PROPERTIES OF CONCRETE CONTAINING HIGH VOLUME FLY ASH

BALAMOHAN BALAKRISHNAN

A thesis submitted in fulfilment of the
requirement of the award of degree of
Master of Engineering (Structure & Materials)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

OCTOBER 2014

To My Loving Wife Letchumy and Parents Balakrishnan & Kastury

ACKNOWLEDGEMENT

I would like to extend my gratitude and appreciation to my supervisor Assoc. Prof. Dr. A.S.M Abdul Awal for his guidance, advice and supervision that contributed to the completion of this thesis.

I am very thankful to the management of Holcim Malaysia Sdn. Bhd. especially to Mr. Mahanama Ralapanawa, the Chief Executive Officer for his support and encouragement towards this research. The permission given to carry out tests at Holcim's laboratory is also appreciated.

I also would like to thank all the staffs in the structure and materials laboratory, administration office, Faculty of Civil Engineering for their guidance on various occasions throughout the research period.

Finally, my sincere appreciation also extends to all colleagues and friends particularly Dr. Shehu Abu Bakar and Dr. Shathees Baskaran who have provided assistance in many occasions. The views, tips and guidance are helpful in all aspects.

ABSTRACT

The utilization of waste materials in concrete is one of the best value added solutions can be provided to the construction industry. To realize this aim, waste of coal combustion from power plant, known as fly ash is used. Although various researches conducted on the properties of fly ash concrete with fly ash, very little is known on high volume substitution of cement with Class F fly ash particularly for concrete with common water to cement ratio and strength in the concrete application in Malaysia. This research was dedicated to investigate various fresh and hardened state properties of concrete containing high volume fly ash (HVFA). In this investigation, the HVFA were tested in mortar and concrete, and both specimens were tested by substituting 40 to 60% of OPC with fly ash. Properties studied in this research includes fresh concrete properties, mechanical properties and durability properties of concrete exposed to chloride, acid and sulphate solutions. The test result indicates that HVFA positively influenced the workability; however the setting times of the concrete were retarded. The development of strength of HVFA concrete was relatively slower, but the strength development of HVFA concrete after 28 days was greater than concrete with OPC cement. In-terms of durability, the HVFA concrete demonstrated better resistance to destructive chemical penetration and attacks such as chloride, acid and sulphate. Additionally, the test results on the concrete temperature rise suggests that the replacement of cement with HVFA is advantageous, particularly for mass concrete where thermal cracking is of a major concern. However, the performance of concrete at elevated temperatures reveals that concrete without any fly ash has better resistance than HVFA concrete at high temperature. Conclusively, high volume fly ash integration as partial cement replacement increases the resistance of concrete towards chloride penetration, acid and sulphate attack and reduces the temperature rise while obtaining good strength and modulus properties.

ABSTRAK

Penggunaan bahan buangan dalam konkrit adalah salah satu penambahan nilai yang terbaik untuk industri pembinaan. Abu terbang adalah bahan buangan daripada pembakaran arang batu dari stesen janakuasa yang digunakan untuk merealisasikan matlamat ini. Walaupun pelbagai kajian telah dijalankan pada sifat-sifat konkrit abu terbang, agak sedikit yang diketahui tentang penggantian simen dengan abu terbang Kelas F dikonkrit dalam kuantiti tinggi di Malaysia, terutamanya untuk konkrit dengan nisbah air kepada simen dan kekuatan yang biasa digunakan. Kajian ini adalah untuk menyiasat sifat konkrit segar dan keras yang mengandungi abu terbang dalam kuantiti yang tinggi (HVFA). Dalam kajian ini, HVFA telah diuji dalam mortar dan konkrit dengan menggantikan 40 hingga 60% daripada OPC dengan abu terbang. Sifat konkrit yang dikaji adalah sifat konkrit basah, sifat mekanik dan sifat-sifat ketahanan konkrit apabila didedahkan kepada larutan klorida, asid dan sulfat. Keputusannya, HVFA pengaruhi kebolehkerjaan konkrit secara positif, tetapi masa pengerasan konkrit agak terbantut. Pembangunan kekuatan konkrit HVFA juga agak perlahan, tetapi pembangunan kekuatan konkrit selepas 28 hari HVFA adalah jauh lebih baik. Konkrit HVFA juga menunjukkan ketahanan yang amat baik terhadap serangan dan penembusan kimia klorida, asid dan sulfat berbanding dengan konkrit OPC. Ujian ke atas penaikan haba konkrit juga menunjukkan bahawa abu terbang adalah berfaedah, terutamanya bagi konkrit dimana keretakan haba adalah satu kebimbangan utama. Prestasi konkrit pada suhu tinggi mendedahkan bahawa konkrit tanpa abu terbang adalah lebih baik daripada konkrit HVFA.Secara kesimpulan, konkrit dengan penggantian simen dengan abu terbang dalam kuantiti tinggi mempunyai rintangan yang baik terhadap penembusan klorida, serangan asid dan sulfat dan pengurang haba penghidratan sambil mempunyai sifat-sifat kekuatan dan modulus yang baik.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BS	British Standard
C_2S	Dicalcium Silicate
C_3S	Tricalcium Silicate
C_3A	Tricalcium Aluminate
CAH	Calcium Aluminate Hydrate
CSH	Calcium Silicate Hydrate
CaO	Calcium Oxide
Fc	Compressive Strength
HVFA	High Volume Fly Ash
LOI	Loss on Ignition
MOE	Modulus of Elasticity
MW	Megawatt
OPC	Ordinary Portland Cement
S	Silicon Dioxide
SAI	Strength Activity Index
m	Mass
W/B	Water to binder ratio
W/C	Water to cement ratio
μ	Micron

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

There are many ways to generate electric power. In Malaysia, this power is generated primarily by hydroelectric and thermal power plants. The thermal power plant uses steam from water to run steam turbines and generators, in which the steam is produced by firing the source of fuels such as coal, oil, natural gas and diesel. There are 7 coal fired power plants in Malaysia, namely; Jimah Power Station, Manjung Power Station, Mukah Power Station, PPLS Power Generation Plant, Sejingkat Power Corporation Plant, Sultan Salahuddin Abdul Aziz Shah Power Plant and Tanjung Bin Power Station. The details of the plants are shown in Table 1.1. Meanwhile, Figure 1.1 reveals that the power generations from coal fired power plants are at the increasing trend. According to Tenaga Nasional Berhad (2013), the percentage of power generation from coal fired power plant in peninsular has increased from 27.9% in 2008 to 40.5% in 2013.

The power generators prefer the coal due to its higher natural reserve and to reduce dependency on the natural-gas reserve. The combustion process of coal in the power plants leaves behind wastes called fly ash and bottom ash. Fly ash is collected by electrostatic precipitation after the pulverized coal is fired in a furnace and carried away by the exhaust gases to the dust filter. Larger particles will settle to the bottom of the boiler as bottom ash. The heat generated from the combustion of coal is utilized to generate steam to drive the generator turbines.

Table 1.1: Coal fired power plants in Malaysia (Tenaga Nasional Berhad, 2013; Oxford Business Group, 2010)

No.	**Power Plant**	**Location**	**Established (Years)**	**Capacity**
1	Jimah Power Plant	N. Sembilan	2009	1400 MW
2	Tanjung Bin Power Station	Johor	2006	2100 MW
3	Sultan Salahuddin Abdul Aziz Shah Power Plant	Selangor	1987	2420 MW
4	Sultan Azlan Shah Power Plant	Perak	2004	2100 MW
5	PPLS Power Generation	Sarawak	2002	110 MW
6	Sejingkat Power Corporation	Sarawak	1993	210 MW
7	Mukah Power Station	Sarawak	2010	135 MW

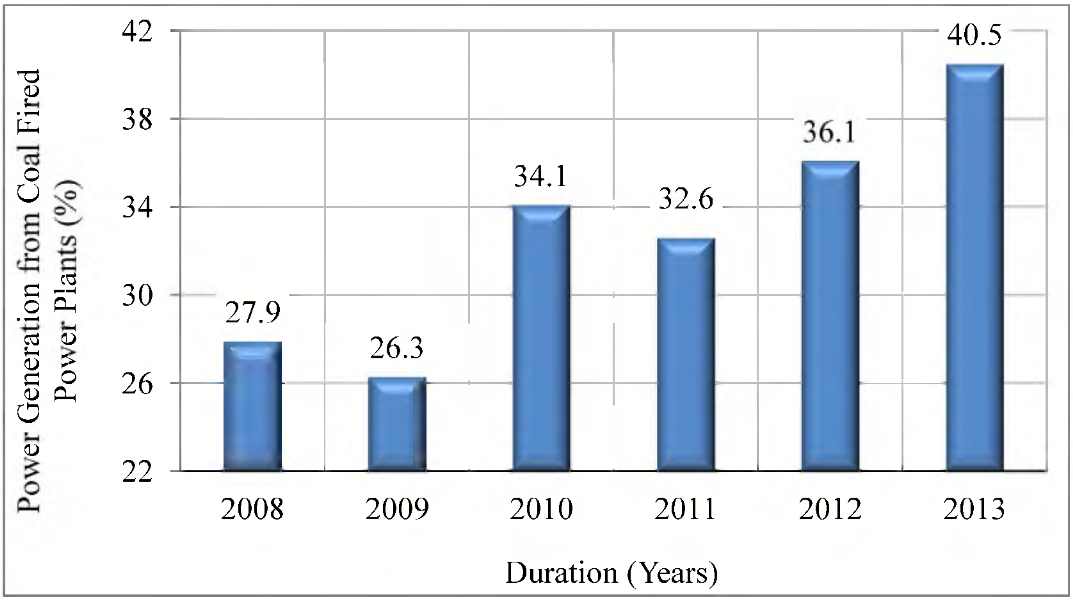
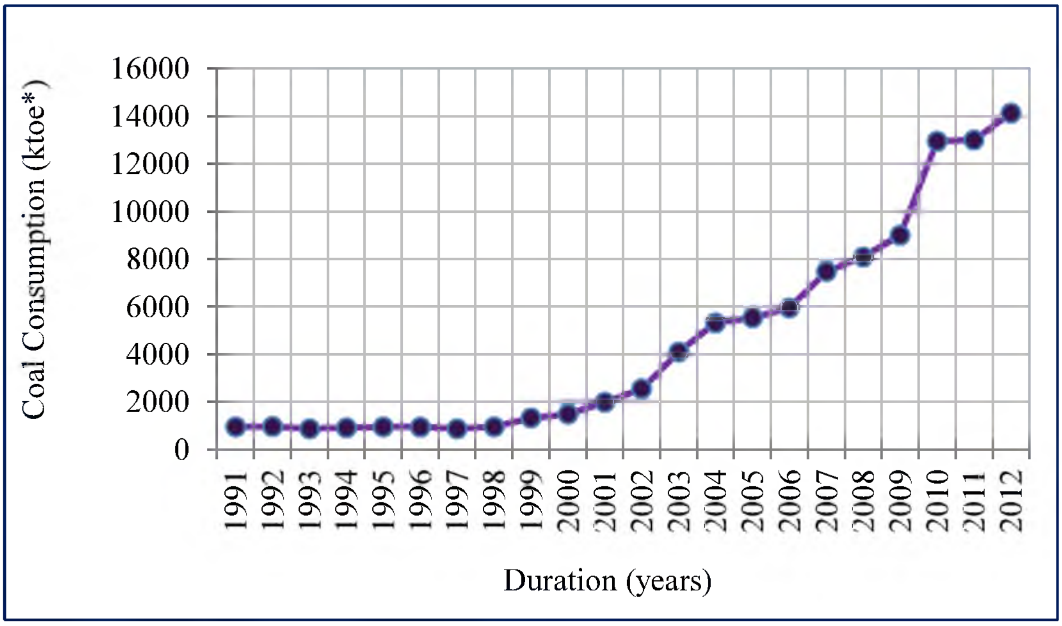


Figure 1.1 Proportions of power generation from coal fired power plants in Peninsular Malaysia (Tenaga Nasional Berhad, 2013)

1.2 Problem Statement

Fly ash is the principal by-product of the coal combustion of the power plant. It is usually dumped as a waste material if it cannot be recycled or reused elsewhere and this activity causes degradation to natural ecology of the environment. According to Rocktron International (2010), it is estimated that 2 million tonnes of fly ash are generated annually in Malaysia. Besides that, the consumption of coal for the thermal power plant has increased over 1000% over the past 20 years as shown in Figure 1.2. Adding to this, it can be also observed in Figure 1.3 that the production and consumption of cement is at a substantial increasing trend from 1993 to 2011 in Malaysia which results in increasing CO_2 emission to environment.

Considering the amount of fly ash generation in Malaysia and the CO_2 associated with this production, there is a need to consider further on high volume application of this ash in concrete. High Volume Fly Ash (HVFA) concrete is a structural concrete with cement/ash replacement substantially above 50%. This practice has been reported to be very popular with fly ash generation in other part of the world, whereas Malaysia with this level of fly ash generation has not put into practice this noble approach in concreting. The local experimental works are scarcely available to study the effects of high volume fly ash in Malaysian concrete which possibility creates the perception that HVFA concrete is inferior to Ordinary Portland Cement (OPC) concrete. Additionally, the degree of difference in the type of concrete used by other researchers in the world grants this HVFA concrete study in Malaysia. Many of the previous studies on the durability of high volume fly ash concrete were mainly carried out either in a relatively lower w/c ratio or compressive strength. For example, tests by Torii *et al.* (1995); Nehdi *et al.* (2004); Amrutha *et al.* (2011); Atis (2002) and Yazici (2008) used a w/c ratio as low as 0.28 or compressive strength of HVFA concrete at 28 days as low as 13 MPa for 60% fly ash. As w/c ratio and the compressive strength has great influence on other concrete's mechanical and durability performance, the more practical and common w/c ratio and HVFA concrete's 28 day compressive strength of 0.44 and 40-50 MPa, respectively was investigated.



* 1 tonne of coal ~ 0.7 toe (tonne oil equivalent)

Figure 1.2 Malaysian power plant coal consumptions, 1991 to 2012 (Suruhanjaya Tenaga, 2012)

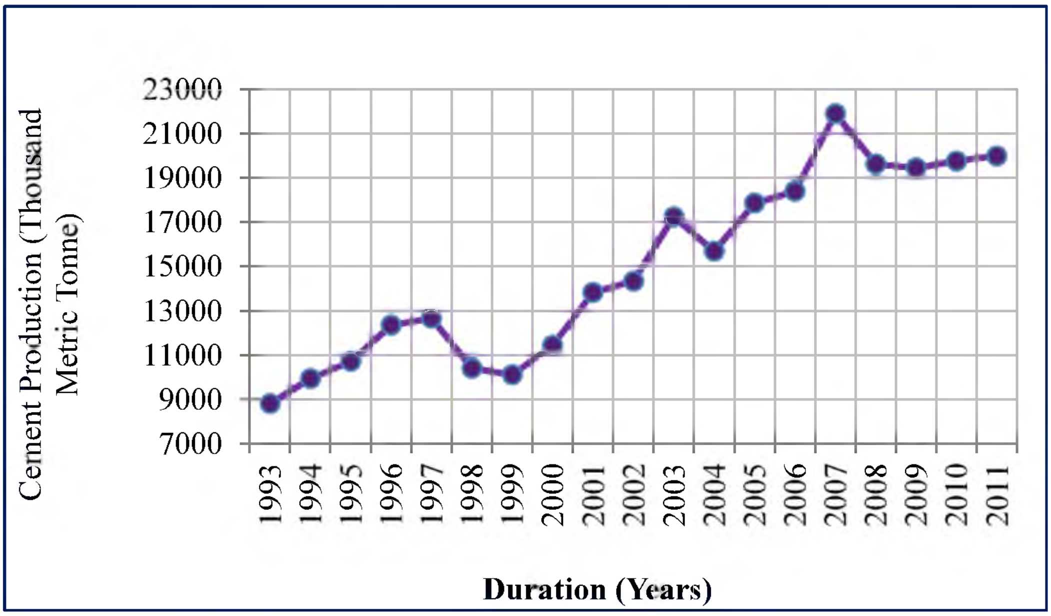


Figure 1.3 Malaysian cement productions, 1993 to 2011 (U. S. Geological Survey, 2011)

1.3 The Significance of the Study

The use of fly ash in a large quantity as a supplementary cementitious material in concrete can benefit power generators, cement and concrete producers and construction industry. For power generators, when high volumes fly ash is used in concrete, it help to get rid of large volume of the waste (fly ash) which would have otherwise be used as landfilled with additional cost. The use of large volume fly ash in concrete can also be considered as an ecological disposal approach which reduces the damages to the environment.

Moreover, as cement and concrete producers intensifies effort to reduce their CO_2 emission as required by global legislation and for their corporate social responsibility, the use of HVFA (High Volume Fly Ash) in their production can be the fastest and easiest way of achieving the objective. Every 1 tonne of fly ash used to replace the cement will result in 1 tonne of CO_2 reduced in the concrete.

Additionally, when fly ash is used properly, it can significantly improve concrete performance. Although fly ash is known to improve concrete properties, the usual small proportion may not be enough to improve the concrete durability significantly. Although it is known that concrete made with high volume fly ash can provide an excellent resistance to chemical attacks such as chloride, acid and sulphate, the HVFA concrete mix proportion has big effect on the concrete performance. As such, the strength and water to cement ratio used is practical for concrete application in Malaysia.

As high volume fly ash concrete benefits in all three sustainability issues, its adoption will enable the construction industry to become more sustainable. Moreover, it is believed that concrete made with HVFA is one of the best value added uses of waste material (Malhotra and Bilodeau, 1999).

1.4 Aim and Objectives

The aim of the research is to investigate the effect of high volume fly ash on the fresh and hardened state properties of concrete with w/c of 0.44 and strength up to 70 MPa at 90 days. The objective is set forth to study the followings:

a) To examine the physical and chemical properties of fly ash.
b) To study the effect of high volume fly ash on the fresh concrete properties.
c) To examine the effect of high volume fly ash on the strength and elastic modulus of concrete.
d) To evaluate the behavior of concrete when exposed to aggressive condition.

1.5 Scope

The scope of the study is limited to the laboratory investigation and does not include field and the economic aspects of the high volume fly ash application. This does not entail to overlook the economy to the background, but rather the technical aspects are required to be fixed right before the economic aspects.

1.6 Research Hypothesis

High volume Tg. Bin Power Plant fly ash has significant effects on the fresh and hardened state properties of concrete.

1.7 Organisation of Thesis

The body of the thesis contains 7 main chapters and the orientation of the thesis and highlights of each chapter are shown in Figure 1.4.

Chapter 1 Introduction	Background, problem statement, significance of the study, aim and objectives, scope, hypothesis and structure of thesis
Chapter 2 Review of Literature	Fly ash introduction, HVFA background, hydration and pozzolanic reaction, HVFA effects on concrete properties
Chapter 3 Materials and Test Details	Materials preparation, design of concrete mixtures, specimen preparation and testing plan, testing procedures
Chapter 4 Properties of Fly Ash and Fresh Concrete	Test results of physical and chemical properties of fly ash and fresh concrete properties
Chapter 5 Strength Properties of Concrete	Test results of the compressive strength, splitting tensile strength and modulus of elasticity of concrete
Chapter 6 Behaviour in Aggressive Conditions	Test results of temperature rise, resistance to chloride penetrations, acid attack, sulphate attack and high temperature.
Chapter 7 Conclusion and Recommendation	The summary for the testing finding and the recommended future studies associated with HVFA concrete.

Figure 1.4 The organisation of thesis

REFERENCES

Ahmad, M. H. and Noor, N. M. (2009). Chemical Attack of Malaysian Pozzolans Concrete. *Journal of Science and Technology*. 1(1):11-24.

Ahmaruzzaman, M. (2010). A Review on the Utilization of Fly Ash. *Progress in Energy and Combustion Science*. 36(3):327-363.

Allahverdi, A. and Skvara, F. (2006). Sulfuric Acid Attack on Hardened Paste of Geopolymer Cements-Part 2. Corrosion Mechanism at Mild and Relatively Low Concentrations. *Ceramics Silikaty.* 50(1): 1-4.

American Concrete Institute (1992). *ACI 363R*. United States of America: American Concrete Institute.

American Concrete Institute (1999). *ACI 318.* United States of America: American Concrete Institute.

American Concrete Institute (2000) *ACI 116R*. United States of America: American Concrete Institute.

American Concrete Institute (2003). *ACI 232.2R.* United States of America: American Concrete Institute.

American Concrete Institute (2010) *ACI 301*. United States of America: American Concrete Institute.

American Society for Testing and Materials (2008) *ASTM C403*. West Conshohocken, PA: Annual Book of ASTM Standards.

American Society for Testing and Materials (2008) *ASTM C430*. West Conshohocken, PA: Annual Book of ASTM Standards.

American Society for Testing and Materials (2010) *ASTM C1543*. West Conshohocken, PA: Annual Book of ASTM Standards.

American Society for Testing and Materials (2010) *ASTM C469*. West Conshohocken, PA: Annual Book of ASTM Standards.

American Society for Testing and Materials (2011) *ASTM C496*. West Conshohocken, PA: Annual Book of ASTM Standards.

American Society for Testing and Materials (2012) *ASTM C150*. West Conshohocken, PA: Annual Book of ASTM Standards.

American Society for Testing and Materials (2012) *ASTM C618*. West Conshohocken, PA: Annual Book of ASTM Standards.

American Society for Testing and Materials (2013) *ASTM C114*. West Conshohocken, PA: Annual Book of ASTM Standards.

American Society for Testing and Materials (2013) *ASTM C311*. West Conshohocken, PA: Annual Book of ASTM Standards.

Amrutha, Nayak, G., Narasimhan, M. C. and Rajeeva S. V. (2011). Chloride-Ion Impermeability of Self-Compacting High-Volume Fly Ash Concrete Mix. *International Journal of Civil & Environmental Engineering*. 11(4):29-35.

Arioz, O. (2007). Effects of Elevated Temperatures on Properties of Concrete. *Fire Safety Journal*. 42(8):516–522.

Atis, C. D. (2002). Heat Evolution of High-Volume Fly Ash Concrete. *Cement and Concrete Researc*h. 32(5):751–756.

Atis, C. D. (2005). Strength Properties of High-Volume Fly Ash Roller Compacted and Workable Concrete, and Influence of Curing Condition. *Cement and Concrete Research.* 35(6):1112-1121.

Awal, A. S. M. A. and Hussin, M. W. (1997) Some Aspects of Durability Performances of Concrete Incorporating Palm Oil Fuel Ash. *Proceedings of the 5th International Conference on Structural Failure Durability and Retrofitting*. Nov. 1997. Singapore, 210-218.

Awal, A. S. M. A. and Hussin, M.W. (2011) Effect of Palm Oil Fuel Ash in Controlling Heat of Hydration of Concrete. *Procedia Engineering,* 14:2650-2657.

Awal, A.S.M.A. and Shehu, I. A. (2013). Evaluation of Heat of Hydration of Concrete Containing High Volume Palm Oil Fuel Ash. *Fuel.* 105:728-731.

Aydin, S., Karatay, C. and Baradan, B. (2010). The Effect of Grinding Process on Mechanical Properties and Alkali–Silica Reaction Resistance of Fly Ash Incorporated Cement Mortars. *Powder Technology.* 197(1):68–72.

Aydin, S., Yazici, H., Yigiter, H. and Baradan, B. (2007). Sulfuric Acid Resistance of High-Volume Fly Ash Concrete. *Building and Environment*. 42(2):717-721.

Baert, G., Driesch, I. V., Hoste, S., Schutter, G. D. and Belie. N. D. (2007). Interaction Between the Pozzolanic Reaction of Fly Ash and the Hydration of Cement. *Forthcoming Congress ICCC2007*. 8-13 July 2007. Montreal.

Bagchi, S. S., Ghule, S. V. and Jadhav, R. T. (2012). Fly Ash Fineness – Comparing Residue on 45 Micron Sieve with Blaine's Surface Area. *The Indian Concrete Journal*. 86:39-42.

Barbhuiya, S. A., Gbagbo, J. K., Russell, M. I. and Basheer P. A. M. (2009). Properties of Fly Ash Concrete Modified with Hydrated Lime and Silica Fume. *Construction and Building Materials*. 23(10):3233–3239.

Barrett, T. J., De La Varga, L., Schlitter, J. and Weiss, W. J. (2011). Reducing the Risk of Cracking in High Volume Fly Ash Concrete by Using Internal Curing. *World of Coal Ash (WOCA) Conference.* 9-12 May 2011, Denver.

Bentz, D. P. and Ferraris C. F. (2010). Rheology and Setting of High Volume Fly Ash Mixtures. *Cement and Concrete Composites*. 32(4):265-270.

Bouzoubaa, N., Zhang M. H. and Malhotra V.M. (2001). Mechanical Properties and Durability of Concrete Made With High-Volume Fly Ash Blended Cements Using a Coarse Fly Ash. *Cement and Concrete Research.* 31(3): 1393-1402.

Bouzoubaa, N., Zhang, M. H. and Malhotra, V. M. (2000). Laboratory-Produced High-Volume Fly Ash Blended Cements Compressive Strength and Resistance to the Chloride-Ion Penetration of Concrete. *Cement and Concrete Research*. 30(7):1037- 1046.

Bouzoubaa, N., Zhang, M. H., Bilodeau, A. and Malhotra, V. M. (1998). Laboratory-Produced High Volume Fly Ash Blended Cements: Physical Properties and Compressive Strength of Mortars. *Cement and Concrete Research*. 28(11): 1555-1569.

Brick, R. H. and Halstead, W. J. (1956). Studies Relating to Testing of Fly Ash for Use in Concrete. *Proceedings of the American Society for Testing and Materials.* 56:1161-1206.

British Standard Institution (2005). *BS EN 196-3*. London: British Standard Institution.

British Standard Institution (2009). *BS EN 12350-2*. London: British Standard Institution.

British Standard Institution (2010). *BS EN 12390-1*. London: British Standard Institution.

British Standard Institution (2009). BS EN 12390-3. London: British Standard Institution.

British Standard Institution (2011). *BS EN 197-1*. London: British Standard Institution.

British Standard Institution (2012). *BS EN 450-1*. London: British Standard Institution.

British Standard Institution (1981). *BS 5328*. London: British Standard Institution.

British Standard Institution (1992). *BS 882*. London: British Standard Institution.

Brooks, J. J., Johari, M.A. M. and Mazloom, M. (2000). Effect of Admixtures on the Setting Times of High-Strength Concrete. *Cement and Concrete Composites*. 22(4):293-301.

Broomfield, J. P. (2007). *Corrosion of Steel in Concrete: Understanding, Investigation and Repair*. Taylor & Francis (Second Edition).

Budiea, A. M. A. (1998). *Study on Durability of High Strength Palm Oil Fuel Ash Pofa Concrete*. Masters of Engineering, Universiti Teknologi Malaysia, Skudai.

Budiea, A., Hussin, M. W., Muthusamy, K. and Ismail, M. E. (2010). Performance of High Strength POFA Concrete in Acidic Environment. *Concrete Research Letters*. 1(1):14-18.

Ceukelaire, L. D. (1992). The Effects of Hydrochloric Acid on Mortar. *Cement and Concrete Research*. 22(5):903-914.

Chalee, W., Jaturapitakkil, C. and Chindaprasirt, P. (2009). Predicting the Chloride Penetration of Fly Ash Concrete in Seawater. *Marine Structures*. 22(3):341-353.

Chan, Y. N, Luo, X. and Sun, W. (2000). Compressive Strength and Pore Structure of High-Performance Concrete After Exposure to High Temperature Up To 800^{o}c. *Cement and Concrete Research*. 30(2):247–251.

Chandra, S. (1988). Hydrochloric Acid Attack on Cement Mortar – An Analytical Study. *Cement and Concrete Research*. 18(2):193-203.

Cheewat, T., Jaturapitakkul, C. and Chalee, W. (2010). Long Term Performance of Chloride Binding Capacity in Fly Ash Concrete in a Marine Environment. *Construction and Building Materials*. 24(8):1352-1357.

Chen, Z. J. (2004). *Effect of Reinforcement Corrosion on the Serviceability of Reinforced Concrete Structures*. Masters of Science in Engineering. University of Dundee, United Kingdom.

Chindaprasirt, P., Chotithanorm, C., Cao, H. T. and Sirivivatnanon, V. (2007). Influence of Fly Ash Fineness on the Chloride Penetration of Concrete. *Construction and Building Materials*. 21(2): 356–361.

Chindaprasirt, P., Homwuttiwong, S. and Sirivivatnanon, V. (2004). Influence of Fly Ash Fineness on Strength, Drying Shrinkage and Sulfate Resistance of Blended Cement Mortar. *Cement and Concrete Research*, *34*(7):1087-1092.

Comite Euro-International du Beton (1992). *Durable Concrete Structures: Design Guide* (Vol. 182). Switzerland: Thomas Telford.

Davis, R. E., Carlson, R. W., Kelly, J. W. and Davis, H. E. (1937). Properties of Cements and Concretes Containing Fly Ash. *ACI Journal*. 33:577-612.

Dawkrajai, P. (2006). *Temperature Prediction Model for a Producing Horizontal Well*, Ph.D Thesis, the University of Texas at Austin, Austin.

Demirel, B. and Keleştemur, O. (2010). Effect of Elevated Temperature on The Mechanical Properties of Concrete Produced with Finely Ground Pumice and Silica Fume. *Fire Safety Journal*, *45*(6):385-391.

Dhale, S. A. and Pande, A. M. (2013). Investigation and Comparative Study of Effect of Silica Fume in Cementitious Grouts. *International Journal of Civil & Structural Engineering*, *4*(2):183-191.

Dinakar, P., Babu, K. G. and Santhanam, M. (2008). Durability Properties of High Volume Fly Ash Self Compacting Concretes. *Cement and Concrete Composite*. 30(10):880-886.

Duran-Herrera, A., Juarez, C. A., Valdez, P. and Bentz, D. P. (2011). Evaluation of Sustainable High-Volume Fly Ash Concretes. *Cement & Concrete Composites*. 33(1):39–45.

Elmetwally, M. M. A. (2003). Behaviour of Epoxy-Coated Reinforcement Concrete Beams with Sodium Chloride Contamination. In Franco, B. (ED.) *System-Based Vision for Strategic and Creative Design* (pp.1349-1354). Netherlands:A.A Balkema.

Fattuhi, N. I. and Hughes, B. P. (1988). The Performance of Cement Paste and Concrete Subjected To Sulphuric Acid Attack. *Cement and Concrete Research*. 18(4):545-553.

Feldman, R. F., Carette, G. G. and Malhotra, V. M. (1990). Studies on Mechanism of Development of Physical and Mechanical Properties of High-Volume Fly-Ash Cement Paste. *Cement and Concrete Composites*. 12(4):245-251.

Franke, L., and Sisomphon, K. (2004). A New Chemical Method for Analyzing Free Calcium Hydroxide Content in Cementing Material. *Cement and concrete research*, *34*(7):1161-1165.

Freeman, R. B. and Carrasquillo R. L. (1991). Influence of the Method of Fly Ash Incorporation on the Sulfate Resistance of Fly Ash Concrete. *Cement and Concrete Composites*. 13(3): 209-217

Gardner, N. J. (1990). *Effect of Temperature on the Early-Age Properties of Type I, Type III, and Type I/Fly Ash Concretes*. ACI Materials Journal. 87(1):68-78.

Georgali, B. and Tsakiridis, P. E. (2005). Microstructure of Fire-Damaged Concrete. *Cement and Concrete Composites*. 27(2):255–259.

Georgescu, M. and Saca, N. (2009). Properties of Blended Cements with Limestone Filler and Fly Ash Content. *Scientific Bulletin B Chemistry and Materials Science*, 71(3): ISSN 1454-2331.

Girardi, F., Vaona, W. and Di Maggio R. (2010). Resistance of Different Types of Concretes to Cyclic Sulfuric Acid and Sodium Sulfate Attack. *Cement and Concrete Composites*. 32(8):595–602.

Guerrero, A., Hernández, M. S. and Goni, S. (2000). The Role of the Fly Ash Pozzolanic Activity in Simulated Sulphate Radioactive Liquid Waste. *Waste Management*. 20(1):51-58.

Hadipramana, J., Samad, A. A. A., Zaidi, A. M. A., Mohammad, N., and Riza, F. V. (2013). Effect of Uncontrolled Burning Rice Husk Ash in Foamed Concrete. *Advanced Materials Research*. 626: 769-775.

Hertz, K. D. (2005). Concrete Strength for Fire Safety Design. *Magazine of Concrete Research*. 57(8):445–53.

Hodhod, O. and Salama, G. A. (2013). Analysis of Sulfate Resistance in Concrete Based On Artificial Neural Networks and USBR4908-Modeling. *Ain Shams Engineering Journal*. 4(4):651-660.

Hopkins, D. S., Thomas, M. D. A., Oates, D. B., Girn, G. and Munro, R. (2001). York University Uses High-Volume Fly Ash Concrete for Green Building. *Proceedings- Canadian Society for Civil Engineering.* June 2011. Canada.

Husem, M. (2006). The Effects of High Temperature on Compressive and Flexural Strengths of Ordinary and High-Performance Concrete. *Fire Safety Journal.* 41(2):155–163.

Hussin, M. W., Ismail M. A,. Budiea, A. and Muthusamy, K. (2009). Durability of High Strength Concrete Containing Palm Oil Fuel Ash of Different Fineness. *Malaysian Journal of Civil engineering.* 21(2):180-194

Idiart, A. E., Lopez, C. M. and Carol, I. (2011). Chemo-Mechanical Analysis of Concrete Cracking and Degradation Due to External Sulfate Attack: A Meso-Scale Model. Cement and Concrete Composites. 33(3):411-423.

Isaia, G. C., Gastaldini, A. L. G. znd Moraes, R. (2003). Physical and Pozzolanic Action of Mineral Additions on the Mechanical Strength of High-Performance Concrete. *Cement & Concrete Composites.* 25(1):69–76.

Janotka, I. and Nurnbergerova, T. (2005). Effect of Temperature on Structural Quality of the Cement Paste and High-Strength Concrete with Silica Fume. *Nuclear Engineering and Design.* 235(17-19): 2019-2032.

Jiang, L. H., & Malhotra, V. M. (2000). Reduction in Water Demand of Non-Air-Entrained Concrete Incorporating Large Volumes of Fly Ash. *Cement and Concrete Research.* 30(11):1785-1789.

Karakurt, C. and Tapcu, I. B. (2011) Effect of Blended Cements Produced With Natural Zeolite and Industrial By-Products on Alkali-Silica Reaction and Sulfate Resistance of Concrete. *Construction and Building Materials.* 25(4):1789-1795.

Karim, M. R., Zain, M. F. M., Jamil, M., Lai, F. C. and Islam, M. N. (2011). Strength Development of Mortar and Concrete Containing Fly Ash: A Review. *International Journal of the Physical Sciences.* 6(17):4137-4153.

Kartini, K. (2011). Rice Husk Ash – Pozzolanic Material for Sustainability. *International Journal of Applied Science and Technology.* 1(6):169-178.

Khan, M. S. and Prasad, J. (2010). Fly Ash Concrete Subjected to Thermal Cyclic Loads. *Fatigue and Fracture of Engineering Materials and Structures.* 33(5):276–283.

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):1369-1378.

Lam, L., Wong, Y. L. and Poon, C. S. (2000). Degree of Hydration and Gel/Space Ratio of High-Volume Fly Ash/Cement Systems. *Cement and Concrete Research*, *30*(5): 747-756.

Lee, S. L., Wong, S. F., Swaddiwudhipong, S., Wee, T. H. and Loo, Y. H. (1996). Accelerated Test of Ingress of Chloride Ions in Concrete Under Pressure and Concentration Gradients. *Magazine of Concrete Research*. 48(174):15-25.

Lerch, W. (1946). *The Influence of Gypsum on the Hydration and Properties of Portland Cement Pastes*. Portland Cement Association.

Li, G. (2004). Properties of High-Volume Fly Ash Concrete Incorporating Nano-SiO_2. *Cement and Concrete Research*. 34(6):1043–1049.

Li, G. and Zhao, X. (2003). Properties of Concrete Incorporating Fly Ash and Ground Granulated Blast-Furnace Slag. *Cement and Concrete Composites*. 25(3):293-299.

Li, M., Qian, C. X. and Sun, W. (2004). Mechanical Properties of High-Strength Concrete After Fire. *Cement and Concrete Research*. 34(6):1001–1005.

Luo, X., Sun, W. and Chan, S. Y. N. (2000). Effect of Heating and Cooling Regimes on Residual Strength and Microstructure of Normal Strength and High-Performance Concrete. *Cement and Concrete Research*. 30(30): 379-383.

Mahjoub, R., Jamaludin M. Y. and Abdul Rahman M. S. (2013). A Review of Structural Performance of Oil Palm Empty Fruit Bunch Fiber in Polymer Composites. *Advances in Materials Science and Engineering*. http://dx.doi.org/10.1155/2013/415359.

Malhotra, V. M. (1990). Durability of Concrete Incorporating High-Volume of Low-Calcium (ASTM Class F) Fly Ash. *Cement and Concrete Composites*. 12(4):271-277.

Malhotra, V. M. and Bilodeau, A. (1999). High-Volume Fly Ash System: The Concrete Solution for Sustainable Development. In Metha, P. K. (Ed.) *Concrete Technology for Sustainable Development in 21st Century*. (43-64) New Delhi: CMA.

Malhotra, V. M. (1995). High-Volume Fly Ash and Slag Concrete. In Ramachandran, V. S. (Ed.) *Concrete Admixtures Handbook* (800-838). United States of America: Noyes Publications.

Malhotra, V. M. (1978). *Superplasticizers in concrete*. National Ready Mixed Concrete Association.

Mansfield, F. (1981). Recording and Analysis of AC Impedance Data for Corrosion Studies. *Corrosion*. 37(5):301-307.

Marsh, B. K. (1997). *Design of normal concrete mixes* (2nd ed) . London, Building Research Establishment: BRE Press.

Marthong, C. and Agrawal, T. P. (2012). Effect of Fly Ash Additive on Concrete Properties. *International Journal of Engineering Research and Applications.* 2(4):1986-1991.

Marto, A., Kassim, K. A., Makhtar, A. M., Wei, L. F and Lim Y. S. (2010). Engineering Characteristics of Tanjung Bin coal ash. *Journal of Geotechnical Engineering*. 15:1117-1129.

Marinescu, M. V. A. & Brouwers, H. J. H. (2009). Chloride binding in OPC hydration products. In H.B. Fischer & K.A. Bode (Eds.), Proceedings 17th Ibausil, international conference on building materials (internationale baustofftagung), 23-26 September 2009, Weimar, Germany (pp. 1-0271-1-0276). Weimar, Germany: Bauhaus-Universitat Weimar (ISBN 978-3-00-027265-3).

Megat Johari M. A., Brooks, J. J., Kabir, S. and Rivard, P. (2011). Influence of Supplementary Cementitious Materials on Engineering Properties of High Strength Concrete. *Construction and Building Materials*. 25(5):2639–2648.

Megat Johari M. A., Zeyad, A. M., Muhamad Bunnori, N. and Ariffin, K. S. (2012). Engineering and Transport Properties of High-Strength Green Concrete Containing High Volume of Ultrafine Palm Oil Fuel Ash. *Construction and Building Materials*. 30:281–288.

Mehta, K. (2004). High-Performance, High-Volume Fly Ash Concrete for Sustainable Development. *International Workshop on Sustainable Development and Concrete Technology*. 20 May 2004, Beijing, China.

Mccarthy, M. J. and Dhir R. K. (2005). Development of High Volume Fly Ash Cements for Use in Concrete Construction. *Fuel*. 84(11):1423–1432.

Muthusamy, K. and Sabri, N. A. (2012). Cockle Shell: A Potential Partial Coarse Aggregate Replacement in Concrete. *International Journal of Science, Environment and Technology*. 1(4):260 – 267.

Naik, R. Y. and Shiw, S. S. (1997). Influence of Fly Ash on Setting and Hardening Characteristics of Concrete Systems. *ACI Material Journal*. 94(5):355- 60.

Naik, T. R., Ramme, B. W., and Tews, J. H. (1995a). Pavement Construction with High Volume Class C and Class F Fly Ash Concrete. *ACI Materials Journal*, 92(2): 200- 210.

Naik, T. R., Singh, S. S. and Hossain, M. M. (1995b). Properties of High Performance Concrete System Incorporating Large Amounts of High-Lime Fly Ash. *Construction and Building Materials.* 9(4):195-204.

Naik, T. R., Wei, L. and Golden, M. (1991). The Use of Fly Ash in Pumpable Mass Concrete. *Department of Civil Engineering and Mechanics College of Engineering and Applied Science*. June 16-21, 1991, British Columbia.

Narmluk, M. and Nawa, T. (2011). Effects of Fly Ash on the Kinetics of Portland Cement Hydration at Different Temperatures. *Cement and Concrete Research*. 41(6): 579-589.

Narmluk, M. and Nawa, T. (2014). Effect of Curing Temperature on Pozzolanic Reaction of Fly Ash in Blended Cement Paste. *International Journal of Chemical Engineering and Applications.* 5(1):579-589.

Nataraja, M. C., Jayaram, M. A. and Ravikumar C. N. (2006). Prediction of Early Strength of Concrete: A Fuzzy Inference System Model. *International Journal of Physical Sciences*. 1(2):047-056.

Nehdi, M., Pardhan, M. and Koshowski, S. (2004). Durability of Self-Consolidating Concrete Incorporating High-Volume Replacement Composite Cements. *Cement and Concrete Research*. 34(11):2103-2112.

Neville, A. M. (1995). *Properties of Concrete*. (4th ed.) United Kingdom,: Pearson Prentice Hall.

Oxford Business Group (2010). *In The Report: Malaysia 2010*. Oxford Business Group.

Poon, C. S., Lam, L. and Wong, Y. L. (2000). A Study on High Strength Concrete Prepared With Large Volumes of Low Calcium Fly Ash. *Cement and Concrete Research*. 30(3):447-455.

Marinescu, M. V. A. and Brouwers, H. J. H. (2009). Chloride Binding in OPC Hydration Products. *Proceedings 17th Ibausil, International Conference on Building Materials Internationale Baustofftagung*, 23-26 September 2009. Weimar, Germany, 1-0271 – 10276.

Ramezanianpour, A. A., (1995). Effect of Curing on the Compressive Strength, Resistance to Chloride-Ion Penetration and Porosity of Concretes Incorporating Slag, Fly Ash or Silica Fume. *Cement and Concrete Composites*. 17(2):125-133.

Ravindrarajah, R. S. and Moses, P. R. (1993). Effect of Binder Type on Chloride Penetration in Mortar. *Proceedings of the Forth International Conference on Structural Failure, Durability and Retrofitting*. 14 July 1993. Singapore, 303-309.

Rocktron International (2010), "International Greentech & Eco Products Exibition & Conference Malaysia". *www.rktron.com.my.*

Sahmaran, M., Yaman, I. O., Tokyay, M. (2009). Transport and Mechanical Properties of Self Consolidating Concrete with High Volume Fly Ash. *Cement and Concrete Composites*. 31(2):99-106.

Şahmaran, M., Christianto, H. A. and Yaman, İ. Ö. (2006). The Effect of Chemical Admixtures and Mineral Additives on the Properties of Self-Compacting Mortars. *Cement and concrete composites*. 28(5):432-440.

Sata, V., Jaturapitakkul, C. and Rattanashotinunt, C. (2010). Compressive Strength and Heat Evolution of Concretes Containing Palm Oil Fuel Ash. *Journal of Materials in Civil Engineering*. 22(10):1033-1038.

Shrivastava, Y. and Bajaj, K. (2012). Performance of Fly Ash and High Volume Fly Ash Concrete in Pavement Design. *IPCSIT.* 28: 188-192.

Siddique, R. (2004). Performance Characteristics of High-Volume Class F Fly Ash Concrete. *Cement and Concrete Research*. 34(3):487–493.

Siddique, R. and Khan, M. I. (2011). *Supplementary Cementing Materials.* (11^{th} Edition) Berlin Heidelberg: Springer.

Sivasundaram, V., Carette G. G. and Malhotra V. M. (1990). Long-Term Strength Development of High-Volume Fly Ash Concrete. *Cement and Concrete Composites*. 12(4):263-270.

Skalny J., Gebauer J, and Odler, I. (2000). Material Science of Concrete Special Volume: Calcium Hydroxide in Concrete. *Workshop on the Role of Calcium Hydroxide in Concrete.* Nov. 2000. Florida, 59-72.

Skalny, J., Marchand, J. and Odler, I. (1997). "Sulfate Attack on Concrete." 1st. ed. London.: Spon Press:45-101.

Somna, R., Jaturapitakkul, C. and Amde A. M. (2012). Effect of Ground Fly Ash and Ground Bagasse Ash on the Durability of Recycled Aggregate Concrete. *Cement and Concrete Composites*. 34(7): 848–854.

Sounthararajan, V. M. and Sivakumar, K. S. A. (2013). Micro Filler Effects of Silica-Fume on the Setting and Hardened Properties of Concrete. *Research Journal of Applied Sciences, Engineering and Technology*. 6(14): 2649-2654.

Sumer, M. (2012). Compressive Strength and Sulfate Resistance Properties of Concretes Containing Class F And Class C Fly Ashes. *Construction and Building Materials*. 34:531–536.

Suruhanjaya Tenaga, (2012). *National Energy Balance*. Putrajaya: Suruhjaya Tenaga.

Swamy, R. N. (1990). Fly Ash Concrete – Potential Without Misuse. *Materials and Structures*. 23(6):397-411.

Tahir, M. A. and Moeen, E. B. (2005) Strength Development of Concrete Due to Chemical Composition of Incorporated Fly Ash. *30th Conference on Our World in Concrete and Structures*. 3 - 24 August 2005, Singapore.

Tenaga Nasional Berhad, (2013). *Annual Report*. Kuala Lumpur: TNB

Thomas, M. D. A. and Skalny, J. (2006). Chemical Resistance of Concrete. In Joseph, F. L. and Pielert, J. H. (Ed). Significance of Tests and *Properties of Concrete and Concrete-Making Materials*. (pp. 253-273). New Jersey: ASTM International

Torii, K., Taniguchi, K. and Kawamura, M. (1995). Sulfate Resistance of High Fly Ash Content Concrete. *Cement and Concrete Research*. 25(4):759-768.

Toutanji, H., Delatte, N., Aggoun, S., Duval, R. and Danson, A. (2004). Effect of Supplementary Cementitious Materials on the Compressive Strength and Durability of Short-Term Cured Concrete. *Cement and Concrete Research*. 34(2):311-319.

U.S. Geological Survey (2011). *In 2011 Minerals Yearbook.* Washington :USGS.

Uysal, M., Yilmaz, K. and Ipek, M. (2011). The Effect of Mineral Admixtures on Mechanical Properties, Chloride Ion Permeability and Impermeability of Self-Compacting Concrete. *Construction and Building Materials*. 27(1):263-270.

Wei, S., Handong, Y. and Binggen, Z. (2003). Analysis of Mechanism on Water-Reducing Effect of Fine Ground Slag, High-Calcium Fly Ash, and Low-Calcium Fly Ash. *Cement and Concrete Research*. 33(8):1119–1125.

Woolley, G. R. and Dhir, R. K. Specifying for Different Applications. *Proceedings, National Seminar on the Use of PFA in Construction*. February 1992. University of Dundee, 213-26.

Yazici, H. (2008). Effects of Silica Fume and High-Volume Class C Fly Ash on Mechanical Properties, Chloride Penetration and Freeze-Thaw Resistance of Self-Compacting Concrete. *Construction and Building Materials*. 22(4):456-462.

Yazici, H., Aydin, S., Yigiter, H. and Baradan, B. (2004). Effect of Steam Curing on Class C High-Volume Fly Ash Concrete Mixtures. *Cement and Concrete Research*. 35(6):1122–1127.