BEHAVIOUR OF HIGH STRENGTH REINFORCED CONCRETE BEAM WITH METAKAOLIN UNDER STATIC LOADING

AMER BIN YUSUFF @ MD YUSOFF

UNIVERSITI TEKNOLOGI MALAYSIA

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SESI PENGAJIAN: 2004 / 2005

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Alamat Tetap:

30, Taman Seri Aman,
Jalan Permatang Pasir,
34950 Bandar Baharu, Kedah

ASSOC. PROF. DR. ABD LATIF SALEH
Nama Penyelia

Tarikh: 16 APRIL 2005

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AMER B YUSUFF @ MD YUSOFF

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

Faculty of Civil Engineering
Universiti Teknologi Malaysia

APRIL 2005

I declare that this thesis entitled "Behaviour of High Strength Reinforced Concrete Beam with Metakaolin under Static Loading" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : AMER YUSUFF @ MD. YUSOFF

Date : 16 APRIL 2005

To my mother Arison bt Haron and late father Yusuff @ Md Yusoff bin Puteh
for your companionship, understanding and
continuous encouragement over the years.

ACKNOWLEDGEMENT

The name of Allah, the most Gracious, the Dispenser of Grace, Salam to Nabi Muhammad SAW. His companion and friends as well to all the people who follow his path.

I would like to express my highest appreciation to my supervisor Assoc Prof Dr Abd Latif Saleh for his advice and guidance during the course of this project. His invaluable assistance and the constructive criticisms offered have resulted in the completion of this project.

Unforgettable, I would like to thank to Laboratory Technicians and research assistance of Civil Engineering Faculty, UiTM Penang for their kind help in assisting my project.

Last but not least, I would like to express special gratitude to my family, Khalilah Adibah Muhammad, Aiman Haziq, Aina Hazwani and Aimi Batrishiya for their persistent support in my studying at UTM. Also to my colleagues, your helps are really appreciated and will be remembered forever

ABSTRACT

The need of cement replacement material (CRM) in reinforced concrete has gained its popularity among the researchers to produce a high strength concrete (HSC) for structural engineering application. This paper presents the experimental results of the static loading effect on reinforced concrete beam with metakaolin (MK7003). Three different percentages, 5%, 10% and 15% of MK7003 were incorporated as CRM in reinforced concrete beam, and 0% of MK7003 as the control specimen. Eight no of beams, with dimension of 1400mm x 150mm x 125mm, were tested, two for each different percentages and two beams as control specimens. The beams were subjected to four point loading test until failure. The findings of the experiment been shown that the structural performance were improved with the inclusion of MK7003. The observation made suggested that MK7003 with 10% replacement gave the optimum performance of the reinforced concrete.

ABSTRAK

Keperluan bahan ganti simen dalam konkrit bertetulang semakin popular di kalangan penyelidik dalam menghasilkan konkrit berkekuatan tinggi untuk kegunaan kejuruteraan struktur. Laporan ini membentangkan keputusan ujikaji kesan beban statik ke atas rasuk konkrit bertetulang yang dicampur dengan Metakaolin (MK7003). Peratusan MK7003 yang digunakan dalam campuran konkrit bertetulang adalah 5%, 10% dan 15% sebagai bahan ganti kepada simen dan 0% MK7003 dijadikan sampel kawalan. Lapan rasuk bersaiz 1400mm panjang, 150mm dalam dan 125mm lebar telah diuji, setiap peratusan MK7003 mempunyai dua sample rasuk. Rasuk dikenakan ujian empat titik beban sehingga gagal. Hasil ujikaji menunjukkan keupayaan struktur rasuk telah meningkat dengan kehadiran MK 7003. Pemerhatian juga mendapati MK7003 dengan peratusan gantian sebanyak 10% telah memberikan keupayaan yang optimum kepada rasuk konkrit bertetulang.

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A_s	Cross section area for tension reinforcement
A_{sc}	Cross section area for compression reinforcement
A_c	Cross section area for concrete
b	Width of concrete section
h	Depth of concrete section
z	lever arm distance of concrete section
a_v	Shear span
I	Moment of inertia
E	Modulus of elasticity
V	Shear force
v	Shear stress
f_{cu}	Concrete compressive strength
f_y	Reinforcement tensile strength

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CHAPTER 1

INTRODUCTION

1.1 General

The study of High Strength Concrete has become interesting, with the tendency of concrete building structure to become taller and larger. The importance has been shown by the Malaysian construction industry for the production of high strength concrete. An example of the use of HSC is in construction of the Petronas Twin Towers at the Kuala Kumpur City Centre which high early strength of about 15 N/mm^2 were achieved within 12 hours after casting (Zamin et al, 1995).

The usage of high strength concrete in structure application has been increasing worldwide and has begun to make an impact in Malaysia. A few years ago, a characteristic compressive strength of $40N/mm^2$ would have been considered high in Malaysia, but now it was become normal phenomena. Nowadays, concrete with a 28 days curing and has characteristic cube strength of $60N/mm^2$ and above will be considered as a high strength concrete. The achievement of such high strength concrete has been possible primarily through the introduction of materials such as Metakaolin.

Metakaolin is the most recent mineral to be commercially introduced to the concrete construction industry. A few report investigated the potential of local kaolin from several areas in Malaysia such Tapah, Perak and Johor. Metakaolin the product of processed heat treatment of natural kaolin is widely reported as a quality and effective pozzolanic material, particularly for the early strength development. In addition to pozzolanic reaction, the action of micro filler has been reported to partly improve strength development of cement-metakaolin mortar (Sabir et al, 2001).

There are several advantages of incorporating metakaolin to produce high strength for high rise building. These include reductions in member thickness resulting in reduced foundation loads, increased rentable areas and smaller structural element, as well as high early strength development of concrete which allows early stripping of formwork, thus speeding up concrete construction.

The HSC fracture behaviour is being studied with great seriousness. High strength concrete is nearer to linear theories of fracture and is relatively more brittle. The challenge is whether one can make high strength concrete relatively more ductile by improving the cohesiveness of cracks.

1.2 Objectives and Scope of Study

The objective of this study is to determine the structural behaviour of high strength concrete beam grade 60 N/mm^2 with replacement of 5%, 10% and 15% MK7003 to weight of ordinary Portland cement due to static load. The water binder ratio is fixed at 0.35 and cured in room temperature. Parameters to be investigated include cracking, deflection, moment resistance and modulus of elasticity due to bending.

Laboratory experiment will be conducted in the Civil Engineering Laboratory, UiTM Pulau Pinang, using 1000 kN Universal Testing Machine. The result will identify the following responses:

i) Mid span deflection
ii) Initial crack occur

iii) Location of crack and type of crack failure
iv) Moment resistance of the beam
v) Modulus of elasticity due to bending.

1.3 Problem Statement

This chapter will discuss the justification and the requirement of the study. The three main aspects such as high strength concrete, cement replacement material ie. MK 7003 and structure behaviour will be explain detail to support the justification in this study.

1.3.1 High Strength Concrete

The tendency of concrete building structures to become taller and simpler has led to the:

i) Increased the member size dimension and heavily loaded columns in high rise building structure.
ii) The need to design flat slabs economically, constrain of the punching effect would lead to undesirably thick slabs.

The necessity of using higher strength concrete to obtain columns of reduced section and floor systems without internal beams, for heavy loaded structure is obvious sometimes without any beam. In the case of columns, the increase of concrete strength often result in more economical sections, while allowing increased usable floor space.

For flat slabs, the main reason to use higher strength is to obtain minimum slab height with sufficient punching shear resistance.

1.3.2 Cement Replacement Material (CRM)

The construction industry has taken considerable strides forward over the last two or three decades with regard to many materials, in particular – High Strength Concrete and generally High Performance Concrete.

The development of new technology in the material sciences is progressing rapidly. Advanced composite construction material and HSC/HPC are gaining wide acceptance in the construction industry of today, and are well positioned for increasing proliferation in use in the future. HSC and HPC will continue to make important contributions to the enhanced quality and efficiency in the construction of infrastructure and our communities in the next century.

The utilization of high strength and high performance concrete has been increasing throughout the world. Amongst the various methods used to improved the strength and performance of concrete, the use of CRM like MK7003 is a relatively new approach.

1.3.3 Structure Behaviour

Visual behaviour is very important in assessing the reason for deterioration of concrete structures. The first stage in an evaluation of concrete structure is to study the condition of the concrete, to note any defect in the concrete. Among of the important are the presence of cracking, the crack propagation and deflection of the structure. Visual assessment determine whether or not to proceed with detailed investigation.

The understanding of fracture mechanism of RC structure is important and under this study its focusing to crack and deflection behaviour for RC beam under static loading.

CHAPTER 2

LITERATURE REVIEW

2.1 Concrete Grade

The grade of concrete is defined as that number, which indicated the characteristic compressive strength of concrete in N/mm^2, determined by cubes test made at 28 days. Thus grade 60 concrete has a characteristic strength of 60 N/mm^2. This grade 60 of concrete is used to produce high strength of concrete.

2.2 High Strength Concrete

In the early 1970s, experts predicted that the practical limit of ready mixed concrete would be unlikely to exceed a compressive strength greater than 11,000 psi (43 MPa). Over the past two decades, the development of high-strength concrete has enabled builders to easily meet and surpass this estimate. Two buildings in Seattle, Washington, contain concrete with a compressive strength of 19,000 psi (131 MPa).

The primary difference between high-strength concrete and normal-strength concrete relates to the compressive strength that refers to the maximum resistance of a concrete sample to applied pressure. Although there is no precise point of separation between high-strength concrete and normal-strength concrete, the American Concrete Institute defines high-strength concrete as concrete with a compressive strength greater than 6000 psi (41 MPa).

Manufacture of high-strength concrete involves making optimal use of the basic ingredients that constitute normal-strength concrete. Producers of high-strength concrete know what factors affect compressive strength and know how to manipulate those factors to achieve the required strength. In addition to selecting a high-quality portland cement, producers optimize aggregates, then optimize the combination of materials by varying the proportions of cement, water, aggregates, and admixtures.

When selecting aggregates for high-strength concrete, producers consider the strength of the aggregate, the optimum size of the aggregate, the bond between the cement paste and the aggregate, and the surface characteristics of the aggregate. Any of these properties could limit the ultimate strength of high-strength concrete.

High strength concrete (HSC) is not fundamentally different from normal strength concrete. It is different in its level and strength and associated properties and their ramifications. It is interesting to consider, as a very elementary approach to the nominal compressive strength, the three elements of concrete namely paste, aggregate and paste-aggregate bond. In high strength concrete, the paste is hard, strong aggregate are used with crushing strength of perhaps 200 N/mm^2 and higher. Therefore failure in the concrete seems likely to be initiated at the aggregate or paste interface. In the other words, the strength of concrete is depending on the bond strength of paste aggregates. In this study, the high HSC refers to the concrete obtained through using Ordinary Portland Cements cured at normal temperatures. The total cementitious material will be typically around 415 to 650 kg/m^3.

Generally, HSC is to be extremely useful in the construction of high rise building and other large structures in that with their use the structural element of these structures become reasonable such as bridges, coastal and offshore structures, prestressed structural components, airport and road pavement and compressive structures.

Optimum concrete mixture design result from selecting locally available materials that make the fresh concrete placeable and finishable and that ensure the strength development and other desired properties of hardened concretes is achieved.

Some of the basic concept that needs to be understood for higher strength concrete is:

i) Aggregate should be strong and durable. They need not necessarily be hard and of high strength but need to be compatible, in term of stiffness and strength, with the cement paste. Generally smaller maximum size coarse aggregate is used for higher strength concretes.

ii) High strength concrete mixtures will have a high cementitious material contents.

iii) HSC mixtures generally need to have low water cementitious material ratio. This low water cementitious ratio may need water reducing admixtures ie superplasticizer.

iv) The total cementitious materials content will be around 415 kg/mm^3 to 650kg/ mm^3.

2.2.1 Admixtures in high strength concrete.

Concrete is probably the most extensively used construction material in the world. It is only second to water as the most heavily consumed substance with about six million tones being produced every year. This is largely due to the abundance of raw materials for cement manufacture, low relative cost and the versatility and adaptability of concrete in forming various structural shapes. However, environmental concern both in term of damage caused by the extraction of raw material and CO_2 emission during cement manufacture have brough about pressures to reduce cement consumption by the use of supplementary materials. These materials may be naturally occurring, industrial wastes or by products or those that require relatively less energy to manufacture. Other concerns that have contributed to these pressures are related to the increase in the number of incidents where concrete structures have experienced serious deterioration.

In addressing these concerns and other environmental problems relating to the disposal of waste industrial by products and also because of economic advantages, mixture of Portland cement and pozzilana are now very commonly used in concrete production.

Originally the term pozzolan was associated with naturally formed volcanic ashes and calcined earths, which react with lime at ambient temperatures in the presence of water.

Pozzolans, such as fly ash and silica fume, are the most commonly used mineral admixtures in high-strength concrete. These materials impart additional strength to the concrete by reacting with portland cement hydration products to create additional C-S-H gel, the part of the paste responsible for concrete strength.

It would be difficult to produce high-strength concrete mixtures without using chemical admixtures. A common practice is to use a superplasticizer in combination with a water-reducing retarder. The superplasticizer gives the concrete adequate workability at low water-cement ratios, leading to concrete with greater strength. The water-reducing retarder slows the hydration of the cement and allows workers more time to place the concrete.

High-strength concrete is specified where reduced weight is important or where architectural considerations call for small support elements. By carrying loads more efficiently than normal-strength concrete, high-strength concrete also reduces the total amount of material placed and lowers the overall cost of the structure.

The most common use of high-strength concrete is for construction of high-rise buildings. At 969 ft (295 m), Chicago's 311 South Wacker Drive uses concrete with compressive strengths up to 12,000 psi (41 MPa) and is the tallest concrete building in the United States.

2.3 Metakaolin as Cement Replacement Material Concrete.

2.3.1 Introduction of Kaolin.

The raw material input in the manufacture of metakaolin (MK) is kaolin clay. Kaolin is a fine, white, clay mineral that has been traditionally used in the manufacture of porcelain. It is thought that the term kaolin is derived from the Chinese *Kaoling*, which translates loosely to *white hill* and has been related to the name of a mountain in China that yielded the first kaolins that were sent to Europe.

Kaolinite is the mineralogical term that is applicable to kaolin clays. Kaolinite is defined as a common mineral, hydrated aluminum disilicate, $Al_2Si_2O_5(OH)_4$, the most common constituent of kaolin (Megat J. 2001).

2.3.2 Formation of Metakaolin

The *meta* prefix in the term is used to denote change. It is a borrowing from Greek meaning *after*, *along with*, *beyond*. It is used, and is recognizable, in the formation of compound words: *meta*bolic, *meta*morphosis. The scientific use of the prefix is used for a combining form denoting *the least hydrated of a series*.

In the case of metakaolin, the change that is taking place is *dehydroxylization*, brought on by the application of heat over a defined period of time. At about 100-200 degrees C, clay minerals lose most of their adsorbed water. The temperature at which kaolinite loses water by dehydroxilization is in the range of 500-800 degrees C. This thermal activation of a mineral is also referred to as calcining. Beyond the temperature of dehydroxylization, kaolinite retains two-dimensional order in the crystal structure and the product is termed metakaolin.