PROPERTIES OF CONCRETE CONTAINING HIGH VOLUME FLY ASH

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To My Loving Wife Letchumy and Parents Balakrishnan & Kastury

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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.

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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

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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

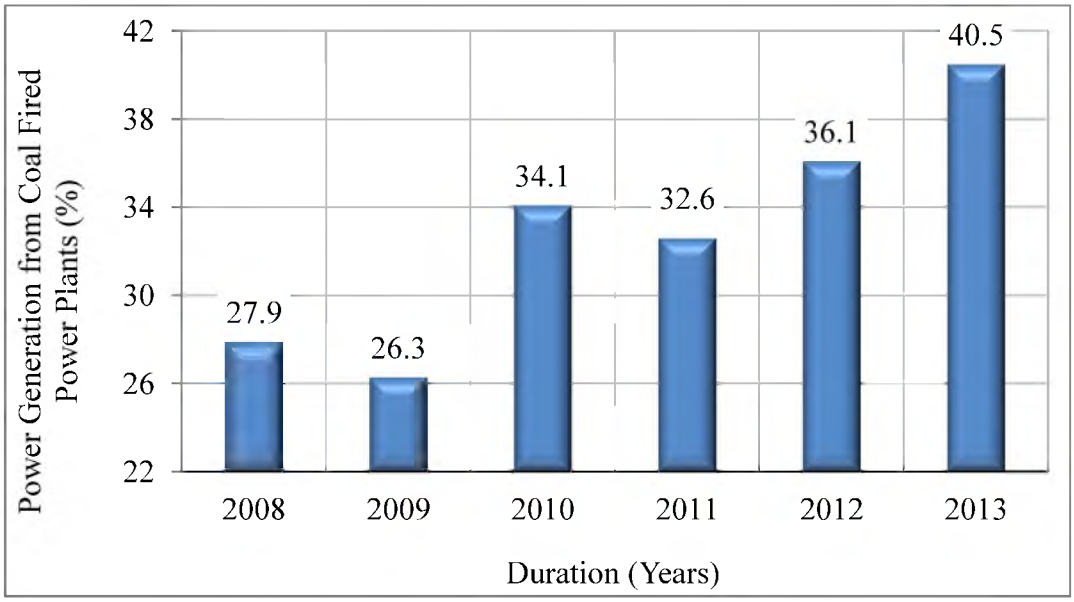
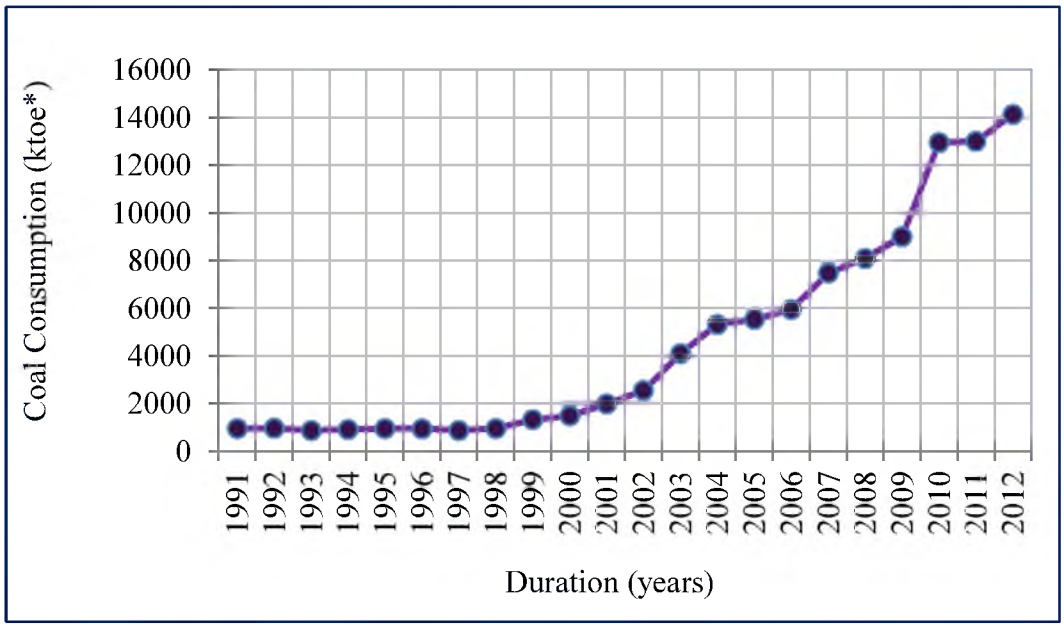


Figure 1.1 Proportions of power generation from coal fired power plants in Peninsular Malaysia (Tenaga Nasional Berhad, 2013)

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)

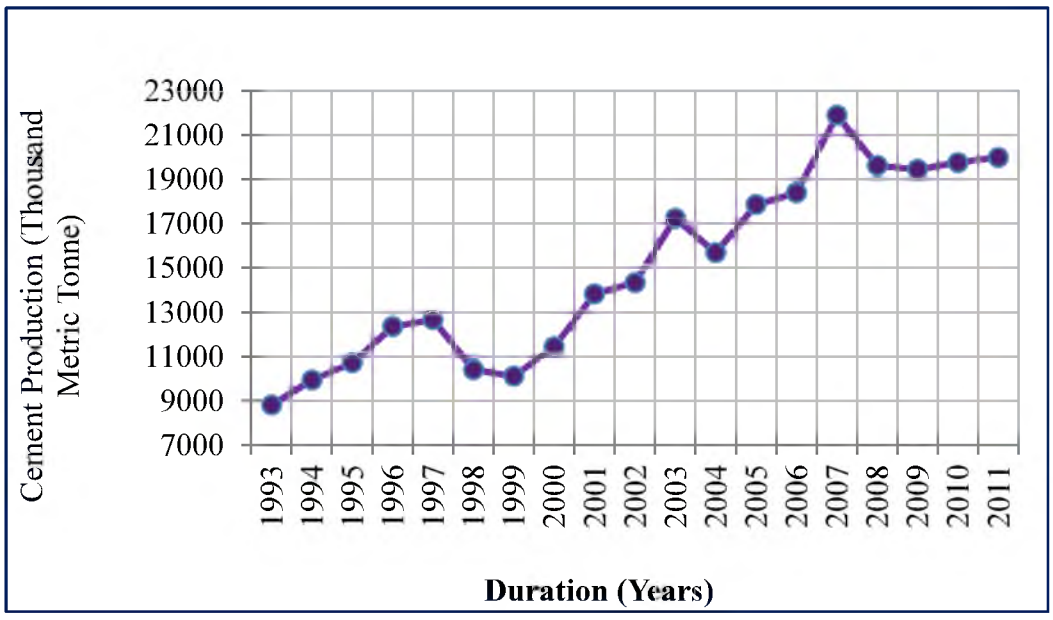


Figure 1.3 Malaysian cement productions, 1993 to 2011 (U. S. Geological Survey, 2011)

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.

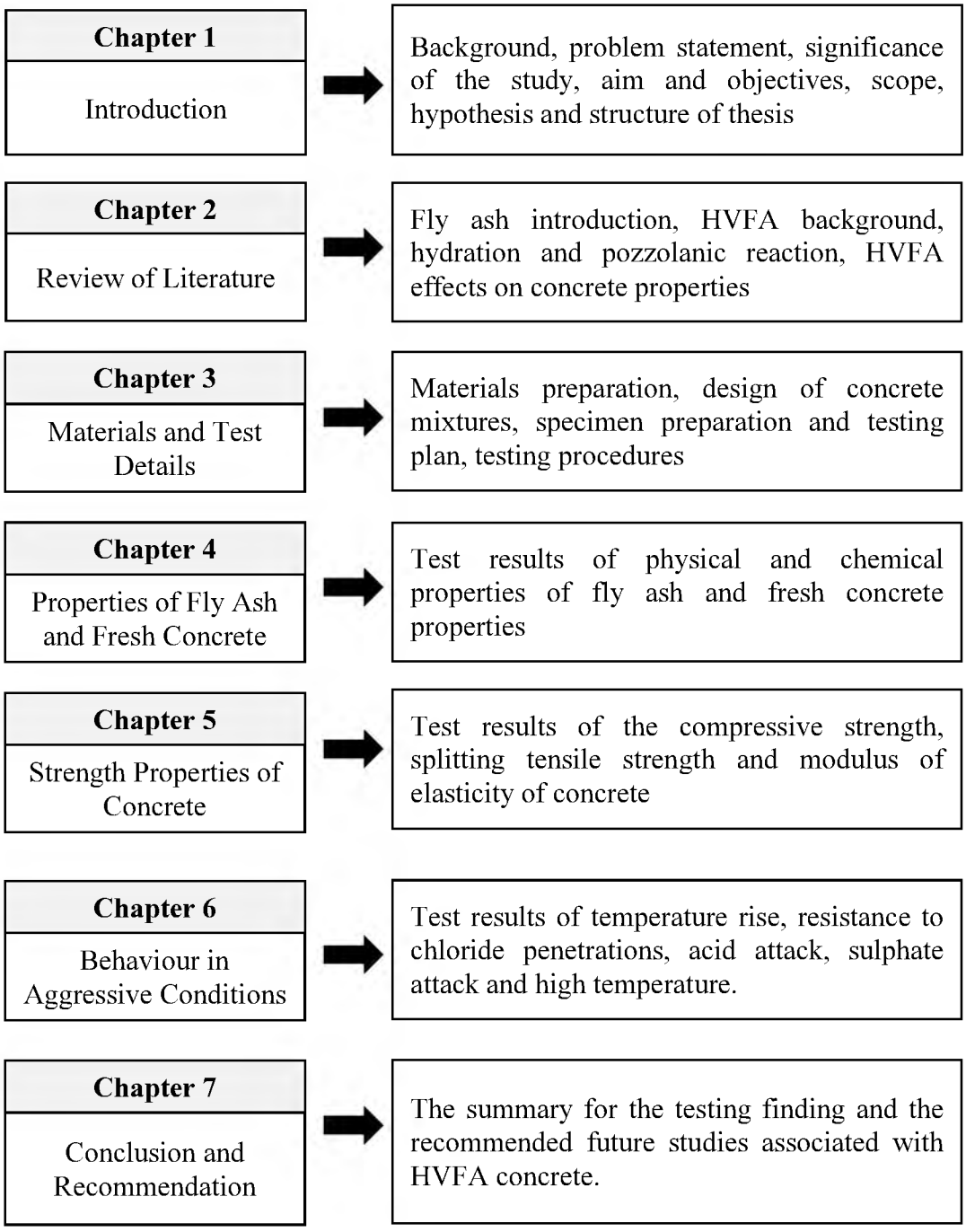


Figure 1.4 The organisation of thesis

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