

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

**AMER BIN YUSUFF @ MD YUSOFF**

**UNIVERSITI TEKNOLOGI MALAYSIA**

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

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

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.

## TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
<b>1</b>	<b>INTRODUCTION</b>	<b>1</b>
1.1	General	2
1.2	Objectives and Scope of Study	3
1.3	Problem Statements	3
1.3.1	High Strength Concrete	3
1.3.2	Cement Replacement Material	3
1.3.3	Structure Behaviour	4
<b>2</b>	<b>LITERATURE REVIEW</b>	<b>5</b>
2.1	Concrete Grade	5
2.2	High Strength Concrete	5
2.2.1	Admixture in High Strength Concrete	7
2.3	Metakaolin as Cement Replacement Material of Concrete	9
2.3.1	Introduction of Kaolin	9
2.3.2	Formation of Metakaolin	9
2.3.3	Effects of Metakaolin as a Pozzolan in Concrete	10
2.3.4	Effect of Metakaolin to the Concrete	
	Compressive Strength	10
2.4	Design Condition	12
2.4.1	Concrete Mixes Design	12
2.4.1.1	Workability of Concrete	13
2.4.1.2	The Compressive Strength of Concrete	13
2.4.1.3	Durability of Concrete	15
2.4.2	Design Consideration for Reinforcement	
	Concrete Beam	17

2.4.2.1	Reinforcement Requirement in Beam	17
2.5	Structure Behaviour of Reinforced Concrete Beam	18
2.5.1	Deflection	18
2.5.1.1	Macaulay's Method	19
2.5.1.2	Behaviour of Flexural Member under Deflection	20
2.5.2	Cracking	20
2.5.2.1	Cracking under Static Load	21
2.5.2.2	Cracking Mechanism	22
2.5.3	Failure of Beam Subjected to Four Points Load	23
2.6	Modulus Elasticity of Concrete	26
<b>3</b>	<b>METHODOLOGY</b>	<b>30</b>
3.1	Raw Material	30
3.1.1	Preparation of MK7003	30
3.1.2	Ordinary Portland Cement (OPC)	31
3.1.3	Coarse and Fine Aggregate	31
3.1.4	High Yield Deformed and Mild Steel Bars	31
3.1.5	Formwork	33
3.2	Preparation of Beam Specimens	33
3.3	Experimental Set Up	33
3.3.1	Strain Gauge	33
3.3.2	Testing Equipment	33
3.3.3	Static Loading	34
<b>4</b>	<b>RESULT, ANALYSIS AND DISCUSSION</b>	<b>41</b>
4.1	Result	41
4.1.1	Preliminary Testing	41
4.1.1.1	Concrete Mixed Design and Trial Mix for Grade 60	41
4.1.1.2	Reinforcement Tensile Test	42
4.1.2	Static Loading Test Results	42
4.1.2.1	Experimental Reading	42
4.2	Analysis and Discussion	42



4.2.1	Ultimate Moment Resistance of the Beam	43
4.2.2	Stress and Strain Relationship	43
4.2.3	Deflection Behaviour	43
4.2.4	Crack Behaviour	44
<b>5</b>	<b>CONCLUSION AND RECOMMENDATION</b>	<b>60</b>
5.1	Conclusion	60
5.2	Recommendation	61
	<b>REFERENCES</b>	<b>62</b>
	Appendixes A - D	64 - 68

## LIST OF TABLE

<b>TABLE NO.</b>	<b>TITLE</b>	<b>PAGE</b>
2.1	Chemical composition of OPC and metakaolin.	27
2.2	Relationship between compressive strength and static modulus of concrete.	27
4.1	Average compressive strength at various MK7003 Contents	46
4.2	Tensile test result	46
4.3	Data from experimental reading	47
4.4 (a)	Average strain, bending moment and bending stress for 0%MK7003	49
4.4 (b)	Average strain, bending moment and bending stress for 5%MK7003	50
4.4 (c)	Average strain, bending moment and bending stress for 10% MK7003	51
4.4 (d)	Average strain, bending moment and bending stress for 15% MK7003	52
4.5	Theoretical and experimental load versus deflection	53
4.6	Initial crack load	55
4.7	Theoretical and experimental ultimate moment resistance	55
4.8	Theoretical and experimental modulus of elasticity	55

## LIST OF FIGURES

<b>FIGURES NO</b>	<b>TITLE</b>	<b>PAGE</b>
2.1 (a-c)	Concept of shear and diagonal tension	28
2.2	Flexural shear crack	28
2.3	Shear compression failure	29
2.4	Shear failure	29
3.1	Metakaolin ( MK 7003 )	35
3.2	Beam size and reinforcement detail	35
3.3	Tensile test	36
3.4	Concrete mix	36
3.5	Compaction process	37
3.6	Curing process	37
3.7	Strain gauge location	38
3.8	Diagram of strain gauge location	38
3.9	Test set up	39
3.10	Diagram of test set up	39
3.11	Deflection measurement by transducer	40
3.12	Measuring of crack by microscope	40
4.1 ( a )	Stress strain relationship 0% MK 7003	56
4.1 ( b )	Stress strain relationship 5% MK 7003	56
4.1 ( c )	Stress strain relationship 10% MK 7003	57

4.1 ( d )	Stress strain relationship 15% MK 7003	57
4.2	Load versus theoretical and experimental deflections	58
4.3	Initial crack occur at middle span	58
4.4	Location and pattern of crack at failure	59
4.5	Location and pattern of crack for all beams	59

## LIST OF SYMBOLS

$A_s$	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

**LIST OF APPENDICES**

<b>APPENDIX</b>	<b>TITLE</b>	<b>PAGE</b>
A	Calculation for concrete mix design grade 60	64
B	Sample calculation for ultimate moment resistance	65
C	Sample calculation for modulus of elasticity and initial crack theory	66
D	Sample calculation for deflection theory by macaulay method	67

## 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 Lumpur City Centre which high early strength of about  $15 \text{ N/mm}^2$  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  $40 \text{ N/mm}^2$  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  $60 \text{ N/mm}^2$  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<sup>2</sup> 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.

## REFERENCES

Amerogen C.V. (1971). *Reinforced Concrete*; An International Mannual; The Butterworth Group.

Amer Y. (1999). *Behaviour of Reinforced Concrete Beam With Silica Fumes Under Static Loading*; University Technology of Mara : Degree Thesis (unpublished).

British Standard Institution (1990). *Code of Practice For Design and Construction*, London BS 8110.

British Standard Institution (1970). *Method of Testing Concrete*. London BS 1881, Part 5.

Caldarone M.A, Gruber K.A., Burg R.G. (1994). *High Reactivity Metakaolin: A New Generation Mineral Admixture*. Concrete Institute : 37 – 40.

Chong Y. S. et al (1994). *Deflection and Cracking Controlled RC Beam Under Repeated Loading and Fatigue*; University Malaya: Master Thesis

Jirawat, S., Jaroenwut P.(2001). *Impact of Low Sulfate Metakaolin on Strength and Chloride Resistance of Cement Mortar and High Strength Concrete*. Department of Civil Engineering Kasetsart University; Elsevier.

Johnson R.P. (1975). *Composite Structure of Steel and Concrete*, Volume 1; Granada Publishing Limited

Kong, F. K., Evans, R. H. (1987). *Reinforced and Prestresses Concrete 3<sup>rd</sup> edition*. London: Chapman and Hall.

Lydon, F. D. (1982), *Concrete Mix Design*; University of Wales Cardiff.

Megat J. et al (2000). *Effect of admixture on Setting Times of High Strength Concrete*; Cement & Concrete Composite; Elsevier

Naville, A.M. (1987). *Properties of Concrete*; Longman

Regan P.E., Al Hussaini (1993). *Behaviour of High Strength Concrete*; Proceeding of the International Conferences; Scotland, UK

Sabir, B. B., Wild, S. and Bai, J. (2001). *Metakaolin and Calcined Clays as Pozzolans for Concrete: A review*; Cement & Concrete Composite: Elsevier

Sih, G.C. and Ryan, N.E. (1983), *Fracture Mechanic Technology Applied to Material Evaluation and Structure Design*; Martinus Nijhof Publisher.

Wild S., Khatib J.M. and Jones A. (1996), *Relative Strength, Pozzolanic Activity and Cement Hydration in Superplasticised Metakaolin Concrete*. Cement Concrete Res. 26: 1537 – 1544.

Zamin M. J. et al (1995); *Initial Study on Behaviour of High Strength Concrete Beam Under Static and Dynamic Loading*, Fourth International Conference on Concrete Engineering & Technology (CONCET 95).