as compared to the low acidic media (pH 4.93). However, results of leaching of all the elements showed that the concentration values are far below the limit regulation as provided by US EPA. Therefore, BA as a sand replacement and FA as a substitute for cement can potentially be used in the production of concrete with acceptable characteristics.

Acknowledgements

The authors thank to Universiti Teknologi Malaysia for the financial support provided through the Ministry of Education Malaysia under OTR grant, Vot. R.J1300000.7301.4B145. They also appreciate the support given by the Japan International Cooperation Agency (JICA) under the scheme of SATREPS Program (Science and Technology Research Partnership for Sustainable Development) for the project Development of Low Carbon Society Scenarios for Asian Region.

References

Aggarwal Y., Siddique R., 2014, Microstructure and properties of concrete using bottom ash and waste foundry sand as partial replacement of fine aggregates, Construction and Building Materials 54, 210–223.

ASTM C150, 2007, Standard Specification for Cement, Annual Book of ASTM Standards i, 1–4.

ASTM C33 / C33M, 2013, Standard Specification for Concrete Aggregates, Annual Book of ASTM Standards, 11.

Beard J., 2002, A Study of Leaching Tests for Cement Stabilised Waste, Victoria University of Technology, Melborn, Australia.

BS EN 12390-03, 2009, Testing hardened concrete Compressive Strength, <shop.bsigroup.com/ProductDetail/?pid=000000000030253049> accessed 17.03.2016.

BS EN 206, 2013, Concrete - Specification, performance, production and conformity, <shop.bsigroup.com/ProductDetail/?pid=000000000030297896> accessed 17.03.2016.

Cheriaf M., Rocha J.C., Péra J., 1999, Pozzolanic properties of pulverized coal combustion bottom ash, Cement and Concrete Research 29 (9), 1387–1391.

Drakonaki S., Diamadopoulos E., Vamvouka D., Lahaniatis M., 1998, Leaching behavior of lignite fly ash, Journal of Environmental Science and Health Part A 33, 237–248.

Ghafoori N., Bucholc J., 1997, Properties of high-calcium dry bottom ash concrete, ACI Materials Journal 94 (2), 90–101.

Gwenzi W., Mupatsi N.M., 2016, Evaluation of heavy metal leaching from coal ash-versus conventional concrete monoliths and debris, Waste Management 49, 114–123.

Heidrich C., Feuerborn H.-J., Weir A., 2013, Coal Combustion Products: a Global Perspective, World of Coal Ash (WOCA) Conference, 22-25 April 2013, Lexington, Kentucky.

Jang J.G., Kim H.J., Kim H.K., Lee H.K., 2016, Resistance of coal bottom ash mortar against the coupled deterioration of carbonation and chloride penetration, Materials and Design 93, 160–167.

Jankowski J., Ward C.R., French D., Groves S., 2006, Mobility of trace elements from selected Australian fly ashes and its potential impact on aquatic ecosystems, Fuel 85 (2), 243–256.

Khankhaje E., Hussin M.W., Mirza J., Rafieizonooz M., Salim M.R., Siong H.C., Mohd Warid M.N., 2015, On blended cement and geopolymer concretes containing palm oil fuel ash, Materials and Design 89, 385-398

Kim H.K., Lee H.K., 2011, Use of power plant bottom ash as fine and coarse aggregates in high-strength concrete, Construction and Building Materials 25 (2), 1115–1122.

Musyoka N.M., Petrik L.F., Fatoba O.O., Hums E., 2013. Synthesis of zeolites from coal fly ash using mine waters, Minerals Engineering 53, 9–15.

Prasad B., Mondal K.K., 2008, Heavy metals leaching in Indian fly ash, Journal of environmental science and engineering engineering 50 (2), 127–132.
Rafieizonooz M., Mirza J., Salim M.R., Hussin M.W., Khankhaje E., 2016, Investigation of coal bottom ash and fly ash in concrete as replacement for sand and cement, Construction and Building Materials 116, 15–24.
Singh M., Siddique R., 2014a, Compressive strength, drying shrinkage and chemical resistance of concrete incorporating coal bottom ash as partial or total replacement of sand, Construction and Building Materials 68, 39–48.
Singh M., Siddique R., 2013, Effect of coal bottom ash as partial replacement of sand on properties of concrete. Resources, Conservation and Recycling 72, 20–32.
Singh M., Siddique R., 2015, Properties of concrete containing high volumes of coal bottom ash as fine aggregate. Journal of Cleaner Production 91, 269–278.
Singh M., Siddique R., 2014b, Strength properties and micro-structural properties of concrete containing coal bottom ash as partial replacement of fine aggregate, Construction and Building Materials 50, 246–256.
Sushil S., Batra V.S., 2006, Analysis of fly ash heavy metal content and disposal in three thermal power plants in India, Fuel 85 (17-18), 2676-2679.
ST (Suruhanjaya Tenaga), 2014, Malaysia Electricity Supply and Voltage, <www.malaysia-trulyasia.com/tourism/electricity_supply.htm> Accessed 25.11.2015.
U.S. EPA, 2015, TCLP Method 1311, The effects of brief mindfulness intervention on acute pain experience: An examination of individual difference, 1 (July 1992), 1–36.
Yilmaz H., 2015, Characterization and comparison of leaching behaviors of fly ash samples from three different power plants in Turkey, Fuel Processing Technology 137, 240–249.