DURABILITY AND LEACHABILITY OF CONCRETE CONTAINING COAL BOTTOM ASH AND FLY ASH

MAHDI RAFIEIZONOOZ

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Civil Engineering)

Faculty of Civil Environment
Universiti Teknologi Malaysia

FEBRUARY 2017

To My Lovely Parents
Safar Rafieizonooz and Batool Rafighi

And

My Beloved Wife
Elnaz Khankhaje

ACKNOWLEDGEMENT

There are a number of people without whom this thesis might not have been written and to whom I greatly indebted. First of all, I would like to thank God, who has blessed and guided me so that I was able to accomplish this thesis.

I would like to express my sincere gratitude to my main thesis supervisor, Professor Dr. Mohd Razman Salim for his encouragement, patience, motivation, immense knowledge and friendship. Besides my supervisor, I am also very thankful to my co-supervisors Professor Dr. Mohd Warid Hussin and Professor Dr. Jahangir Mirza for their insightful comments, guidance, advices and motivation. Without their support it would not be possible to conduct this research.

The patient demonstrated by my lovely wife Elnaz Khankhaje during the studies is gratefully acknowledged. Her support, help, benevolence and encouragement was in the end what made this research possible. My parents, Saffar Rafieizonooz and Batool Rafighi, receive my deepest gratitude and love for their dedication and the many years of support during my whole life. Last, but not least, I would like to thank to my wife's parents Razi Khankhaje and Tima Khanahmadi and my sibilings Nazanin & Hadi for their support and encouragement.

My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. I would like to thank all members of structure and environmental lab for their friendship and kind assistance. I am also thankful to Tanjung Bin Power Plant for supplying coal bottom ash and fly ash. I also desire to express acknowledgement to my friends for their helpful support and assistance through the years.

ABSTRACT

Concrete is one of the main construction materials, though its application in construction has negative environmental impact such as carbon dioxide (CO_2) emission and depletion of natural resources. In order to reduce the use of river sand as natural fine aggregate, the utilization of waste materials such as coal bottom ash (CBA), recycle concrete aggregate and recycle glass is quite effective. Moreover, in terms of reducing the amount of CO_2 emission from cement industry, the utilization of supplementary cementitious materials (SCMs) such as coal fly ash (CFA), silica fume, blast-furnace slag and biomass ash is quite common and beneficial. In this study, the effect of using CBA as sand replacement and CFA as partial replacement of cement on various mix designs, was examined. The performance was investigated based on physical and mechanical properties, durability and leaching performance. The resistance to sulfuric acid and sulfate solutions and elevated temperature was also investigated. Two different leaching methods to obtain leaching performance of coal ash concrete performed were batch and tank leaching tests. Results revealed that concrete workability reduced with increasing percentage of CBA content replacing sand. At the early age of 28 days, no significant effect was observed in compressive, flexural and tensile strengths of all concrete samples. After curing ages of 91 and 180 days, compressive strength of both the experimental and control concrete samples increased significantly but remained almost similar. However, flexural and splitting tensile strengths of the experimental mix containing 75% CBA and 20% CFA exceeded more than the control sample. Moreover, drying-shrinkage of experimental concrete mixtures containing 50%, 75% and 100% CBA and 20% CFA was lower than the control mix. In general, the study revealed that coal ash concrete exhibited good influence in terms of resistance to chemical attacks than the control specimen. On the other hand, coal ash concrete mixtures showed higher loss in weight when exposed to higher temperature. Finally, from the results of leaching tests, it is observed that there is no leaching of any heavy metals. It is concluded that the experimental concrete mixes can be used which will minimize the use of natural resources, reducing energy and environmental problems to a great extent.

ABSTRAK

Konkrit merupakan salah satu daripada bahan binaan utama, walaupun penggunaannya dalam pembinaan memberi kesan negatif terhadap alam sekitar seperti pelepasan karbon dioksida (CO_2) dan pengurangan sumber asli. Dalam usaha untuk mengurangkan penggunaan pasir sungai sebagai agregat halus semula jadi, penggunaan bahan buangan seperti abu dasar arang batu (CBA), agregat konkrit kitar semula dan kaca kitar semula adalah agak berkesan. Selain itu, untuk mengurangkan jumlah pelepasan CO_2 daripada industri simen, penggunaan bahan bersimen tambahan (SCM_S) seperti abu terbang arang batu (CFA), wasap silika, sanga relau bagas dan abu biojisim biasa diguna dan bermanfaat. Dalam kajian ini, kesan penggunaan CBA sebagai gantian pasir dan CFA sebagai gantian separa simen dalam pelbagai reka bentuk campuran, telah dikaji. Prestasi yang diselidiki adalah berdasarkan ciri-ciri fizikal dan mekanikal, keboleh tahanan dan prestasi larut lesap. Kajian juga dijalankan ke atas kerintangan asid sulfurik dan larutan sulfat serta peningkatan suhu. Dua kaedah larut lesap berbeza yang dijalankan untuk memperolehi prestasi larut lesap konkrit abu arang batu merupakan ujian larut lesapan berkelompok dan tangki. Keputusan menunjukkan bahawa kebolehkerjaan konkrit berkurangan dengan peningkatan peratusan kandungan CBA menggantikan pasir. Pada usia awal 28 hari, tiada kesan yang ketara diperhatikan dalam kekuatan mampatan, lenturan dan tegangan semua sampel konkrit. Selepas usia pengawetan 91 dan 180 hari, kekuatan mampatan bagi kedua-dua sampel konkrit bagi eksperimen dan kawalan meningkat dengan ketara tetapi kekal hampir sama. Walau bagaimanapun, kekuatan lenturan dan tegangan terbelah campuran eksperimen yang mengandungi 75% CBA dan 20% CFA didapati melebihi daripada sampel kawalan. Selain itu, pengeringan-pengecutan campuran konkrit eksperimen dengan kandungan 50%, 75% dan 100% CBA dan 20% CFA adalah lebih rendah berbanding campuran kawalan. Secara umum, kajian ini mendedahkan bahawa konkrit abu arang batu menunjukkan pengaruh yang baik dari segi rintangan kepada serangan kimia berbanding spesimen kawalan. Sebaliknya, campuran konkrit abu arang batu menunjukkan kehilangan berat yang lebih tinggi apabila terdedah kepada suhu yang tinggi. Akhir sekali, dari keputusan ujian larut lesap, diperhatikan tiada kesan larut lesapan sebarang logam berat. Dapat disimpulkan bahawa campuran konkrit eksperimen boleh digunakan untuk meminimumkan penggunaan sumber asli, mengurangkan tenaga dan masalah alam sekitar ke tahap yang lebih hebat.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE

LIST OF ABBREVIATIONS

ACAA	-	American Caol Ash Association
ACI	-	American Concrete Institute
ASTM	-	American Society for Testing and Materials
BS	-	British Standars
CAC	-	Coal Ash Concrete
CFA	-	Coal Fly Ash
CBA	-	Coal Bottom Ash
C-H	-	Calcium Hydrate
C-S-H	-	Calcium Silicate Hydrate
E	-	Ettringite
ELT	-	Equilibrium Leach Test
FESEM	-	Field Emission Scanning Electron Microscopy
HDPE	-	High Density Polyethylene
ICP-MS	-	Inductively Coupled Plasma - Mass Spectrometry
LOI	-	Loss On Ignition
L/S	-	Liquid to Solid ratio
MSWI	-	Municipal Solid Waste Incineration
MWLP	-	Mine Water Leaching Procedure
NETL	-	National Energy Technology Laboratory
OPC	-	Ordinary Portland Cement
rpm	-	Recolutions Per Minute
SBLP	-	Serial Batch Leaching Procedure
SDTLP	-	Semi-Dynamic Tank Leaching Procedure
SEM	-	Scanning Electron Micrograph
SSD	-	Saturated Surface Dry
TCLP	-	Toxicity Characteristics Leaching Procedure
UPV	-	Ultrasonic Pulse Velocity

US EPA	-	United State Environmental Protection Agency
UTM	-	Universiti Teknologi Malaysia
WVWRI	-	West Virginia Water Research Institute
W/C	-	Water to Cement ratio
XRF	-	X-Ray Fluorescence Spectrometry

LIST OF SYMBOLS

V	-	pulse velocity (km/s)
L	-	length of the specimen
T	-	transit time
W	-	percentage mass loss (%)
$W_{initial}$	-	mass of the samples before submersion in sulfuric acid solution
W_t	-	mass of the samples at (t) days after submersion in sulfuric acid solution
f_c	-	compressive strength reduction
$f_{c\ (28\ d)}$	-	28 days compressive strength of the concrete specimens
$f_{c\ (t\ d)}$	-	compressive strength at (t) days after submersion in sulfuric acid solution.
$M_{t\ i}$	-	mass released during the current leaching interval, i (mg/m^2)
C_i	-	constituent concentration in the eluate for interval i (mg/L)
V_i	-	eluate volume in interval i (L)
A	-	specimen external geometric surface area exposed to the eluent (m^2)
F_i	-	flux for interval, i (mg/m^2·s)
M_i	-	mass released during the current leaching interval, i (mg/m^2)
T_i	-	cumulative time at the end of the current leaching interval, i (s)
T_{i-1}	-	cumulative time at the end of the previous leaching interval, i-1 (s)
C_i	-	constituent concentration in the eluate for interval i (mg/L)
f_{cu}	-	Compressive strength of cube in MPa
R^2	-	coefficient of determination
f_f	-	Flexural strength of concrete in MPa

f_t	-	Tensile strength of concrete in MPa
ơf	-	the percentage of compressive strength loss
ơm	-	the percentage of loss in weight

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Concrete is one of the most important materials in building construction and other infrastructure works. About 2.7 billion m^3 of concrete was generated in 2002 worldwide, which is more than 0.4 m^3 of concrete generated per person annually (Naik 2008). It is anticipated that the need for concrete will increase further to almost 7.5 billion m^3 (about 18 billion tons) a year by 2050 (Monteiro 2015) . Such an enormous utilization of concrete calls for higher use of natural aggregates and cement, thus taking toll on the environment. At least three-quarters of the total volume of concrete consists of coarse and fine aggregates. Obviously, natural resources such as river sand are getting depleted (Mardani-Aghabaglou et al. 2014). The prohibition on mining in some areas and the growing needs for natural environment conservation further exacerbate the problem of river sand availability.

Finding new alternative materials for sustainable development so as to substantially decrease the consumption of natural resources became imperative to safeguard the interests of future generations. Moreover, high consumption of natural resources led to greater amount of industrial wastes and environmental degradation (Khankhaje et al. 2015). Therefore, the interest of researchers increased to utilize industrial waste materials as replacement of natural resources in construction industry.

Coal is one of the most significant sources of energy with fuelling almost 40 percent of electricity in the world. In many countries this figure is much more: Poland relies on coal for over 97 percent of its electricity; South Africa for 92 percent; China for 77 percent; and Australia for 76 percent. Coal was introduced as a raw material for power generation since 1988 in Malaysia (International Energy Agency 2012).

The projected forecast for electricity usage in peninsular Malaysia produced from coal and gas by the year 2024, are 58% and 25%, respectively. Even though, some difference exists between these figures and those of 2014, it appears that dependence on fossil fuels may be reduced but won't be eliminated altogether. In fact coal consumption will likely mount from 43% to 58% (Tenaga 2014).

Two types of ash, coal fly ash (CFA) of 80 percent and coal bottom ash (CBA) of 20 percent are produced at coal power plant. Most of them are being dumped at the waste disposal site near the factory. This will pollute the environment and creating a disposal problem because a large dumping space is required. Electricity production in Malaysia leads to a whopping amount of CFA some 6.8 million tonnes and CBA roughly 1.7 million tonnes. While CFA is being used to manufacture pozzolanic Portland cement, CBA is not commonly used at all.

The coal ash content depends upon the non-combustible matter present in coal. Rock detritus filled in the fissures of coal becomes separated from the coal during pulverization. In the furnace, carbon and other combustible matter are burnt, whereas the non-combustible matter results in coal ash. Swirling air carries ash particles out of hot zone where it cools down and CFA is produced through this process. CBA is displaced from under the furnace which is directed to suspension ponds that take over several acres of countryside land.

Previously, most of the available researches had been focusing on the properties of CFA since CFA accounts for a larger portion (approximately two-third) of the total coal ash produced as compared to bottom ash (American Coal Ash Association (ACAA), 1998). There have been a substantial number of studies on concrete production incorporating coal ash either as cement replacements, fine and coarse aggregates. Cheriaf et al. (1999) studied the property of CBA concrete and found that CBA has pozzolanic property as sand replacement and is suitable for using in concrete manufacturing. It was also reported by Kim and Lee (2011) that CBA can be used as aggregates (fine and coarse) in high-strength concrete. Singh and Siddique (2013) in their review reported that CBA is a potential substitute material for sand in concrete. Singh and Siddique (2015) also investigated the properties of concrete incorporating high volume of CBA as sand replacement. Aggarwal and Siddique (2014) investigated the microstructure and properties of concrete containing CBA and waste foundry sand as replacement of natural sand in concrete.

Concrete made with low calcium CBA as a replacement of river sand displayed strength properties comparable to that of conventional concrete (Singh and Siddique 2014b). The major advantages of using CBA as fine aggregate in concrete production is that reduction in dead weight of structure as well as alleviation of environmental hazards. Concrete made with using CBA has low density as compared to control concrete, since CBA has low specific gravity. Sua-iam and Makul (2014) have reported that the use of waste materials either as cement supplementary material or as sand replacement in concrete can result in cost savings and help in reducing the environmental problems.

However, from literature search, no study on durability and stability properties of concrete incorporating CBA as fine aggregate and CFA as replacement of Ordinary Portland Cement (OPC) has been published. Hence, detailed studies about durability of concrete incorporating CFA as cement replacement and CBA as fine aggregate are required before the CFA and CBA as construction material are accepted in manufacturing of concrete.

One of the most important factor in anticipated life of the structure is durability and stability of concrete made utilizing industrial by-products. Concrete made utilizing industrial waste materials can be considered as durable concrete if it preserves its initial quality, serviceability and form when subjected to chemical attacks, elevated temperature, weathering process and other activities of deterioration for the anticipated life time.

The movements of moisture in concrete cause deterioration because of sulfuric acid and sulfate attack. Concrete made with CBA as replacement of fine aggregate shows a notable performance when subjected to chemical attacks. Singh and Siddique (2014a) studied the performance of concrete incorporating CBA as sand replacement when exposed to sulfate and sulfuric acid attack.

Elevated temperature is another kind of process that can effects the performance of concrete in its intended life. The main factors which influence the heat resistance of concrete are temperature and duration of fire, the type of cement and aggregates used in its structure, moisture content of concrete and size of structural members. CBA is porous material and its presence as sand replacement in concrete causes in porous structure in the concrete. The higher porosity of concrete can be believed positive when concrete is exposed to high temperature up to 200 °C. This might be due to the evaporation of internal water is not complete. Yuksel et al. (2011) evaluated the effect of high temperature on properties of CBA concrete.

1.2 Problem Statement

The growing demand for electricity resulted in the construction of many coal fired power plants. As the consumption of coal by power plants increases, so does the production of coal by product such as CBA and CFA. While the use of coal increases, waste issues associated with coal production are tempted more and more thoughtfulness. Malaysia is very serious about environmental issues resulting in the introduction of stringent control about the emission standards on the new projects for coal power (Joseph, 2005). Even though there is no report about the production of coal ash annually in Malaysia, but theoretically, there is about 10% of total weight of the coal burned produces ash (Huang, 1990).

By the year 2024, it is predicted that Malaysia will have to rely on coal and gas (58% and 25% respectively) to generate electricity (Tenaga 2014). Although there are some disparities between the aforementioned figures and those of 2014 (43% coal), it is likely that the requirement for fossil fuels could increase. This increase in utilization of coal will lead to generate of more coal ash that could eventually result in more environmental problems.

Disposal of unused coal ash is costly and places a considerable burden on the power industry, and finally transferred to the electricity consumer. In addition, the disposing of ash in landfills contributes to the ongoing problem of diminishing landfill space in Malaysia, and as a result of that, ash disposal may pose an environmental hazard.

There are several researches documenting heavy metal concentrations and leaching in coal ash 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 these researches concentrate on leaching behaviour of heavy metals from unbound coal ash. The findings of these literatures are in contrast with each other: Some researchers (Jianmin Wang et al. 2004; Sushil and Batra 2006) stated that some heavy metals could be leached out from coal ash; whereas others (Drakonaki et al. 1998a; Beard 2002; 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, degree of coal pulverization, firing conditions in the furnace, ash handling practice and processing technologies used in thermal power stations.

There is a requirement for a methodical approach to assess locally existing of CBA and CFA for potential construction utilization because as mentioned earlier even coal ash produced from the same source of fuel can be completely difference depending on the procedures and operating conditions.

The using of CBA as alternative replacement of the natural sand and CFA as cement substitute in concrete production are going to solve the problem of these kind of waste. Therefore, Malaysia has a great potential to turn its profuse source of electrical by coal industry by-products into worth added products especially in construction material. However, looking on the brighter side of things, extensive research has provided an alternative way of optimizing the usage of coal residues based into value added product in construction industry.

1.3 Aim and Objectives

The aim of this research is to use CBA as partial and total replacement of fine aggregate (sand) and CFA as partial replacement of OPC in production of concrete. Moreover, this research aimed to analyse the leachability of CBA, CFA and coal ash concrete. To achieve the aim of this research, following objectives are prepared:

1. To characterise the physical and chemical properties of CBA and CFA
2. To develop a mixture proportioning to prepare coal ash concrete (CAC)
3. To evaluate the mechanical properties of concrete containing CBA and CFA

4. To determine the durability of coal ash concrete when exposed to aggressive condition: sulfate attack, acid attack and elevated temperature
5. To evaluate the leachability of CBA, CFA and coal ash concrete (CAC)

1.4 Significant of Study

Since construction is inevitable in many areas of the world and Malaysia is not an exception, which has the environmental problem such as leaching hazardous material, air pollution and disposal of wastes. One of the most common wastes which can be used in construction industry is coal fired fuel ash. Thus basic knowledge and understanding of concrete, CFA and CBA properties are of great importance to produce coal ash concrete. Using this mixture, could increase the use of disposal wastes which can reduce the environmental problems as mentioned earlier.

1.5 Scope of Study

In this project, CBA and CFA from Tanjung Bin power station in South Malaysia (Johor Bahru) are concerned. Tanjung Bin power station is located in south coast of Malaysia, producing 180 tons/day of CBA and 1,620 tons/day of CFA from 18,000 tons/day of coal burning. Tanjung Bin power station produces 2100 MW per year.

The study focuses on the characteristics of CBA and CFA which is collected from Tanjung Bin power plant in Malaysia. After that sustainable concrete are produced by using CBA as fine aggregate replacement and CFA as partial replacement of OPC. Then, the engineering properties and durability performance of this concrete are carried out. Finally, the leaching test on CBA, CFA and coal ash concrete are proposed.

The engineering properties of the materials are tested using the standard method such as the British Standard (BS) or the American Society for Testing and Materials (ASTM), depending upon the suitability or the availability of the equipment in the laboratory within Universiti Teknologi Malaysia (UTM).

1.6 Research Methodology

The methodology utilized in this research can be described as follows: Information was collected through studies of the literature and study visits. Previous Malaysia experience was evaluated and foreign experiences also considered, thus identifying areas in which there was a lack of knowledge.

Moreover, experimental work was carried out by evaluating characteristics of CBA and CFA, properties of new production (concrete) in terms of workability and durability tests, leaching test, planning and evaluating new laboratory experiments.

1.7 Thesis Layout

The thesis is divided into seven chapters that consist of Chapter 1 (Introduction), chapter 2 (Literature Review), chapter 3 (Research Methodology: Program of Experimental and Characteristics of Materials), Chapter 4 (Characteristics of Ash and its Effect on Mechanical Properties of Concrete), Chapter 5 (Durability, Sulfuric Acid, Elevated Temperature and Sulfate Resistance), Chapter 6 (Leaching Test) and Chapter 7 (Conclusion and Recommendations). The explanations for each chapter are as follows:

Chapter One: Provides the general background of the research and a brief description of the statement problem. Additionally, aims and objectives, scope and limitation, significance of study and the research highlight are also described in this chapter.

Chapter Two: Explains the physical and chemical properties of CBA and CFA and description of the previous research studies on the utilization of CBA and CFA in construction industry. In next step, the leaching properties of concrete containing CBA and CFA was studied. However, there are few literatures on utilization CBA and CFA at same time in mix design of concrete, the properties of concrete containing CBA as fine aggregate replacement in concrete and CFA concrete were reviewed. The workability and mechanical properties such ash compressive, flexural and split tensile strength, Ultrasonic pulse velocity (UPV) and drying shrinkage of CBA concrete and CFA concrete were reviewed separately. The final part of chapter two, illustrated previous researches works on chemical attack (sulfuric acid attack and sulfate attack) and elevated temperature resistance of CBA concrete and CFA concrete.

Chapter Three: Describes the experimental procedure including materials characteristics, leaching tests, mix design, workability, mechanical properties and durability experiments under aggressive environmental conditions.

Chapter Four: Shows the results of characteristics of CBA and CFA. The physical and chemical properties of CBA and CFA is discussed in detail in this chapter. Moreover, this chapter Reports the mechanical properties of fresh and hardened concrete. The main properties of testing comprised compressive, split tensile and flexural strength tests; comprising UPV and drying shrinkage. In addition of that relationship between compressive, flexural and tensile strength are presented.

Chapter Five: The results and discussion of durability tests including sulfate attack, sulfuric acid attack and heat resistance conducted on normal concrete and those containing CBA and CFA are provided in this chapter. In addition of that, in this chapter microstructure involving field-emission scanning electron micrograph (FESEM), change in compressive strength and change in mass of concrete specimens under different durability tests are presented and discussed.

Chapter Six: This chapter evaluates and presents the leaching behavior of CBA, CFA and concrete particles incorporating CBA and CFA. It explains the result of Toxicity Characteristics Leaching Procedure (TCLP) and Semi-Dynamic Tank Leaching Procedure (SDTLP) methods by making relevant discussions base on the laboratory condition upon which the tests were conducted.

Chapter Seven: Concludes the findings and achievements of this study. Moreover, some recommendations are provided for future works in related areas to develop concrete application using CBA and CFA as replacement of sand and OPC.

REFERENCES

ACAA, 2008. Bottom Ash properties. *American coal ash association international alexandria, VA.*

ACAA, 1998. Coal Cumbustion Product (CCP) Production and Use. *American coal ash association international alexandria, VA.*

ACI Comittee 232. 2002. Use of fly ash in concrete Reported by ACI Comittee 232. *NCHRP Synthesis of Highway Practice*, 96(Reapproved), pp.1–34.

Aggarwal, P., Aggarwal, Y. and Gupta, S. 2007. Effect of bottom ash as replacement of fine aggregates in concrete. *Asian Journal of Civil Engineering (Building and Housing)*, 8(1), pp.49–62.

Aggarwal, Y. and 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, pp.210–223.

Ahmaruzzaman, M. 2010. A review on the utilization of fly ash. *Progress in Energy and Combustion Science*, 36(3), pp.327–363.

Akar, C. and Canbaz, M. 2016. Effect of molasses as an admixture on concrete durability. *Journal of Cleaner Production*, 112, pp.2374–2380.

Akar, Gul., Polat, Mehmet., Galecki, Greg. and Ipekoglu, Uner. 2012. Leaching behavior of selected trace elements in coal fly ash samples from Yenikoy coal-fired power plants. *Fuel Processing Technology*, 104, pp.50–56.

Andrade, L.B., Rocha, J.C. and Cheriaf, M. 2009. Influence of coal bottom ash as fine aggregate on fresh properties of concrete. *Construction and Building Materials*, 23(2), pp.609–614.

Antonio, O.V.M. and Zarco, M.A.H. 2007. Engineering Properties of Calaca Batangas Bottom Ash. *PHILIPPINE ENGINEERING JOURNAL*, 28(1), pp.37–56.

Aramraks, T. 2006. Experimental Study of Concrete Mix with Bottom Ash as Fine Aggregate in Thailand. *Symposium on infrastructure development and the* *environment*, pp.1–5.

Arumugam, K., Ilangovan, R. and James, M.D. 2011. A study on characterization and use of Pond Ash as fine aggregate in Concrete. *International Journal of Civil and Structural Engineering*, 2(2), pp.466–474.

ASTM:C157/C157M, 2008. Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete. *Annual Book of ASTM Standards*, 8(Reapproved), pp.1–7.

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

ASTM C267 - 01, 2012. Standard Test Methods for Chemical Resistance of Mortars, Grouts, and Monolithic Surfacings and Polymer Concretes. *Annual Book of ASTM Standards*.

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

ASTM C496, 2014. Standard Test Method for Splitting Tensile Strength. *Annual Book of ASTM Standards*, i, pp.1–5.

ASTM C597, 2009. Standard Specification for Pulse Velocity Through Concrete. *Annual Book of ASTM Standards*, (Note 2), pp.6–9.

ASTM C618, 2012. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use. *Annual Book of ASTM Standards*, pp.3–6.

ASTM C778, 2014. Standard Specification for Sand. *Annual Book of ASTM Standards*, pp.1–3.

Baba, A., Gurdal, G. and Sengunalp, F. 2010. Leaching characteristics of fly ash from fluidized bed combustion thermal power plant: Case study: Çan (Çanakkale-Turkey). *Fuel Processing Technology*, 91(9), pp.1073–1080.

Baert, G., De Belie, N. and Poppe, A.-M. 2008. Strength and durability of high-volume fly ash concrete. *Structural Concrete*, 9(2), pp.101–108.

Bai, Y., Darcy, F. and Basheer, P.A.M. 2005. Strength and drying shrinkage properties of concrete containing furnace bottom ash as fine aggregate. *Construction and Building Materials*, 19(9), pp.691–697.

Balakrishnan, B. and Awal, A.S.M.A. 2014. Durability Properties of Concrete Containing High Volume Malaysian Fly Ash. *International Journal of Research in Engineering and Technology*, 3(4), pp.529–533.

Beard, J. 2002. A Study of Leaching Tests for Cement Stabilised Waste. *Victoria*

University of Technology.

Behin, Jamshid., Bukhari, Syed Salman., Kazemian, Hossein. and Rohani, Sohrab. 2016. Developing a zero liquid discharge process for zeolitization of coal fly ash to synthetic NaP zeolite. *Fuel*, 171, pp.195–202.

Berndt, M.L. 2009. Properties of sustainable concrete containing fly ash, slag and recycled concrete aggregate. *Construction and Building Materials*, 23(7), pp.2606–2613.

Bhattacharyya, S., Donahoe, R.J. and Patel, D. 2009. Experimental study of chemical treatment of coal fly ash to reduce the mobility of priority trace elements. *Fuel*, 88(7), pp.1173–1184.

Blissett, R.S.S. and Rowson, N.A. a. 2012. *A review of the multi-component utilisation of coal fly ash*,

Bouzoubaâ, N., Bilodeau A., Tamtsia B. and Foo, S. 2010. Carbonation of fly ash concrete: laboratory and field data. *Canadian Journal of Civil Engineering*, 37(12), pp.1535–1549.

BS 1881: Part 102, 1983. BS 1881: Part 102: Method for determination of slump.

BS 812-103-1, 1985. Part103: Method for determination of particle size distribution —Section103.2 Sedimentation test.

BS EN 12390-02, 2009. Testing hardened concrete Curing. , pp.420–457.

BS EN 12390-03, 2009. Testing hardened concrete Compressive Strength. , (August), pp.420–457.

BS EN 12390-05, 2009. Testing hardened concrete Flexural Strength. , pp.420–457.

BS EN 206, 2013. Concrete - Specification, performance, production and conformity.

Cheng, Chin-Min., Taerakul, Panuwat., Tu, Wei., Zand, Behrad., Butalia, Tarunjit., Wolfe, William. and Walker, Harold. 2008. Surface Runoff from Full-Scale Coal Combustion Product Pavements during Accelerated Loading. *Journal of Environmental Engineering*, 134(8), pp.591–599.

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

Chiang, Yi Wai., Ghyselbrecht, Karel., Santos, Rafael M., Meesschaert, Boudewijn. and Martens, Johan A. 2012. Synthesis of zeolitic-type adsorbent material from municipal solid waste incinerator bottom ash and its application in heavy metal adsorption. *Catalysis Today*, 190(1), pp.23–30.

Chou, Jing Dong., Wey, Ming Yen., Liang, Hsiu Hao. and Chang, Shih Hsien. 2009. Biotoxicity evaluation of fly ash and bottom ash from different municipal solid waste incinerators. *Journal of Hazardous Materials*, 168(1), pp.197–202.

Chun, L.B., Sung, K.J., Sang, K.T. and Chae, S.T. 2008. A study on the fundamental properties of concrete incorporating pond-ash in Korea. In *The 3rd ACF International Conference-ACF/VCA*. pp. 401–408.

Churchill, E.V. and Amirkhanian, S.N. 1999. Coal Ash Utilization in Asphalt Concrete Mixtures. *Journal of Materials in Civil Engineering*, 11(4), pp.295–301.

Delagrave, A., Marchand, J., Pigeon, M. and Boisvert, J. 1997. Deicer salt scaling resistance of roller-compacted concrete pavements. *ACI Materials Journal*, 94(2).

Drakonaki, S., Diamadopoulos, E., Vamvouka, D. and Lahaniatis, M. 1998. Leaching behavior of lignite fly ash. *Journal of Environmental Science and Health, Part A*, 33(2), pp.237–248.

Durán-Herrera, A., Juárez, C.A. A., Valdez, P. and Bentz, D.P. P. 2011. Evaluation of sustainable high-volume fly ash concretes. *Cement and Concrete Composites*, 33(1), pp.39–45.

Eckert, J.O. and Guo, Q. 1998. Heavy metals in cement and cement kiln dust from kilns co-fired with hazardous waste-derived fuel: application of EPA leaching and acid-digestion procedures. *Journal of Hazardous Materials*, 59(1), pp.55–93.

EL-Chabib, H. and Ibrahim, A. 2013. The performance of high-strength flowable concrete made with binary, ternary, or quaternary binder in hot climate. *Construction and Building Materials*, 47, pp.245–253.

Famy, C., Brough, A.R. and Taylor, H.F.W. 2003. The C-S-H gel of Portland cement mortars: Part I. The interpretation of energy-dispersive X-ray microanalyses from scanning electron microscopy, with some observations on C-S-H, AFm and AFt phase compositions. *Cement and Concrete Research*, 33(9), pp.1389–1398.

Fernandez-Turiel, Jose-Luis., Georgakopoulos, Andreas., Gimeno, Domingo., Papastergios, Georgios. and Kolovos, Nestoras 2004. Ash Deposition in a Pulverized Coal-Fired Power Plant after High-Calcium Lignite Combustion. *Energy & Fuels*, 18(5), pp.1512–1518.

Filho, J. Hoppe., Medeiros, M. H. F., Pereira, E., Helene, P. and Isaia, G. C. 2013. High-Volume Fly Ash Concrete with and without Hydrated Lime: Chloride Diffusion Coefficient from Accelerated Test. *Journal of Materials in Civil Engineering*, 25(3), pp.411–418.

Garrabrants, A., Kosson, D., DeLapp, R., Kariher, P., Seignette, P., van der Sloot,H., Stefanski, L. and Baldwin, M. 2012. Interlaboratory Validation of the Leaching Environmental Assessment Framework (LEAF) Method 1314 and Method 1315. *EPA/600/R-12/624*.

Garrabrants, Andrew C., Kosson, David S., DeLapp, Rossane., van der Sloot. and Hans A. 2014. Effect of coal combustion fly ash use in concrete on the mass transport release of constituents of potential concern. *Chemosphere*, 103, pp.131–139.

Gesoğlu, M., Güneyisi, E. and Özbay, E. 2009. Properties of self-compacting concretes made with binary, ternary, and quaternary cementitious blends of fly ash, blast furnace slag, and silica fume. *Construction and Building Materials*, 23(5), pp.1847–1854.

Ghafoori, N. and Bucholc, J. 1996. Investigation of Lignite-Based Bottom Ash for Structural Concrete. *Journal of Materials in Civil Engineering*, 8(3), pp.128–137.

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

Ghafoori, N. and Cai, Y. 1998. Laboratory-made roller compacted concretes containing dry bottom ash: Part II - Long-term durability. *ACI Materials Journal*, 95(3), pp.244–251.

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

Hattaway, Jenet., Hardin, Christopher D., Daniels, John L. and Drive, Jones Branch. 2013. Recommended Guidelines for the Use and Application of the Leaching Environmental Assessment Framework (LEAF) for Coal Combustion Residuals. In *World of Coal Ash (WOCA) Conference, Lexington, KY, April 22-25, 2013*.

Hayes, Joshua B., Wang, Jun., Roessler, Justin G., Ferraro, Christopher C., Wu, Chang Yu., Deford, Dale. and Townsend, Timothy G. 2015. Evaluation of leaching of trace metals from concrete amended with cement kiln baghouse filter dust. *Resources, Conservation and Recycling*, 94, pp.92–98.

Heidrich, C., Feuerborn, H.-J. and Weir, A. 2013. Coal Combustion Products: a Global Perspective. In *World of Coal Ash (WOCA) Conference*.

Hesbach, Peter A., Kim, Ann G., Abel, Alexander S. P. and Lamey, Steven C. 2010. Serial batch leaching procedure for characterization of coal fly ash. *Environmental Monitoring and Assessment*, 168(1–4), pp.523–545.

Hesbach, Peter A., Abel, Alexander S P., Kim, Ann G. and Lamey, Steven C. 2005. Rapid Batch Characterization of Coal Utilization By-Products. *World of Coal Ash (WOCA) Conference*, pp.1–27.

Huang, H. 1990. *The Use of Bottom Ash in Highway Embankments, Subgrade and Subbases*, Indiana, USA.

International Energy Agency, 2012. *IEA Statistics - COAL Information,*

Irassar, E.F., Di Maio, A. and Batic, O.R. 1996. Sulfate attack on concrete with mineral admixtures. *Cement and Concrete Research*, 26(1), pp.113–123.

Ismail, M., ElGelany Ismail, M. and Muhammad, B. 2011. Influence of elevated temperatures on physical and compressive strength properties of concrete containing palm oil fuel ash. *Construction and Building Materials*, 25(5), pp.2358–2364.

Jankowski, Jerzy., Ward, Colin R., French, David. and Groves, Sarah. 2006. Mobility of trace elements from selected Australian fly ashes and its potential impact on aquatic ecosystems. *Fuel*, 85(2), pp.243–256.

Jia, Y., Aruhan, B. and Yan, P. 2012. Natural and accelerated carbonation of concrete containing fly ash and GGBS after different initial curing period. *Magazine of Concrete Research*, 64(2), pp.143–150.

Jiang, L., Liu, Z. and Ye, Y. 2004. *Durability of concrete incorporating large volumes of low-quality fly ash,*

Jianmin Wang., Xinjun Teng., Hao Wang. and Ban Heng. 2004. Characterizing the Metal Adsorption Capability of a Class F Coal Fly Ash.

John, J. and Ashok, M. 2014. Strength study on high volume fly ash concrete. *Int. J. Adv. Struct. Geotech. Eng*, 3(2), pp.168–171.

Joseph, C.C. 2005. *Report of the Fourth Meeting of The Asean Forum on Coal (AFOC) Council*, Makati City, Philippines.

Junaid, M.T., Khennane, A. and Kayali, O. 2015. Performance of fly ash based geopolymer concrete made using non-pelletized fly ash aggregates after exposure to high temperatures. *Materials and Structures*, 48(10), pp.3357–3365.

Kasemchaisiri, R. and Tangtermsirikul, S. 2007. A method to determine water retainability of porous fine aggregate for design and quality control of fresh concrete. *Construction and Building Materials*, 21(6), pp.1322–1334.

Kaya, A.İ. 2010. *A STUDY ON BLENDED BOTTOM ASH CEMENTS*.

Kayali, O. and Sharfuddin Ahmed, M. 2013. Assessment of high volume replacement fly ash concrete – Concept of performance index. *Construction and Building Materials*, 39, pp.71–76.

Khan, M.S., Prasad, J. and Abbas, H. 2013. Effect of High Temperature on High-Volume Fly Ash Concrete. *Arabian Journal for Science and Engineering*, 38(6), pp.1369–1378.

Khankhaje, Elnaz., Hussin, Mohd Warid., Mirza, Jahangir., Rafieizonooz, Mahdi., Salim, Mohd Razman., Siong, Ho Chin. and Warid, Muhammad Naqiuddin Mohd. 2016. On blended cement and geopolymer concretes containing palm oil fuel ash. *Materials & Design*.Vol. 125, pp. 385-398.

Kim, A.G. and Hesbach, P. 2009. Comparison of fly ash leaching methods. *Fuel*, 88(5), pp.926–937.

Kim, H.K. and 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), pp.1115–1122.

Kosson, D.S., Van der sloot, H.A., Sanchez, F. and Garrabrants, A.C. 2004. An Integrated Framework for Evaluating Leaching in Waste Management and Utilization of Secondary Materials. *Environmental Engineering Science*, 19(3), pp.159–204.

Kou, S.-C. and Poon, C.-S. 2009. Properties of concrete prepared with crushed fine stone, furnace bottom ash and fine recycled aggregate as fine aggregates. *Construction and Building Materials*, 23(8), pp.2877–2886.

Kumar, B., Tike, G.K. and Nanda, P.K. 2007. Evaluation of Properties of High-Volume Fly-Ash Concrete for Pavements. *Journal of Materials in Civil Engineering*, 19(10), pp.906–911.

Kumar, S., Stewart, J. and Mishra, S. 2004. Strength characteristics of illinois coal combustion by-product: PCC dry bottom ash. *International Journal of*

Environmental Studies, 61(5), pp.551–562.

Kurama, H. and Kaya, M. 2008. Usage of coal combustion bottom ash in concrete mixture. *Construction and Building Materials*, 22(9), pp.1922–1928.

Lam, L., Wong, Y.. and Poon, C. 1998. Effect of Fly Ash and Silica Fume on Compressive and Fracture Behaviors of Concrete. *Cement and Concrete Research*, 28(2), pp.271–283.

Li, Xiang-Guo., Lv, Yang., Ma, Bao-Guo., Chen, Quan-Bin., Yin, Xiao-Bo. and Jian, Shou-Wei. 2012. Utilization of municipal solid waste incineration bottom ash in blended cement. *Journal of Cleaner Production*, 32, pp.96–100.

Limbachiya, M., Meddah, M.S. and Ouchagour, Y. 2012. Use of recycled concrete aggregate in fly-ash concrete. *Construction and Building Materials*, 27(1), pp.439–449.

Lu, S.G., Chen, Y.Y., Shan, H.D. and Bai, S.Q. 2009. Mineralogy and heavy metal leachability of magnetic fractions separated from some Chinese coal fly ashes. *Journal of Hazardous Materials*, 169(1), pp.246–255.

Mardani-Aghabaglou, A. and Ramyar, K. 2013. Mechanical properties of high-volume fly ash roller compacted concrete designed by maximum density method. *Construction and Building Materials*, 38, pp.356–364.

Mardani-Aghabaglou, A., Tuyan, M. and Ramyar, K. 2014. Mechanical and durability performance of concrete incorporating fine recycled concrete and glass aggregates. *Materials and Structures*, 48(8), pp.2629–2640.

Monteiro, M.P. 2015. Concrete :microstructure, properties, and materials. *Prentice-Hall; Incorporated; Route 9W; Englewood Cliffs; NJ 07632 USA*, p.450.

Muhardi., Marto, Aminaton., Kassim, Khairul Anuar., Makhtar, Ahmad Mahir., Wei, Lee Foo. and Lim, Yap Shih. 2010. Engineering characteristics of Tanjung Bin coal ash. *Electronic Journal of Geotechnical Engineering*, 15, pp.1117–1129.

Mukherjee, S., Mandal, S. and Adhikari, U.B. 2013. Comparative study on physical and mechanical properties of high slump and zero slump high volume fly ash concrete (HVFAC). *Global NEST Journal*, 15(4), pp.578–584.

Musyoka, Nicholas M., Petrik, Leslie F., Fatoba, Ojo O. and Hums, Eric. 2013. Synthesis of zeolites from coal fly ash using mine waters. *Minerals Engineering*, 53, pp.9–15.

Naganathan, S., Subramaniam, N. and Nasharuddin Bin Mustapha, K. 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.

Naik, By Tarun R., Kraus, Rudolph N., Chun, Yoon-moon. and Nageotte, Samuel O. 2007. Coal-Combustuib Bottom Ash for Reducing Shrinkage of Concrete Made with Portland Cement and Sulfoaluminate Cement. In *International Conference on Recent Advances in Concrete Technology*. Warsaw, Poland.

Naik, T.R. 2008. Sustainability of Concrete Construction. *Practice Periodical on Structural Design and Construction*, 13(2), pp.98–103.

Nanni, A. and Shoenberger, J. 1996. Roller compacted concrete for highway pavements. *Concrete International*, 18(5), pp.33–38.

Narmluk, M. and Nawa, T. 2011. Effect of fly ash on the kinetics of Portland cement hydration at different curing temperatures. *Cement and Concrete Research*, 41(6), pp.579–589.

Neville, A.M. 2012. *Properties of Concrete*, Prentice Hall.

Neville, A.M. 1995. *Properties Of Concrete*. 4th And Final Edition.

Nikhil, T.R. 2014. Use of high volume fly ash in concrete pavements for sustainable development. *International Journal of Scientific Research*, 3(1), pp.131–133.

Oh, T.H. 2010. Carbon capture and storage potential in coal-fired plant in Malaysia--A review. *Renewable and Sustainable Energy Reviews*, 14(9), pp.2697–2709.

Paulus, H., Schick, J. and Poirier, J.-E. 2016. Assessment of dynamic surface leaching of monolithic surface road materials. *Journal of Environmental Management*, 176, pp.79–85.

Pennsylvania, W. 2016. Burning Waste Coal in CFB Power Plants. *Pennsylvania Department of Environmental Protection (DEP)*, (724).

Pittman, D. and Ragan, S. 1998. Drying shrinkage of roller-compacted concrete for pavement applications. *Materials Journal*.

Prasad, B. and Mondal, K.K. 2008. Heavy metals leaching in Indian fly ash. *Journal of environmental science and engineering engineering*, 50(2), pp.127–132.

Prudent, P., Domeizel, M. and Massiani, C. 1996. Chemical sequential extraction as decision-making tool: application to municipal solid waste and its individual constituents. *Science of The Total Environment*, 178(1–3), pp.55–61.

Rashad, A.M. 2015. A brief on high-volume Class F fly ash as cement replacement – A guide for Civil Engineer. *International Journal of Sustainable Built Environment*, 4(2), pp.278–306.

Rashad, A.M., Seleem, H.E.-D.H. and Yousry, K.M. 2009. Compressive strength of concrete mixtures with binary and ternary cement blends. *Building Research Journal*, 57(2), pp.107–130.

Ravina, D. and Mehta, P.K. 1986. Properties of fresh concrete containing large amounts of fly ash. *Cement and Concrete Research*, 16(2), pp.227–238.

Rowe, R.K. 2005. Long-term performance of contaminant barrier systems. *Géotechnique*, 55(9), pp.631–678.

Sahmaran, M. and Yaman, I.O. 2007. Hybrid fiber reinforced self-compacting concrete with a high-volume coarse fly ash. *Construction and Building Materials*, 21(1), pp.150–156.

Şahmaran, M., Yaman, İ.Ö. and Tokyay, M. 2009. Transport and mechanical properties of self consolidating concrete with high volume fly ash. *Cement and Concrete Composites*, 31(2), pp.99–106.

Santos, Rafael M., Mertens, Gilles., Salman, Muhammad., Cizer, Özlem. and Van Gerven, Tom. 2013. Comparative study of ageing, heat treatment and accelerated carbonation for stabilization of municipal solid waste incineration bottom ash in view of reducing regulated heavy metal/metalloid leaching. *Journal of Environmental Management*, 128, pp.807–821.

Saravanakumar, P. and Dhinakaran, G. 2013. Strength Characteristics of High-Volume Fly Ash–Based Recycled Aggregate Concrete. *Journal of Materials in Civil Engineering*, 25(8), pp.1127–1133.

Sata, V., Sathonsaowaphak, A. and Chindaprasirt, P. 2012. Resistance of lignite bottom ash geopolymer mortar to sulfate and sulfuric acid attack. *Cement and Concrete Composites*, 34(5), pp.700–708.

Schiopu, N. 2007. *Caractérisation des Émissions dans L'eau des Produits de Construction Pendant Leur vie en Œuvre*. PhD Thesis INSA Lyon, France.

Seleem, H.E.H., Rashad, A.M. and Elsokary, T. 2011. Effect of elevated temperature on physico-mechanical properties of blended cement concrete. *Construction and Building Materials*, 25(2), pp.1009–1017.

Serclérat, I., Moszkowicz, P. and Pollet, B. 2000. Retention mechanisms in mortars of the trace metals contained in Portland cement clinkers. *Waste Management*, 20(2), pp.259–264.

Shaikh, F.U.A. and Supit, S.W.M. 2014. Mechanical and durability properties of high volume fly ash (HVFA) concrete containing calcium carbonate (CaCO3) nanoparticles. *Construction and Building Materials*, 70, pp.309–321.

Shaikh, F.U.A., Supit, S.W.M. and Sarker, P.K. 2014. *A study on the effect of nano silica on compressive strength of high volume fly ash mortars and concretes*,

Siddique, R. 2004a. Performance characteristics of high-volume Class F fly ash concrete. *Cement and Concrete Research*, 34(3), pp.487–493.

Siddique, R. 2004b. Properties of concrete incorporating high volumes of class F fly ash and san fibers. *Cement and Concrete Research*, 34(1), pp.37–42.

Siddique, R. 2010. Wear resistance of high-volume fly ash concrete. *Leonardo Journal of Sciences*, 17, pp.21–36.

Siddique, R. and Khan, M. 2011. *Supplementary cementing materials*, Springer Science & Business Media.

Singh, Malkit., Siddique, Rafat., Ait-Mokhtar, Karim. and Belarbi, Rafik. 2015. Durability Properties of Concrete Made with High Volumes of Low-Calcium Coal Bottom Ash As a Replacement of Two Types of Sand. *Journal of Materials in Civil Engineering*, p.4015175.

Singh, M. and 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, pp.39–48.

Singh, M. and Siddique, R. 2013. Effect of coal bottom ash as partial replacement of sand on properties of concrete. *Resources, Conservation and Recycling*, 72, pp.20–32.

Singh, M. and Siddique, R. 2016. Effect of coal bottom ash as partial replacement of sand on workability and strength properties of concrete. *Journal of Cleaner Production*, 112, pp.620–630.

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

Singh, M. and 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, pp.246–256.

Sočo, E. and Kalembkiewicz, J. 2007. Investigations of sequential leaching behaviour of Cu and Zn from coal fly ash and their mobility in environmental conditions. *Journal of Hazardous Materials*, 145(3), pp.482–487.

Sofi, A., Swathy, K. and Srija, G. 2013. Toughness study on fly ash based fiber reinforced concrete. *International Journal of Advanced Structural Engineering*, 5(17), pp.1–4.

Song, Huiping., Liu, Jianqiang., Xue, Fangbin. and Cheng, Fangqin. 2016. The application of ultra-fine fly ash in the seal coating for the wall of underground coal mine. *Advanced Powder Technology*, 27(4), pp.1645–1650.

Soni, D.K. and Saini, J. 2014. Mechanical Properties of High Volume Fly Ash (HVFA) and Concrete Subjected to Evaluated 120 0 C Temperature. *International Journal of Civil Engineering Research*, 5(3), pp.241–248.

Sounthararajan, V.M. and Sivakumar, A. 2013. Performance evaluation of metallic fibres on the low and high volume class F flyash based cement concrete. *International Journal of Engineering and Technology*, 5(2), pp.606–619.

Sua-iam, G. and Makul, N. 2014. Utilization of high volumes of unprocessed lignite-coal fly ash and rice husk ash in self-consolidating concrete. *Journal of Cleaner Production*, 78, pp.184–194.

Supit, S.W.M., Shaikh, F.U.A. and Sarker, P.K. 2014. Effect of ultrafine fly ash on mechanical properties of high volume fly ash mortar. *Construction and Building Materials*, 51, pp.278–286.

Sushil, S. and Batra, V.S. 2006. *Analysis of fly ash heavy metal content and disposal in three thermal power plants in India*,

Syahrul, Mohd., Sani, Mohd., Muftah, Fadhluhartini. and 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(2), pp.65–76.

Taylor, H.F.., Famy, C. and Scrivener, K. 2001. Delayed ettringite formation. *Cement and Concrete Research*, 31(5), pp.683–693.

Tenaga, S., 2014. *Malaysia Electricity Supply & Voltage*,

Thorneloe, Susan A., Kosson, David S., Sanchez, Florence., Garrabrants, AndrewC. and Helms, Gregory. 2010. Evaluating the Fate of Metals in Air Pollution Control Residues from Coal-Fired Power Plants. *Environmental Science & Technology*, 44(19), pp.7351–7356.

Tkaczewska, E., Mróz, R. and Łój, G. 2012. Coal-biomass fly ashes for cement production of CEM II/A-V 42.5R. *Construction and Building Materials*, 28, pp.633–639.

Topcu, I.B. and Bilir, T. 2010. Effect of Bottom Ash as Fine Aggregate on Shrinkage Cracking of Mortars. *Materials Journal*, 107(1), pp.48–56.

Topçu, İ.B. and Canbaz, M. 2007. Effect of different fibers on the mechanical properties of concrete containing fly ash. *Construction and Building Materials*, 21(7), pp.1486–1491.

Topçu, İ.B., Toprak, M.U. and Uygunoğlu, T. 2014. Durability and microstructure characteristics of alkali activated coal bottom ash geopolymer cement. *Journal of Cleaner Production*, 81, pp.211–217.

Torii, K., Taniguchi, K. and Kawamura, M. 1995. Sulfate resistance of high fly ash content concrete. *Cement and Concrete Research*, 25(4), pp.759–768.

Torras, Josep., Buj, Irene., Rovira, Miquel. and de Pablo, Joan. 2011. Semi-dynamic leaching tests of nickel containing wastes stabilized/solidified with magnesium potassium phosphate cements. *Journal of Hazardous Materials*, 186(2), pp.1954–1960.

Tossavainen, M. 2005. *Leaching results in the assessment of slag and rock materials as construction material*. LTU - Luleå University of Technology.

Turgut, P. 2004. Research into the correlation between concrete strength and UPV values. *Journal of Nondestructive Testing*, 12(12).

U.S. EPA, 2013. 1315 - 1 Revision 0 January 2013. , 7345(January), pp.1–36.

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), pp.1–36.

Ugurlu, A. 2004. Leaching characteristics of fly ash. *Environmental Geology*, 46(6–7), pp.890–895.

US EPA SW-846, Hazardous Waste Test Methods.

Wang, Q., Feng, J. and Yan, P. 2012. The microstructure of 4-year-old hardened cement-fly ash paste. *Construction and Building Materials*, 29, pp.114–119.

Wang, Z.S. 2011. Influence of fly ash on the mechanical properties of frame concrete. *Sustainable Cities and Society*, 1(3), pp.164–169.

Wu, Jian Hua., Pu, Xin Cheng., Liu, Fang. and Wang, Chong. 2006. High Performance Concrete with High Volume Fly Ash. *Key Engineering Materials*, 302–303, pp.470–478.

Yang, E.H., Yang, Y.Z. and Li, V.C. 2007. Use of high volume of fly ash to improve ECC mechanical properties and material greenness. *ACI*, 104(6), pp.303–311.

Yilmaz, H. 2015. Characterization and comparison of leaching behaviors of fly ash samples from three different power plants in Turkey. *Fuel Processing*

Technology, 137, pp.240–249.

Yin, Chun Yang., Kadir, Sharifah Aishah Syed Abdul., Lim, Ying Pei., Syed-Ariffin., Sharifah Nawirah. and Zamzuri, Zurinawati. 2008. An investigation into physicochemical characteristics of ash produced from combustion of oil palm biomass wastein a boiler. *Fuel Processing Technology*, 89(7), pp.693–696.

Yoshitake, Isamu., Komure, Hiroki., Nassif, Ayman Y. and Fukumoto, Sunao. 2013. Tensile properties of high volume fly-ash (HVFA) concrete with limestone aggregate. *Construction and Building Materials*, 49, pp.101–109.

Younsi, A., Turcry, P., Rozière, E., Aït-Mokhtar, A. and Loukili, A. 2011. Performance-based design and carbonation of concrete with high fly ash content. *Cement and Concrete Composites*, 33(10), pp.993–1000.

Yuksel, I. and Genc, A. 2007. Properties of Concrete Containing Nonground Ash and Slag As Fine Aggregate. *Materials Journal*, 104(4), pp.397–403.

Yuksel, S., Siddique, R. and Uzkan, U. 2011. Influence of high temperature on the properties of concretes made with industrial by-products as fine aggregate replacement. *Construction and Building Materials*, 25(2), pp.967–972.

Zeng, Qiang., Li, Kefei., Fen-chong, Teddy. and Dangla, Patrick. 2012. Determination of cement hydration and pozzolanic reaction extents for fly-ash cement pastes. *Construction and Building Materials*, 27(1), pp.560–569.

Zhang, M.-H., Blanchette, M.C. and Malhotra, V.M. 2001. Leachability of Trace Metal Elements from Fly Ash Concrete: Results from Column-Leaching and Batch-Leaching Tests. *Materials Journal*, 98(2), pp.126–136.

Zhimin, H., Junzhe, L. and Kangwu, Z. 2012. Influence of Mineral Admixtures on the Short and Long-term Performance of Steam-cured Concrete. *Energy Procedia*, 16(16), pp.836–841.

Ziemkiewicz, P.F., Simmons, J.S. and Knox, A.S. 2003. The Mine Water Leaching Procedure: Evaluating the Environmental Risk of Backfilling Mines with Coal Ash. In *Chemistry of Trace Elements in Fly Ash*. Boston, MA: Springer US, pp. 75–90.