THE RELATIONSHIP OF MIX PROPORTIONS AND MECHANICAL PROPERTIES OF HIGH STRENGTH CONCRETE

BEE CHIOU LING

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

JANUARY 2012
To my beloved mother and father
ACKNOWLEDGEMENT

First of all, I would like to express my appreciation to my supervisors, who are Associate Professor Baderul Hisham Ahmad and Mr. Abdullah Zawawi Awang, for giving me the opportunity to carry out this study on the relationship of mix proportions and mechanical properties of high strength concrete. I am highly grateful to them for their valuable comments and advices on my thesis and providing ample amount of knowledge about the high strength concrete.

Also, I would like to take this opportunity to thank my beloved parents, brother and sister for their concerns and supports. Their concern and support have encouraged and motivated me all along.

Last but not least, I would like to thank my friends, Lee Hoong Pin, Song Yu Ming and Kelly Wong. Their suggestions and supports help me to complete my thesis successfully.
ABSTRACT

High strength concrete is commonly used in the construction of high rise buildings. However, many engineers are sceptical about using high strength concrete partly due to the lack of understanding of its mechanical properties and mix proportions. This research presents the investigation of the relationship of mechanical properties and mix proportion of high strength concrete. The findings can help local engineers and contractors to equip themselves with sufficient knowledge on the mix proportions and properties of high strength concrete. The data of mix proportions and mechanical properties of high strength concrete were collected from the existing literature and experimental test. The data is presented graphically. The relationships of mechanical properties of high strength concrete with water-cementitious ratio, cement content and fine-coarse aggregate ratio were studied. The analysis indicates that the mechanical properties, which are compressive strength, splitting tensile strength, elastic modulus and modulus of rupture of high strength concrete decrease with an increase of water-cementitious ratio. It is also found that the mechanical properties of high strength concrete increase with an increase in cement content but decrease with an increase in fine-coarse aggregate ratio. For the experimental data, generally it shows the same relationship of mechanical properties and mix proportions with data obtained from available literature. In addition, there are expressions proposed in literature and standards which are suitable for prediction of the values of mechanical properties of high strength concrete.
ABSTRAK

### TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DECLARATION</td>
<td></td>
<td>ii</td>
</tr>
<tr>
<td>DEDICATION</td>
<td></td>
<td>iii</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td></td>
<td>iv</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td></td>
<td>v</td>
</tr>
<tr>
<td>ABSTRAK</td>
<td></td>
<td>vi</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td></td>
<td>vii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td></td>
<td>xi</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td></td>
<td>xii</td>
</tr>
<tr>
<td>LIST OF SYMBOLS</td>
<td></td>
<td>xiv</td>
</tr>
</tbody>
</table>

1 INTRODUCTION
1.1 Background of Study | 1
1.2 Statement of Problem | 2
1.3 Objectives | 3
1.4 Scopes | 4
1.5 Research Significance | 4

2 LITERATURE REVIEW
2.1 Introduction | 5
2.2 Definition of High Strength Concrete | 5
2.3 Materials of High Strength Concrete | 6
   2.3.1 Cement | 6
   2.3.2 Mixing Water | 7
   2.3.3 Coarse Aggregate | 7
2.3.4 Fine Aggregate 9
2.3.5 Admixture 9
   2.3.5.1 Silica Fume 10
   2.3.5.2 Fly Ash 12
   2.3.5.3 High-Range Water-Reducing Admixture 14
2.4 Mechanical Properties of High Strength Concrete 15
   2.4.1 Compressive Strength 15
   2.4.2 Splitting Tensile Strength 17
   2.4.3 Flexural Strength 17
   2.4.4 Modulus of Elasticity 18

3 METHODOLOGY 20
3.1 Introduction 20
3.2 Problem Statement 21
3.3 Objectives and Scopes 22
3.4 Data Collection 22
   3.4.1 Data Collection Criteria 23
   3.4.2 Correlation of Mechanical Properties 23
3.5 Experimental Test 24
   3.5.1 Specimen 25
   3.5.2 Mix Proportion 26
3.6 Data Analysis 27

4 RESULT AND DISCUSSION 28
4.1 Introduction 28
4.2 Relationship of Compressive Strength and Mix Proportion 28
   4.2.1 Relationship of Compressive Strength and Water-cementitious Ratio 29
   4.2.2 Relationship of Compressive Strength and Cement Content with Different Range of Water-Cementitious Ratio 31
   4.2.3 Relationship of Compressive Strength and
Fine-Coarse Aggregate Ratio for Different Types of Coarse Aggregates

4.2.4 Relationship of Compressive Strength and Maximum Size of Coarse Aggregate 36

4.2.5 Relationship of Compressive Strength and Percentage of Cement Replacement by Silica Fume 37

4.3 Relationship of Splitting Tensile Strength and Mix Proportions 38

4.3.1 Relationship of Splitting Tensile Strength and Cement Content 38

4.3.2 Relationship of Tensile Splitting Strength and Cement Content 40

4.3.3 Relationship of Splitting Tensile Strength and Fine-Coarse Aggregate Ratio 41

4.3.4 Relationship of Splitting Tensile Strength to Compressive Strength Ratio ($f_{ct,sp}/f_{ck}$) and Compressive Strength 43

4.3.5 Relationship of Splitting Tensile Strength and Compressive Strength 44

4.4 Relationship of Modulus of Elasticity and Mix Proportions 47

4.4.1 Relationship of Modulus of Elasticity and Water-Cementitious Ratio 47

4.4.2 Relationship of Modulus of Elasticity and Cement Content 48

4.4.3 Relationship of Modulus of Elasticity and Fine-Coarse Aggregate Ratio 49

4.4.4 Relationship of Modulus of Elasticity and Compressive Strength 51

4.5 Relationship of Modulus of Rupture and Mix Proportions 53

4.5.1 Relationship of Modulus of Rupture and Water-Cementitious Ratio 53
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5.2</td>
<td>Relationship of Modulus of Rupture and Cement Content</td>
<td>54</td>
</tr>
<tr>
<td>4.4.3</td>
<td>Relationship of Modulus of Rupture and Compressive Strength</td>
<td>55</td>
</tr>
<tr>
<td>5</td>
<td>CONCLUSION</td>
<td>58</td>
</tr>
<tr>
<td>5.1</td>
<td>Conclusion</td>
<td>58</td>
</tr>
<tr>
<td>5.2</td>
<td>Recommendation</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>REFERENCE</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td>Appendix A</td>
<td>67-76</td>
</tr>
</tbody>
</table>
LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE NO.</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Contribution of certain components of cement in strength gain rate (Nawy, 1996)</td>
<td>7</td>
</tr>
<tr>
<td>3.1</td>
<td>Mix Proportions</td>
<td>26</td>
</tr>
<tr>
<td>4.1</td>
<td>Range of optimum water-cementitious ratio for different range of compressive strength</td>
<td>31</td>
</tr>
<tr>
<td>4.2</td>
<td>Range of optimum cement content for concrete with different range of cementitious ratio</td>
<td>33</td>
</tr>
<tr>
<td>4.3</td>
<td>Optimum fine-coarse Aggregate Ratio for different range of compressive strength</td>
<td>35</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE NO.</th>
<th>TITLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Surface failure of specimens: 1) debonding; 2) aggregate print; 3) trans-granular fracture (Aitcin and Mehta, 1990)</td>
<td>8</td>
</tr>
<tr>
<td>2.2</td>
<td>Surface texture and particle shape of different types of sands</td>
<td>9</td>
</tr>
<tr>
<td>2.3</td>
<td>Scanning electron microscopy of condensed silica fume (Jaturapitakkul et al., 2004)</td>
<td>11</td>
</tr>
<tr>
<td>2.4</td>
<td>Microstructure of transition zone: (a) concrete without silica fume; (b) concrete with silica fume after 1 day of hydration (Goldman and Bentur, 1989)</td>
<td>12</td>
</tr>
<tr>
<td>2.5</td>
<td>Classification of fly ash (Jaturapitakkul et al., 2004)</td>
<td>13</td>
</tr>
<tr>
<td>2.6</td>
<td>Scanning electron microscopy of ground coarse fly ash (Jaturapitakkul et al., 2004)</td>
<td>14</td>
</tr>
<tr>
<td>2.7</td>
<td>Strength development of (a) silica fume concrete and (b) ground coarse fly ash (Jaturapitakkul et al., 2004)</td>
<td>16</td>
</tr>
<tr>
<td>2.8</td>
<td>Tensile splitting test</td>
<td>17</td>
</tr>
<tr>
<td>2.9</td>
<td>Flexural strength test</td>
<td>18</td>
</tr>
<tr>
<td>2.10</td>
<td>Schematic representation of the stress-strain relation for structural analysis</td>
<td>19</td>
</tr>
<tr>
<td>3.1</td>
<td>Flow chart of methodology</td>
<td>21</td>
</tr>
<tr>
<td>3.2</td>
<td>Casting of specimens</td>
<td>25</td>
</tr>
<tr>
<td>3.3</td>
<td>Equipment used to prepare the top and bottom surface of cylindrical specimens</td>
<td>26</td>
</tr>
<tr>
<td>4.1</td>
<td>Graph of compressive strength against water-cementitious ratio with and without cement replacement material</td>
<td>29</td>
</tr>
<tr>
<td>4.2</td>
<td>Graph of compressive strength against cement content with</td>
<td>32</td>
</tr>
</tbody>
</table>
different range of water-cementitious ratio

4.3  Graph of compressive strength against fine-coarse aggregate ratio for different types of coarse aggregate 34

4.4  Graph of compressive strength against fine-coarse aggregate ratio for different maximum size of coarse aggregate 36

4.5  Graph of compressive strength against cement content with different percentage of cement replacement by silica fume 37

4.6  Graph of splitting tensile strength against water-cementitious ratio 39

4.7  Graph of tensile splitting strength against cement content with different range of water-cementitious ratio 40

4.8  Graph of splitting tensile strength against fine-coarse aggregate 42

4.9  Graph of splitting tensile strength to compressive strength ratio against compressive strength 43

4.10 Graph of splitting tensile strength against compressive strength 45

4.11 Graph of modulus of elasticity against water-cementitious ratio 48

4.12 Graph of modulus of elasticity against cement content with different range of Water-Cementitious Ratio 49

4.13 Graph of modulus of elasticity against fine-coarse aggregate ratio 50

4.14 Graph of modulus of elasticity against compressive strength 51

4.15 Graph of modulus of rupture and water-cementitious ratio 53

4.16 Graph of modulus of rupture against cement content with different range of water-cementitious ratio 55

4.17 Graph of modulus of rupture against compressive strength 56
LIST OF SYMBOLS

$d$ - Size of specimen

$f'_{c}$ - Compressive strength of 150 mm x 300 mm cylinder

$f_{ck}$ - Compressive strength of cylinder

$f_{cm}$ - Mean value of concrete cylinder compressive strength

$f_{cu}(d)$ - Compressive strength of cube

$f_{ct,sp}$ - Splitting tensile strength

$f_{ctm}$ - Mean value of axial tensile strength of concrete

$f_{cy}(d)$ - Compressive strength of cylinder

$f_{r}$ - Modulus of rupture

$f_{sp}$ - Splitting tensile strength

$E_{c}$ - Modulus of elastic

$E_{c,100}$ - Modulus of elastic of cylinder with diameter of 100 mm

$E_{c,150}$ - Modulus of elastic of cylinder with diameter of 150 mm
CHAPTER 1

INTRODUCTION

1.1 Background of Study

Concrete is the most common material in the construction industry. It is a strong and economical material. The common compressive strength of concrete used in construction is from 25 N/mm² to 35 N/mm². The compressive strength of concrete is affected by the mix proportion and the quality of the raw material. In recent years, the utilization of high strength concrete has been increased in the construction industry. The increase of utilization of high strength concrete is due to its good rheological, mechanical and durability properties (Shannag, 2000).

There are many advantages of using high strength concrete in the construction. One of the advantages is the reduction of sizes of beam and. This can reduce the dead load of a building, especially for high rise building. For prestressed concrete construction, longer span can be achieved by using high strength concrete.

The mechanical properties of high strength concrete are affected by the mix proportion. Generally, low water-cementitious ratio is used in producing high strength concrete. Existing publication also agrees that high strength concrete made with low water-cementitious ratio (ACI Committee 363, 1992; Price, 2003; Mazloom et al., 2004). Low water-cementitious can reduce the porosity of concrete. The types and the quality of the aggregate also affected the mechanical properties of high strength concrete. Good quality of aggregate increases the bonding between
aggregate and cement. The ratio of coarse and fine aggregate also contributes to the
difference of mechanical properties of high strength concrete. It is because the ratio
can affect the homogeneity of the concrete.

High cement content is required to produce concrete with high strength. However, thermal cracking may occur in the concrete if the cement content is too high. This is due to the high heat of hydration. The highest strength of high strength concrete cannot be achieved if the cement content used is beyond the optimum cement content (ACI Committee 363, 1992). Therefore, by knowing the optimum mix proportions, high strength concrete can be produced with better mechanical properties.

1.2 Statement of Problem

The properties of high strength concrete are very dependent on the mix proportion of the concrete. Aspects of mix proportioning includes cement content, water-cement ratio, ratio of fine aggregate to coarse aggregate, content of chemical admixture and mineral admixture. Variations in the mix proportion can produce high strength concrete with different mechanical properties. Compare with normal strength concrete, mix proportioning of high strength concrete is more critical.

In recent years, the utilisation of high strength concrete has been increased in the construction industry. Although the utilization of high strength concrete has been increased, there are many engineers from contractors and consultancy firms still lack the knowledge of the mechanical properties and mix proportions of high strength concrete. This knowledge can help the engineers to check on mix proportions provided by the ready mix contractor. By doing so, the engineers can ensure that the concrete mix supplied has meet the requirement. Structural failure may occur if the concrete mixture supplied does not meet the requirement such as compressive strength.
Besides that, there are also doubts on the optimum values of mix proportion. The optimum values include optimum cement content and optimum fine-coarse aggregate ratio. The values of mechanical properties may decrease when the cement content or fine-coarse aggregate ratio are beyond the optimum values. By knowing the optimum values of mix proportion, high strength concrete with better properties can be produced.

1.3 Objectives

The aim of this study is to investigate the relationship of mix proportions and mechanical properties of high strength concrete. The objectives of this study are as follow:

(a) To study the relationship of the mechanical properties of high strength concrete and aspects of mix proportion, such as water-cementitious ratio, cement content and fine-coarse aggregate ratio

(b) To determine the optimum range of mix proportions for different range of compressive strength of high strength concrete

(c) To compare the relationship of mechanical properties and mix proportions for experimental data and data obtained from literature.

(d) To compare the data obtained from literature with the expressions proposed in various literature and standards for prediction of mechanical properties of HSC
1.4  Scopes

In this research, the mechanical properties of high strength concrete that will be studied includes compressive strength, splitting tensile strength, flexural strength and elasticity of modulus. The aspects of mix proportions involved were water-cementitious ratio, cement content and fine-coarse aggregate ratio. The compressive strength of concrete is higher than 40 MPa.

1.5  Research Significance

There are significances in this study. The results, which are the optimum mix proportions, can be used as reference for those who are interested in this field of study. By knowing the optimum mix proportions, such as optimum cement content and fine-coarse aggregate ratio, the researches or manufacturers can produce high strength concrete with better properties. Besides, the findings can help local engineers and contractors to equip themselves with sufficient knowledge on the mix proportions and properties of high strength concrete.
REFERENCE

ACI Committee 116 (1967). *Cement and concrete terminology* Detroit,: American Concrete Institute.


ACI Committee 212 (1999). *Chemical Admixtures for Concrete* Detroit: American Concrete Institute.

ACI Committee 234 (1996). *Guide for the Use of Silica Fume in Concrete* American Concrete Institute.


Shin, S. W., et al. (1997). Shear Strength of Reinforced High-Strength Concrete Beams with Shear Span-to-Depth Ratios between 1.5 and 2.5. *ACI Structural Journal*. 96(4), 549-556.


