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PHYSICAL PROPERTIES AND DURABILITY OF MULTI-BLENDED CEMENT MORTARS

LENNY SHERYME BINTI JASMIN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Engineering (Materials)

Faculty of Civil Engineering
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ALHAMDULILLAH

All Praise For Allah, Creator Of This Universe, Thanks For The Precious Iman & Islam You Bestowed On Me. Thanks For All The Strength And Knowledge You Granted On Me, And Peace Be Upon The Holy Prophet Nabi Muhammad s.a.w. All This Hardship I Dedicate To Some Special People In My Life Namely The Ever Loving Papa, Jasmin & Mama, Rose & My Fiancé, Azran. Endless Appreciation On All Sacrifices You Did For Me. My Ever Supportive Siblings Sheryza, Is & Jayhan, My Caring Supervisor, Prof. Salihuddin, Ever Loving Friends, Nurahmed, Lin,& Nisa, I love all of you dearly, Thanks.

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ABSTRACT

The application of mineral admixture as partial cement replacement in concrete leads to a reduction in construction cost. Usually the single mixture has limitation and some have contrasting influences on properties of concrete. The combination of more kinds of mineral admixtures is postulated to improve concrete properties. Since Rice Husk Ash is highly reactive pozzolan, it has led to the idea of focusing the study on the performance of Multi-blended pozzolan as partial cement replacement in mortar. Over eight different mixes were produced in which four mixes contained varying percentages of admixtures Multi Blended Cement, and the remainders were single mix (Binary Blended Cement) containing optimum percentages (based on literature study) of 20% Pulverized Fuel Ash, 20% Rice Husk Ash, 50% Slag, and 10% Palm Oil Fuel Ash. Three samples for each mix and for different types of tests were prepared. This work initially deals with compressive strength characteristics, water absorption, and total porosity on mortar cured (standard curing) for 7, 28, 60 and 90 days. The performance of optimum Multi Blended Cement mortar was studied in terms of ultimate compressive strength, water absorption and total porosity. The strength properties of the optimum mixes of Multi Blended Cement mortars was also examined at different curing regimes. This research also focuses on studying some durability aspects of the optimum mix of Multi Blended Cement mortars namely acid attack, and carbonation. The effects of saline seawater were also investigated for short term exposure. Finally a brief study was also carried on suitability of the optimum mixes of Multi Blended Cement mortars as a face sheet to produce lightweight non-load bearing sandwich block. From the results obtained, it was found that the early age strength of control, and Binary Blended Cement mortars on average were 20% higher than Multi Blended Cement mortars, and at later age both types were quite similar. The average strength of all mortars at 90 days was 59MPa. The total porosity and water absorption of control and Binary Blended Cement mortar were 28% and 21% total porosity, and 9% and 14% water absorption, higher than Multi Blended Cement mortar, respectively. The compressive strength of Multi Blended Cement mortar after 45 cycles dry and wet curing in seawater exhibited 24% higher than control mortar. The initial water curing for 7 and 14 days and continuous air curing also exhibited 13% and 21% (7 days), and 19% and 26% (14 days), higher early strength than continuous water and air curing, respectively. Multi Blended Cement system produced low permeability mortar compared to control, and Binary Blended Cement mortars. The strength and durability properties of Multi Blended Cement mortar are more pronounced than control and Binary Blended Cement mortar when it is provided with adequate curing.

ABSTRAK

Penggunaan bahan tambah mineral sebagai bahan gantian separa simen dalam konkrit boleh mengurangkan kos pembinaan. Campuran yang mengandungi satu bahan tambah lazimnya mempunyai had dan sebahagiannya memberi pengaruh yang bertentangan dengan sifat konkrit. Gabungan pelbagai bahan tambah mineral adalah benar dapat memperbaiki sifat konkrit. Disebabkan Abu Sekam Padi merupakan pozzolana yang aktif, ia telah memberi idea dalam kajian ini untuk memfokuskan prestasi mortar berasaskan pelbagai bahan tambah mineral sebagai bahan gantian separa simen dalam mortar. Terdapat 8 jenis campuran bahan tambah yang berbeza dihasilkan, di mana empat campuran terdiri daripada beberapa peratus campuran pelbagai bahan tambah dan selebihnya adalah campuran yang mempunyai satu bahan tambah yang terdiri daripada peratus kandungan yang optimum (berdasarkan kajian ilmiah) iaitu 20% Abu Terbang, 20% Abu Sekam Padi, 50% Abu Besi Tersanga dan 10% Abu Kelapa Sawit. Tiga sampel dihasilkan bagi setiap campuran dan bagi setiap ujikaji yang berbeza. Kajian ini pada awalnya menumpukan kepada ciri-ciri kekuatan mampatan, kadar penyerapan air dan jumlah keliangan sesuatu campuran mortar yang diawet (awetan piawai) selama 7, 28, 60 dan 90 hari. Prestasi mortar pelbagai bahan tambah yang optimum dikaji dari segi kekuatan mampatan muktamad, kadar penyerapan air dan jumlah keliangan. Sifat kekuatan mortar pelbagai bahan tambah yang optimum juga diuji dengan pelbagai jenis pengawetan. Kajian juga memfokuskan kepada aspek kebolehtahanlasakan mortar pelbagai bahan tambah yang optimum seperti serangan asid, dan pengkarbonatan. Kesan terhadap air laut (perubahan tercepat) pada tempoh dedahan yang singkat juga dikaji. Akhirnya, kajian secara umum kesesuaian penggunaan mortar pelbagai bahan tambah yang optimum sebagai lapisan yang mengapit blok ringan juga dilakukan. Daripada keputusan ujikaji yang diperolehi, ia didapati kekuatan awalan mortar kawalan dan mortar satu bahan tambah adalah purata 20% lebih tinggi dari mortar pelbagai bahan tambah dan pada akhir umur kedua-dua mortar adalah setara dengan mortar pelbagai bahan tambah. Kekuatan purata bagi semua mortar pada umur 90 hari adalah 59MPa. Jumlah keliangan dan penyerapan air mortar kawalan dan mortar satu bahan tambah adalah 28% dan 21% jumlah keliangan, dan 9% dan 14% penyerapan air, lebih tinggi daripada mortar pelbagai bahan tambah. Kekuatan mampatan mortar pelbagai bahan tambah selepas diawet kering dan direndam air laut sebanyak 45 putaran menunjukkan 24% lebih tinggi daripada mortar kawalan. Pengawetan permulaan di dalam air selama 7 dan 14 hari dan kemudian diawet di udara juga menunjukkan 13% dan 21% (7hari), dan 19% dan 26% (14hari) kekuatan awal yang lebih tinggi daripada awetan air dan udara secara terus. Sistem pelbagai bahan tambah telah menghasilkan kebolehtelapan yang rendah berbanding mortar kawalan dan mortar satu bahan tambah. Sifat kekuatan dan kebolehtahanlasakan mortar pelbagai bahan tambah ini adalah lebih baik daripada mortar kawalan dan mortar satu bahan tambah apabila ia diawet dengan sempurna.

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LIST OF ABBREVIATIONS

AB	Aerated concrete block
ACI	American Concrete Institute
Al_20_3	Aluminium oxide
$Al_2O_3SiO_2$	Aluminosilicate
ASTM	American Society for Testing and Materials
BBC	Binary Blended cement
BS	British Standards
b/s	Binders to sand ratio
C	Carbon content
C_3A	Tricalcium aluminate
C_4A_3S	Tetracalcium aluminosilicate
$CaCO_3$	Calcium carbonate
Ca^{2+}	Calcium ion
C-A-H	Calcium Aluminate hydrate
C_2S	Dicalcium silicate
C_3S	Tricalcium silicate
CaO	Calcium oxide
$Ca(OH)_2$	Calcium hydroxide
Ca-Al-Mg	Calcium Aluminate magnesium
$CaSO_4$	Calcium sulphate
CB	Comercial block
CO_2	Carbon dioxide
CPC	Code practise
CS	Calcium silicate
C-S-H	Calcium silicate hydrate
Cl	Chloride ion Calcium Chloride ($CaCl_2$)
Fe^{++}	Ferric oxide

$Fe_2 2O_3$	Ferric hydroxide
GGBFS	Ground granular blast furnace slag
H^+	Hydrogen ion
H_2O	Hydrogen oxide
HCl	Hydrochloride acid
HSC	High strength concrete
H_2S	Hydrogen sulphate
K_2O	Potassium oxide
LAAT	Los Angelas Abrasion Test
LOI	Loss on ignition
MBC	Multi-blended cement
$MgCl_2$	Magnesium chloride
MgO	Magnesium oxide
$Mg(OH)_2$	Magnesium oxide
$MgSO_4$	Magnesium sulphate
MIP	Mercury intrusion porosimetry
MS	Malaysian Standard
Mvpr	Mean-volume pore radius
Na^+	Natrium ion
NaCl	Sodium chloride
Na_2O	Sodium oxide
NO_x	Nitrogen oxide
OH	Hydroxyl ion
OPC	Ordinary Portland cement
P_2O_5	Phosphorus oxide
PFA	Pulverized Fuel Ash
POFA	Palm Oil Fuel Ash
PPT	Part per thousand
PSD	Pore size distribution
RHA	Rice Husk Ash
SB	Sandwich block
SF	Silica Fume
SiO_2	Silicon dioxide
SO_3	Sulphur oxide

Sp	Superplasticizer
TG	Termogravimetry
UK	United Kingdom
wbr	Water binder ratio
W/C	Water cement ratio
XRD	Xray diffraction

LIST OF SYMBOLS

P_T	percentage of total porosity
Wd	weight of dry specimen
Wsw	weight of specimen in water
Wssd	Weight of saturated specimen in air
WA	percentage of water absorption
Wd	weight of dry sample
Ww	weight of wet sample
%	Percentage

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Pozzolanic materials are widely used in concrete and mortars for various reasons, particularly for reducing the amount of cement required for making concrete and mortar which lead to a reduction in construction cost. Moreover most pozzolanic materials are by-product materials and the use of these materials leads to reduction in waste and save in energy consumption to produce cement. Most recently blended and multi-blended cement by incorporating industrial by-products/pozzolanic materials is becoming an active area of research because of their improved properties such as workability, long-term strength and durability. The common blending agents used are fly ash (PFA), rice husk ash (RHA), palm oil fuel ash (POFA), Slag, silica fume (SF), calcined clay etc. The improved properties such as rheology and cohesiveness, lower heat of hydration, lower permeability and higher resistance to chemical attack are reported in the literature (Khan *et al.*, 2000; and Mehta P.K., 1989).

In general, each of these materials possesses different properties and reacts differently in the presence of water (Toutanji *et al.*, 2004) and usually has limitations while some have contrasting influences on properties of concrete and mortar (Khan *et al.*, 2000). The combination of two or more kinds of mineral admixtures has emerged as a superior choice over single admixture to improve concrete and mortar properties (Bagel, 1998; Khan *et al.*, 2000; and Pandey *et al*., 2000). The

development of ternary (containing two types of pozzolans) and quaternary (containing three types of pozzolans) blended cement is relatively rare. Though the binary blended cements BBC (containing one type of pozzolans) are commonly nowadays in use and further studies to investigate and improve the performance of BBC are in progress but even then those are not used at larger scale. Whereas, the research to develop the multi-blended cement containing three or more pozzolanic materials to replace cement partially is rather rare.

PFA normally results in lower early strength but improved workability, whereas SF causes downturn in workability due to high specific surface but higher reactivity than PFA. The effect on combination of SF and PFA showed increase in early strength due to the balancing effect in reactivity and water demand. Incorporation of Slag and PFA in OPC remains a common practice (Bagel, 1998) because Slag is widely applied in high performance concrete (Huiwen *et al*., 2004). A few researches have demonstrated the suitability of the use of combination of Slag and SF as pozzolanic material by replacing cement partially. The combination of SF, Slag and PFA is reported to produce high strength and resistance to wet-dry exposures and freeze-thaw as experimentally demonstrated by Toutanji *et al*. (2004).

Since RHA is similar to SF in terms of pozzolanic activity because the former also contains significant amount of Silicon dioxide and a highly reactive pozzolanic material (Paya *et al*., 2001; and Qijun *et al*., 1999), thus the replacement of SF with RHA is one of the potential options to be considered. Also the research findings show POFA, as another pozzolanic material to be added in mortar to achieve its better performance (Salihuddin, 1993).

Recently there has been a growing trend towards the use of supplementary cementitious materials, whether natural, waste or by-products, in the production of blended cements because of ecological, economical and diversified product quality reasons (Noor *et al*., 2006). One of the major options adopted for economic reason is to utilize local resources especially waste materials that would provide cost effectiveness and also a potential utilization of hazardous waste which would other wise causes environmental pollution.

Since Malaysia is the largest producer of Palm Oil in the world and also has a large milling paddy capacity, hence the agricultural fly ash is locally available in huge quantity as waste material. This has led to the idea to investigate the suitability of these materials to be incorporated in MBC as partial cement replacement. Also this may lead to resolve the open burning issue in the disposal of these waste materials which causes hazardous effects on the country's environmental conditions.

1.2 Research problems

In Malaysia the pace of development and construction activity achieved since last three decades was beyond expectations. It has spurred the demand for fast, cost-effective and quality residential buildings. Cement is an expensive constituent of construction materials. Thus to reduce the cost of the construction material thereby reducing the over all cost of the project is becoming an active area of research and the need of the present time in almost all countries in general and in developing countries like Malaysia in particular. Various strategies are being adopted to achieve the cost effectiveness. Nevertheless, the application of agricultural and industrial by-products and wastages to replace expensive conventional materials fully or partially is being considered as major technique in this regard.

The utilization of agricultural and industrial by-products offer triple benefits namely: conservation of fast declined natural resources, planned gainful exploration of waste materials, and release of valuable land for more profitable used. As the performance of mortars depends upon the admixtures added as cement replacement whereas the properties of these cement replacement admixtures are dependent on the sources from where those are obtained. It is therefore recommended that experimental studies to be carried out to examine the performance of blended or multi-blended mortars containing agricultural and industrial wastes/by products.

This is why the present study is aimed at investigating the suitability of local agricultural and industrial by products as partial replacement of cements in order to produce MBC which is not only potentially cost effective but also exhibits high performance against aggressive environmental conditions.

1.3 Aim and objectives

The main aim of this study is to produce MBC mortar of adequate strength and durability which can sustain the internal and external effects of aggressive environment of a tropical region like Malaysia. The relative objectives to achieved the aim of study are as follows:

1. To establish the optimum binder to sand ratio of mortar mix.

2. To establish the optimum mix proportion of Multi Blended Cement in a mortar regarding strength, porosity and water absorption.

3. To determine the durability performance of the mortar with MBC in terms of chemical attack such as carbonation, acid attack, and the effect of seawater.

4. Ultimately, to brief study on the application of the MBC mortar as the face sheets to produce lightweight non-load bearing sandwich block.

1.4 Research hypothesis

The MBC system can be utilized to produce high performance mortar. The low early strength of PFA and Slag in MBC mixes can be improved by the incorporation of high reactivity of RHA and POFA. On the other hand, incorporation of RHA and Slag generally will cause a downturn in workability. Whilst, incorporation of PFA in the system can enhance workability hence reduced the water binder ratio. Subsequently low water binder ratio (wbr) of MBC system would achieve low porosity and low absorption mortar compared with control OPC and BBC mortar. Therefore, MBC systems can potentially reduce or eliminate limitations inherent in individual materials (BBC systems). This MBC system is low in alkalinity that contain less amount of CH and also more homogenous and dense mortar, which can potentially withstand chemical attack when exposed to hostile environment compared to control OPC mortar.

1.5 Scope of research

The study is fully experimental in nature and focuses on the development of multi-blended cement (MBC) mortar of optimum mix (sand: binder). The study specially emphasizes to investigate the appropriate proportion of constituents of MBC. The constituents adopted as partial replacement of cement to produce MBC were GGBFS (slag), PFA, RHA, and POFA along with the principal constituent, cement. The content of cement, slag, and POFA was kept constant through out the experimental study. The performance of optimum MBC mortar was studied in terms of ultimate compressive strength, water absorption, total porosity and durability.

The durability of MBC mortar produced was tested in terms of its resistance to acid attack, carbonation, and the saline water from sea. Finally attempt in limited extent was made to investigate the suitability of MBC mortar developed, as the face sheets to produce lightweight non-load bearing sandwich masonry unit with lightweight aerated concrete as core. The thickness of the face sheet provided was

kept constant at 10 ± 2mm. The performance of the sandwich masonry unit was examined in terms of its ultimate compressive strength, physical failure pattern, and the apparent composite behavior of the two materials at their interface.

1.6 Significance of Research

The study is significant to produce high performance MBC mortar by using the agricultural and industrial waste/by-products. The MBC mortar exhibited the compressive strength of at least at par with the OPC mortar and also better performance in aggressive environment of Malaysia by withstanding the internal and external effects of both short term and long term as well. This is expected due to the low permeability and low porosity of MBC mortar mixes. The ultimate product of MBC mortars would be economical. The study is also important in the effort to resolve the burning issue with regard to the disposal of the huge quantity of waste material from Palm Oil and Paddy industry in Malaysia. MBC mortar can be applied as face sheets to produce lightweight sandwich masonry units in order to reduce over all weight and cost of the building and also a step towards industrialization of the building system.

1.7 Thesis Organization

This thesis is divided into six chapters, which can be referred in Figure 1.1. Chapter 1 was described about the introduction of the study, research problems, aim and objectives, research hypothesis, scope of research and significance of research. Chapter 2 was divided into two sections, which was one section described detailed about the literature review of the Blended Cement. Whilst, the other section described about concrete durability. Chapter 3 included the details of test program (stage wise), materials, mix proportions, casting of specimens, curing methods and testing methods. The results and discussion of the study was divided into two chapters, which is Chapter 4 and Chapter 5. Chapter 4 discussed on the results

obtained from tests conducted from stage 1 to stage 3 that focused on the development of MBC mortars to establish the optimum mix proportion of MBC mix. Whilst, Chapter 5 discussed mainly about the MBC mortar durability, other properties and the application using the optimum MBC mix that were the results obtained from tests conducted from stage 4 to stage 6. Chapter 6 is summarized the conclusions for all sections. It was divided into two parts; brief conclusions and detailed conclusions. Detailed conclusions were in three sections, which are conclusions for water requirement test, engineering properties, and chemical properties and microstructural characteristics of mortars.

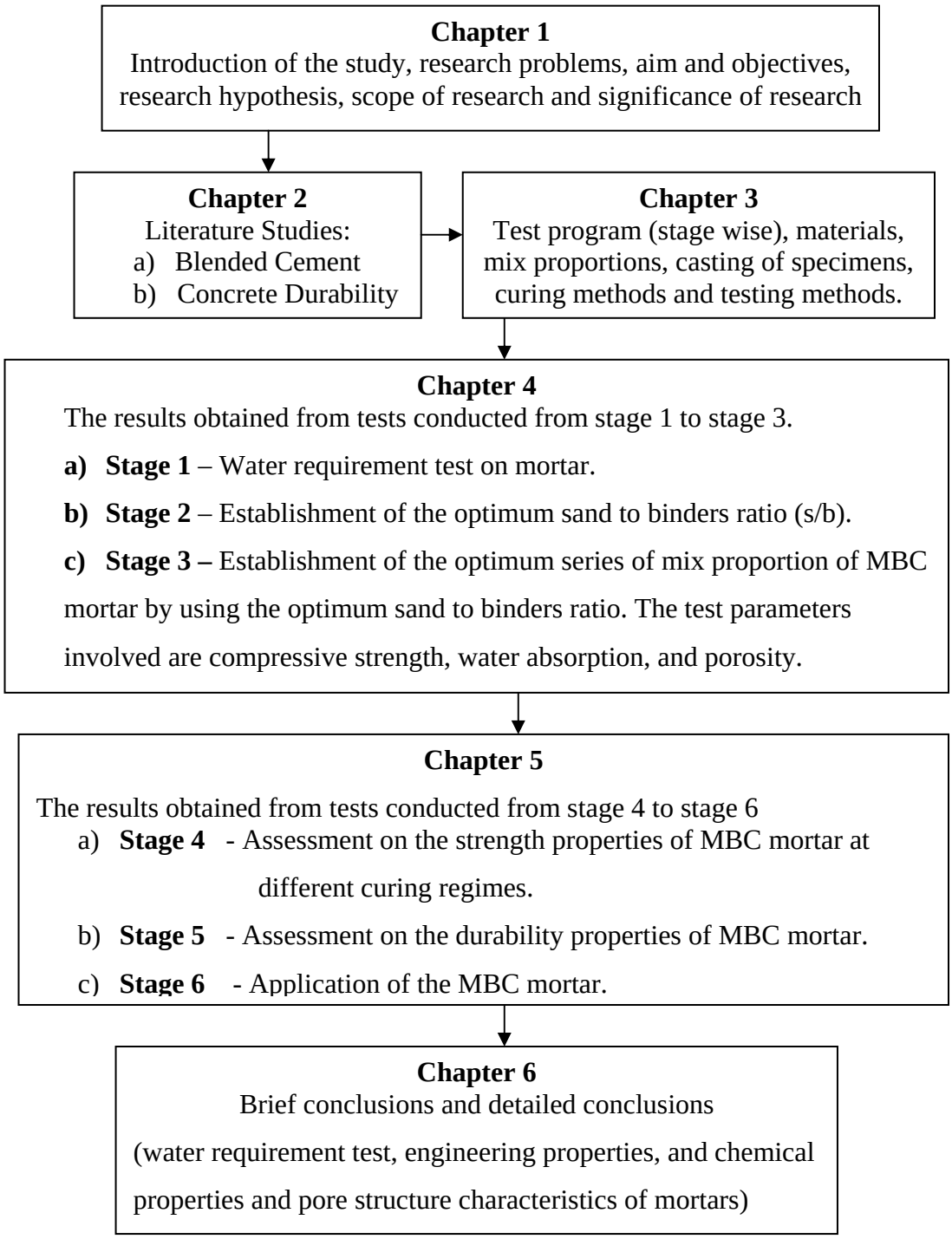

Figure 1.1 Thesis Organization