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JUDUL: **PERFORMANCE OF CONCRETE CONTAINING METAKAOLIN AS CEMENT REPLACEMENT MATERIAL**

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Date	: 6 November 2006

PERFORMANCE OF CONCRETE CONTAINGING METAKAOLIN AS
CEMENT REPLACEMENT MATERIAL

ONG CHEE HUAT

A project report submitted in partial fulfillment of
the requirements for the award of the degree of
Master of Engineering (Civil - Structure)

Faculty of Civil Engineering
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NOVEMBER, 2006

I declare that this project entitled “Performance of Concrete Containing Metakaolin As Cement Replacement Material” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

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Date : 6/11/2006

To my beloved parents and family

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ABSTRACT

Concrete is probably the most extensively used construction material in the world. However, environmental concerns both in terms of damage caused by the extraction of raw material and CO_2 emission during cement manufacture have brought pressures to reduce cement consumption by the use of supplementary materials. The utilization of calcined clay, in the form of metakaolin (MK) in concrete has received considerable attention in recent years. On this matter, a study has been conducted to look into the performance of metakaolin as cement replacement material in concrete. The study focuses on the compressive strength performance of the blended concrete containing different percentage of metakaolin. The cement is replaced accordingly with the percentage of 5 %, 10%, 15%, 20% and 30% by weight. Concrete cubes are tested at the age of 1, 3, 7, and 28 days. In addition, the effect of calcination temperature to the strength performance is included in the study. Finally, the strength performance of metakaolin-concrete is compared with the performance of concrete blended with silica fume and slag. The results show that the strength development of concrete blended with metakaolin is enhanced. It was found that 10% replacement appears to be the optimum replacement where concrete exhibits enhanced compressive strength at all ages comparable to the performance of SF and GGBS. The study also reveals that optimum calcination temperature of 750°C is important to improve the performance of metakaolin-concrete.

ABSTRAK

Konkrit merupakan salah satu bahan binaan yang paling banyak digunakan dalam dunia. Akan tetapi, terdapat masalah pencemeran persekitaran yang disebabkan oleh penggunaan simen dalam konkrit. Pencemaran berlaku semasa pengekstrakan bahan mentah dan penghasilan karbon dioksida semasa pemprosesan simen. Hal ini telah menimbulkan tekanan untuk mengurangkan penggunaan simen dan diganti oleh bahan gantian. Penggunaan tanah liat terbakar dalam bentuk *metakaolin* (MK) dalam konkrit telah mendapat perhatian yang lebih kebelakangan ini. Dalam hal ini, satu kajian telah dijalankan untuk mengkaji prestasi *metakaolin* sebagai bahan gantian simen dalam konkrit. Kajian ditumpukan ke atas kekuatan mampatan konkrit yang mengandungi *metakaolin* dalam peratusan yang berbeza. Simen digantikan dalam peratusan 5 %, 10%, 15%, 20% dan 30% mengikut berat. Kekuatan konkrit diuji pada hari ke-1, 3, 7 dan 28. Pada masa yang sama, pengaruh suhu bakaran ke atas kekuatan mampatan turut dikaji. Prestasi kekuatan konkrit-metakaolin juga dibandingkan dengan prestasi konkrit yang mengandungi wasap silika dan sanga relau bagas. Keputusan eksperimen menunjukkan gantian *metakaolin* dalam konkrit telah meningkatkan perkembangan kekuatan mampatan konkrit di mana gantian 10% merupakan peratusan gantian yang paling optima. Kajian juga mendapati *metakaolin* adalah setara dengan bahan gantian simen yang lain seperti wasap silika dan sanga relau bagas dalan perkembangan dan peningkatan kekuatan mampatan konkrit. Suhu bakaran didapati mempunyai pengaruh yang ketara terhadap kekuatan mampatan konkrit-metakaolin. Kajian menunjukkan Suhu bakaran setinggi 750°C merupakan suhu yang paling sesuai bagi meningkatkan prestasi konkrit-metakaolin.

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%	- percentage
°C	- Celcius
GGBS	- Ground Granulated Blast Furnace Slag
kg	- kilograms
m	- meter
m^3	- meter cubes
MK	- Metakaolin
MPa	- Mega Pascal
SF	- Silica Fume

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CHAPTER 1

INTRODUCTION

1.0 Introduction

Concrete is one of the most common materials used in the construction industry. In the past few years, many research and modification has been done to produce concrete which has the desired characteristics. There is always a search for concrete with higher strength and durability. In this matter, blended cement concrete has been introduced to suit the current requirements. Cementitious materials known as pozzolans are used as concrete constituents, in addition to Portland cement. Originally the term pozzolan was associated with naturally formed volcanic ashes and calcined earths will react with lime at ambient temperatures in the presence of water. Recently, the term has been extended to cover all siliceous/aluminous materials which, in finely divided form and in the presence of water, will react with calcium hydroxide to form compounds that possess cementitious properties. The current area of research in the concrete is introducing clay (metakaolin) in the concrete.

Clays have been and continue to be one of the most important industrial minerals. Clays and clay minerals are widely utilized in our society. They are important in geology, agriculture, construction, engineering, process industries, and environmental applications. Traditional applications of clay including ceramics, paper, paint, plastics, drilling fluids, chemical carriers, liquid barriers, and catalysis. Research and development activities by researchers in higher education and industry are continually resulting new and innovative clay products.

Metakaolin is one of the innovative clay products developed in recent years. It is produced by controlled thermal treatment of kaolin. Metakaolin can be used as a concrete constituent, replacing part of the cement content since it has pozzolanic properties. The use of metakaolin as a partial cement replacement material in mortar and concrete has been studied widely in recent years. Despite of the recent studies, there are still many unknowns with the use of metakaolin. Study is needed to determine the contribution of metakaolin to the performance of hardened concrete. There are great concerns on the strength and durability of metakaolin-concrete when used as construction materials in the construction industries. If it is proven that the concrete is durable and strong, this will lead to the use of metakaolin to replace part of the cement.

1.1 Objective of Study

This study is conducted to accomplish some predefined objectives. These objectives are:

i) To study the performance of concrete containing different percentages of metakaolin and to identify the optimum replacement percentage.

ii) To investigate the effect of calcination temperatures to the strength performance of metakaolin-concrete.

iii) To compare the performance of metakaolin with other cement replacement materials (CRMs).

1.2 Significant of the Study

Concrete has been used in the construction industry for centuries. Many modifications and developments have been made to improve the performance of concrete, especially in terms of strength and durability.

The introduction of pozzolans as cement replacement materials in recent years seems to be successful. The use of pozzolan has proven to be an effective solution in enhancing the properties of concrete in terms of strength and durability. The current pozzolans in use are such as fly ash, silica fume and slag. Development and investigation of other sources of pozzolan such as kaolin will be able to provide more alternatives for the engineer to select the most suitable cement replacement material for different environments.

Unlike other pozzolans, metakaolin is not a by-product which means its engineering values are well-controlled. Therefore, using metakaolin should promise some advantages compared to other cement replacement materials. In this case, studies are needed to study the performance of concrete using metakaolin. The performance of metakaolin-concrete will be compared to the cost of production of metakaolin to determine whether metakaolin is worthy to be developed as a new cement replacement material.

In addition, the use of metakaolin is not common in the Malaysian construction sector. This study will be able to enhance the understanding on the suitability of metakaolin as cement replacement material.

1.4 Scope of Study

This study focuses on the strength performance of concrete with metakaolin. Strength is the most important property of concrete since the first consideration in structural design is that the structural elements must be capable of carrying the imposed loads. Strength characteristic is also important because it is related to several other important properties which are more difficult to measure directly.

With regard to this matter, the development of compression strength of metakaolin concrete is studied. Cement replacements by 5%, 10%, 15%, 20% and 30% with metakaolin are studied. Concrete tests are conducted on the concrete samples at the specific ages. All the strength tests are limited to the ages of 28 days.

In the study of the effect of calcination temperatures to the strength performance of metakaolin, the temperatures is set within the range of 600°C-800°C. The temperatures interval used is 50°C.

For the performance comparison study, the cement replacement materials used are silica fume and ground granulated blast furnace slag. These two cement replacement materials are chosen as they are the most common replacement materials nowadays and will be good comparisons to metakaolin. The comparison is made on the compressive strength performance of metakaolin, silica fume and slag concrete.

CHAPTER 2

LITERATURE REVIEW

2.0 Concrete

Concrete is known to be a simple material in appearance but with a very complex internal nature. In contrast to its internal complexity, versatility, durability, and economy of concrete have made it the most frequently used construction material in the world.

Concrete is a mixture of cement, water, and aggregates, with or without admixtures. The cement and water will form a paste that hardens as a result of a chemical reaction between the cement and water. The paste acts as glue, binding the aggregates (sand and gravel or crushed stone) into a solid rock-like mass. The quality of the paste and the aggregates dictate the engineering properties of this construction material. During hydration and hardening, concrete will develop certain physical and chemical properties, among others, mechanical strength, low permeability and chemical and volume stability. Concrete has relatively high compressive strength, but significantly lower tensile strength (about 10% of the compressive strength). Table 2.1 shows the typical properties of normal strength Portland cement concrete (Hewlett, 1998).

Table 2.1: Typical Properties of Normal-Strength Portland Cement Concrete

Characteristic	
Compressive strength	20–40 MPa
Flexural strength	3–5 MPa
Tensile strength	2–5 MPa
Modulus of elasticity	14,000–41,000 MPa
Permeability	$1x10^{-10}$ cm/sec
Coefficient of thermal expansion	10^{-5}/°C
Drying shrinkage	4–8 x 10^{-4}
Drying shrinkage of reinforced concrete	2–3 x 10^{-4}
Poisson's ratio	0.20–0.21
Shear strain	6000–17,000 MPa
Density	2240–2400 kg/m^3

Concrete is used to make pavements, building structures, foundations, roads, overpasses, parking structures, brick/block walls and bases for gates, fences and poles. Over six billion tons of concrete are made each year, amounting to the equivalent of one ton for every person on Earth, and powers a US$35 billion industry which employs over two million workers in the United States alone (Kosmatka,1999). Over 55,000 miles of freeways and highways in America are made of concrete.

2.1 Cement

Cements may be defined as adhesive substances capable of uniting fragments or masses of solid mater to a compact whole (Lea, 1970). Portland cement was invented in 1824 by an English mason, Joseph Aspdin, who named his product Portland cement because it produced a concrete that was of the same color as natural stone on the Isle of Portland in the English Channel.

Raw materials for manufacturing cement consist of basically calcareous and siliceous (generally argillaceous) material. The mixture is heated to a high temperature within a rotating kiln to produce a complex group of chemicals, collectively called cement clinker (Neville, 1987). Cement is distinct from the ancient cement. It is termed hydraulic cement for its ability to set and harden under water. Briefly, the chemicals present in clinker are nominally the four major potential compounds and several minor compounds. The four major potential compounds are normally termed as tricalcium silicate ($3CaO.SiO_2$), dicalcium silicate ($2CaO.SiO_2$), tricalcium aluminate ($3CaO.Al_2O_3$) and tetracalcium aluminoferrite ($4CaO. Al_2O_3.Fe_2O_3$).

The American Society for Testing and Materials (ASTM) Standard C 150, Specification for Portland cement, provides for the following types of Portland cement:

Type I	General Portland cement
Type II	Moderate-sulfate-resistant cement
Type III	High-early-strength cement
Type IV	Low–heat-of-hydration cement
Type V	High-sulfate-resistant cement

Type I Portland cement is a general cement suitable for all uses where special properties of other cements are not required. It is commonly used in pavements, building, bridges, and precast concrete products.

Type II Portland cement is used where precaution against moderate sulfate attack is important where sulfate concentrations in groundwater or soil are higher than normal, but not severe. Type II cement can also be specified to generate less heat than Type I cement. This moderate heat of hydration requirement is helpful when placing massive structures, such as piers, heavy abutments, and retaining walls. Type II cement may be specified when water-soluble sulfate in soil is between 0.1 and 0.2%, or when the sulfate content in water is between 150 and 1500 ppm. Types I and II are the most common cements available.

Type III Portland cement provides strength at an early age. It is chemically similar to Type I cement except that the particles have been ground finer to increase the rate of hydration. It is commonly used in fast-track paving or when the concrete structure must be put into service as soon as possible, such as in bridge deck repair.

Type IV Portland cement is used where the rate and amount of heat generated from hydration must be minimized. This low heat of hydration cement is intended for large, massive structures, such as gravity dams. Type IV cement is rarely available.

Type V Portland cement is used in concrete exposed to very severe sulfate exposures. Type V cements would be used when concrete is exposed to soil with a water-soluble sulfate content of 0.2% and higher or to water with over 1500 ppm of sulfate. The high sulfate resistance of Type V cement is attributed to its low tricalcium aluminate content.

2.2 Cement Replacement Material

With the extensively use of cement in concrete, there has been some environmental concerns in terms of damage caused by the extraction of raw material and CO_2 emission during cement manufacture. This has brought pressures to reduce the cement consumption in the industry. At the same time, there are getting more requirements for enhancement in concrete durability to sustain the changing environment which is apparently different from the old days.

With the development in concrete technology, cement replacement materials (CRM) have been introduced as substitutes for cement in concrete. Several types of materials are in common use, some of which are by-products from other industrial processes, and hence their use may have economic advantages. However, the main reason for their use is that they can give a variety of useful enhancements or modifications to the concrete properties. All the materials have two common features (Malhotra, 1986):

i) Their particle size range is similar to or smaller than that of Portland cement.

ii) They are pozzolan material.

2.2.1 Pozzolanic Behavior

A common feature of nearly all CRM is that they exhibit pozzolanic behaviour. Pozzolanic materials the materials which contains active silica (SiO_2) and