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 watercementitious 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

Konkrit kekuatan tinggi yang biasa digunakan dalam pembinaan bangunan tinggi. Walau bagaimanapun, ramai jurutera meragui tentang penggunaan konkrit kekuatan tinggi yang sebahagiannya disebabkan oleh kekurangan pemahaman tentang sifat-sifat mekanikal dan kadar campuran. Kajian ini membentangkan penyiasatan hubungan sifat-sifat mekanikal dan kadar campuran konkrit kekuatan tinggi. Hasil kajian boleh membantu jurutera dan kontraktor tempatan untuk melengkapkan diri mereka dengan pengetahuan yang mencukupi tentang kadar campuran dan sifat-sifat mekanikal konkrit kekuatan tinggi. Data kadar campuran dan sifat-sifat mekanikal konkrit kekuatan tinggi yang dikumpulkan dari literatur yang sedia ada dan uji kaji. Data ini dipersembahkan secara grafik. Hubungan sifatsifat mekanikal konkrit kekuatan tinggi dengan nisbah air simen, kandungan simen dan nisbah batu baur halus kasar dikaji.Analisis menunjukkan bahawa sifat-sifat mekanikal konkrit kekuatan tinggi, iaitu kekuatan mampatan, kekuatan tegangan, modulus elastik dan modulus keanjalan, menurun dengan peningkatan nisbah air simen. Ia juga mendapati bahawa sifat-sifat mekanikal konkrit kekuatan tinggi meningkat dengan pertambahan kandungan simen tetapi menurun dengan perningkatan nisbah batu baur halus kasar. Bagi data uji kaji, secara amnya ia menunjukkan hubungan yang sama sifat-sifat mekanikal dan kadar campuran dengan data yang dikumpulkan dari literatur yang sedia ada. Di samping itu, terdapat persamaan yang dicadangkan dalam literatur dan standard yang sesuai untuk ramalan nilai-nilai sifat-sifat mekanikal konkrit kekuatan tinggi.

TABLE OF CONTENTS

CHAPTER	TITLE		PAGE	
	DECLARATION			ii
	DEDI	CATIC)N	iii
	ACKN	NOWL	EDGEMENT	iv
	ABST	RACT		V
	ABST	RAK		vi
	TABL	E OF	CONTENTS	vii
	LIST	OF TA	BLES	xi
	LIST	OF FIG	GURES	xii
	LIST	OF SYI	MBOLS	xiv
1	INTRO	ODUCT	ΓΙΟΝ	1
	1.1	Backg	round of Study	1
	1.2	Staten	nent of Problem	2
	1.3	Objec	tives	3
	1.4	Scope	S	4
	1.5	Resea	rch Significance	4
2	LITER	RATUR	E REVIEW	5
	2.1	Introd	uction	5
	2.2	Defini	tion of High Strength Concrete	5
	2.3	Mater	ials 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	14
			Admixture	
	2.4	Mech	anical 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	MET	HODOI		20
	3.1	Introd	luction	20
	3.2	Proble	em Statement	21
	3.3	Objec	tives 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	Exper	imental Test	24
		3.5.1	Specimen	25
		3.5.2	Mix Proportion	26
	3.6	Data 4	Analysis	27
4	RES	ULT AN	D DISCUSSION	28
	4.1	Introd	luction	28
	4.2	Relati	onship of Compressive Strength and Mix	28
		Propo	rtion	
		4.2.1	Relationship of Compressive Strength	29
			and Water-cementitious Ratio	
		4.2.2	Relationship of Compressive Strength and	31
			Cement Content with Different Range of	
			Water-Cementitious Ratio	
		4.2.3	Relationship of Compressive Strength and	34

		Fine-Coarse Aggregate Ratio for Different	
		Types of Coarse Aggregates	
	4.2.4	Relationship of Compressive Strength and	36
		Maximum Size of Coarse Aggregate	
	4.2.5	Relationship of Compressive Strength and	37
		Percentage of Cement Replacement by Silica	
		Fume	
4.3	Relation	onship of Splitting Tensile Strength and Mix	38
	Propor	rtions	
	4.3.1	Relationship of Splitting Tensile Strength	38
		and Cement Content	
	4.3.2	Relationship of Tensile Splitting Strength	40
		and Cement Content	
	4.3.3	Relationship of Splitting Tensile Strength and	41
		Fine-Coarse Aggregate Ratio	
	4.3.4	Relationship Splitting Tensile Strength to	43
		Compressive Strength Ratio $(f_{ct,sp}/f_{ck})$ and	
		Compressive Strength	
	4.3.5	Relationship of Splitting Tensile Strength	44
		and Compressive Strength	
4.4	Relation	onship of Modulus of Elasticity and Mix	47
	Propor	rtions	
	4.4.1	Relationship of Modulus of Elasticity and	47
		Water-Cementitious Ratio	
	4.4.2	Relationship of Modulus of Elasticity and	48
		Cement Content	
	4.4.3	Relationship of Modulus of Elasticity and	49
		Fine-Coarse Aggregate Ratio	
	4.4.4	Relationship of Modulus of Elasticity and	51
		Compressive Strength	
4.5	Relation	onship of Modulus of Rupture and Mix	53
	Propor	rtions	
	4.5.1	Relationship of Modulus of Rupture and	53
		Water-Cementitious Ratio	

		4.5.2	Relationship of Modulus of Rupture and	54
			Cement Content	
		4.4.3	Relationship of Modulus of Rupture and	55
			Compressive Strength	
5	CONCLUSI	ON		58
	5.1	Concl	usion	58
	5.2	Recon	nmendation	59
REFE	ERENCE			61
Appe	ndix A			67-76

LIST OF TABLES

TABLE NO.TITLE

2.1	Contribution of certain components of cement in	7
	strength gain rate (Nawy, 1996)	
3.1	Mix Proportions	26
4.1	Range of optimum water-cementitious ratio for different	31
	range of compressive strength	
4.2	Range of optimum cement content for concrete with	33
	different range of cementitious ratio	
4.3	Optimum fine-coarse Aggregate Ratio for different	35
	range of compressive strength	

PAGE

LIST OF FIGURES

TITLE

FIGURE NO.

2.1	Surface failure of specimens: 1) debonding; 2) aggregate	8
	print; 3) trans-granular fracture (Aitcin and Mehta, 1990)	
2.2	Surface texture and particle shape of different types of sands	9
2.3	Scanning electron microscopy of condensed silica fume	11
	(Jaturapitakkul et al., 2004)	
2.4	Microstructure of transition zone: (a) concrete without silica	12
	fume; (b) concrete with silica fume after 1 day of hydration	
	(Goldman and Bentur, 1989)	
2.5	Classification of fly ash (Jaturapitakkul et al., 2004)	13
2.6	Scanning electron microscopy of ground coarse fly ash	14
	(Jaturapitakkul et al., 2004)	
2.7	Strength development of (a) silica fume concrete and	16
	(b) ground coarse fly ash (Jaturapitakkul et al., 2004)	
2.8	Tensile splitting test	17
2.9	Flexural strength test	18
2.10	Schematic representation of the stress-strain relation for	19
	structural analysis	
3.1	Flow chart of methodology	21
3.2	Casting of specimens	25
3.3	Equipment used to prepare the top and bottom surface of	26
	cylindrical specimens	
4.1	Graph of compressive strength against water-cementitious	29
	ratio	
	with and without cement replacement material	
4.2	Graph of compressive strength against cement content with	32

PAGE

different range of water-cementitious ratio

	different fange of water-comonitious failo	
4.3	Graph of compressive strength against fine-coarse aggregate	34
	ratio for different types of coarse aggregate	
4.4	Graph of compressive strength against fine-coarse aggregate	36
	ratio for different maximum size of coarse aggregate	
4.5	Graph of compressive strength against cement content with	37
	different percentage of cement replacement by silica fume	
4.6	Graph of splitting tensile strength against water-cementitious	39
	ratio	
4.7	Graph of tensile splitting strength against cement content	40
	with different range of water-cementitious ratio	
4.8	Graph of splitting tensile strength against fine-coarse	42
	aggregate	
4.9	Graph of splitting tensile strength to compressive strength	43
	ratio against compressive strength	
4.10	Graph of splitting tensile strength against compressive	45
	strength	
4.11	Graph of modulus of elasticity against water-cementitious	48
	ratio	
4.12	Graph of modulus of elasticity against cement content with	49
	different range of Water-Cementitious Ratio	
4.13	Graph of modulus of elasticity against fine-coarse aggregate	50
	ratio	
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	55
	different range of water-cementitious ratio	
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 watercementitious 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 211 (1993). Guide for Selecting Proportions for High-Strength Concrete with Portland Cement and Fly Ash 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.
- ACI Committee 363 (1992). State-of-the-art report on high strength concrete Detroit, Mich. (Box 19150, Redford Station, Detroit 48219): American Concrete Institute.
- Aitcin, P. C. and P. K. Mehta (1990). Effect of Coarse-Aggregate Characteristics on Mechanical Properties of High-Strength Concrete. ACI Materials Journal. 87(2), 103-107.
- Aitcin, P. C., et al. (1994). Effects of Size and Curing on Cylinder Compressive Strength of Normal and High-Strength Concretes. ACI Materials Journal. 91(4).
- Alves, M. F., et al. (2004). A Comparison of Mix Proportioning Methods for High Strength Concrete. *Cement & Concrete Composites*. 26, 612-621.
- Baalbaki, W., et al. (1991). Influence of Coarse Aggregate on Elastic Properties of High-Strength Performance Concrete. ACI Materials Journal. 88(5).
- Bharatkumar, B. H., et al. (2001). Mix Proportioning of High Performance Concrete. *Cement & Concrete Composites*. 23, 71-80.
- British Standards, I. (1992). Eurocode 2 design of concrete structures : part 1 general rules and rules for buildings (together with United Kingdom National Application Document) British Standards Institution.

- British Standards, I. (2000). Concrete Part 1: Specification, performance, production and conformity British Standards Institution.
- Chang, P. K. (2004). An Approach To Optimize Mix Design For Properties of High Strength Concrete. *Concrete and Cement Research*. 34, 623-629.
- Chin, M. S., et al. (1997). Effect of Shape, Size, and Casting Direction of Specimens on Stress-Strain Curves of High-Strength Concrete. ACI Materials Journal. 94(3), 209-217.
- Cordon, W. A. and H. A. Gillespie (1963). Variables in Concrete Aggregates and Portland Cement Paste which Influence the Strength of Concrete. ACI Journal Proceedings. 60(8), 1029-1052.
- Daniel, L. and A. Loukili (2002). Behavior of High-Strength Concrete Fiber-Reinforced Concrete Beams under Cyclic Loading. ACI Structural Journal. 99(3), 248-256.
- Darwin, D., et al. (2001). Fracture Energy of High-Strength Concrete. ACI Materials Journal. 98(5), 410-417.
- Demirboga, R. and R. Gul (2006). Production of high strength concrete by use of industrial by-products. *Building and Environment*. 41, 1124-1127.
- Dewar, J. D. (1964). The Indirect Tensile Strength of Concretes of High Compressive Strength. *Cement and Concrete Association*. 12.
- Donza, H., et al. (2002). High-Strength Concrete With Different Fine Aggregate. *Cement and Concrete Research*. 32, 1755-1761.
- Einsfeld, R. A. and M. S. L. Velasco (2006). Fracture parameters for highperformance concrete. *Cement & Concrete Composites*. 36, 576-583.
- Elahi, A., et al. (2010). Mechanical and durability properties of high performance concretes containing supplementary cementitious materials. *Construction and Building Material*. 24, 292-299.
- Eren, O. and T. Celik (1997). Effect of Silica Fume and Steel Fibers On Some Properties of High-Strength Concrete. *Construction and Building Materials*. 11, 373-382.
- Ezeldin, A. S. and P. C. Aitcin (1991). Effect of Coarse Aggregate on xthe Behavior of Normal and High-Strength Concretes. *Journal of Cement, Concrete, and Aggregates.* 13(2), 159-166.

- Gagne, R., et al. (1996). Effect of Superplasticizer Dosage on Mechanical Properties, Permeability, and Freeze-Thaw Durability of High-Strength Concretes With and Without Silica Fume. ACI Materials Journal. 93(2), 111-120.
- Galano, L. and A. Vignoli (2008). Strength and Ductility of HSC and SCC Slender Columns Subjected to Short-Term Eccentric Load. ACI Structural Journal. 105(3).
- Gaynor, R. D. and R. C. Meininger (1983). Evaluationg Concrete Sands: Five Tests to Estimate Quality. *Concrete International*. 5(12), 53-60.
- Gettu, R., et al. (1996). Damage in High-Strength Concrete Due to Monotonic and Cyclic Compression - A Study Based on Splitting Tensile Strength. ACI Materials Journal. 93(6), 1-5.
- Giaccio, G., et al. (1992). High Strength Concretes Incorporating Different Coarse Aggregates. *ACI Materials Journal*. 89(3), 242-246.
- Giaccio, G., et al. (2007). Failure mechanism of normal and high-strength concrete with rice-husk ash. *Cement & Concrete Composites*. 29, 566-574.
- Goldman, A. and A. Bentur (1989). Bond Effects In High-Strength Silica-Fume Concrete. ACI Materials Journal. 86(5), 440-449.
- Haque, M. N. and O. Kayali (1998). Properties of High-Strength Concrete Using Fine Fly Ash. Cement & Concrete Research. 28(10), 1445-1452.
- Hussein, A. and H. Marzouk (2000). Behavior of High-Strength Concrete under Biaxial Stresses. *ACI Materials Journal*. 90(1), 27-36.
- Ismail, M. S. and A. M. Waliuddin (1996). Effect of Rice Husk Ash and High Strength Concrete. *Construction and Building Materials*. 10, 521 526.
- Jaturapitakkul, C., et al. (2004). Use of Ground Coarse Fly Ash As A Replacement of Condensed Silica Fume In Producing High-Strength Concrete. Cement & Concrete Research. 34, 549-555.
- Jerath, S. and L. C. Yamane (1987). Mechanical Properties and Workability of Superplasticized Concrete. *Cement, Concrete, and Aggregates*. 9(1), 12-19.
- Khanzadi, M. and A. Behnood (2009). Mechanical Properties of High-Strength Concrete Incorporating Copper Slag As Coarse Aggregate. *Construction and Building Materials*. 23, 2183-2188.
- Khatri, R. P. and V. Sirivivatnanon (1995). Effect of Different Supplementary Cementitious Materials On Mechanical Properties of High Performance Concrete. *Cement & Concrete Research*. 25(1), 209-220.

- Khayat, K. H., et al. (1995). High-Strength Concrete Properties Derived from Compressive Strength Values. Cement, Concrete, and Aggregates. 17(2), 126-133.
- Lahlou, K., et al. (1992). Behaviour of High-Strength Concrete Under Confined Stresses. *Cement & Concrete Composites*. 14, 185-193.
- Lessard, M., et al. (1993). Compressive Test of High-Strength Concrete ACI Materials Journal. 90(04), 303-308.
- Li, G. and X. Zhao (2003). Properties of Concrete Incorporating Fly Ash and Ground Granulated Blast-Furnace Slag. *Cement & Concrete Composites*. 25, 293-299.
- Li, J. and P. Tian (1997). Effect of Slag adn Silica Fume On Mechanical Properties of High Strength Concrete. *Cement & Concrete Research*. 27(6), 833-837.
- Lydon, F. D. and M. Iacovou (1995). Some Factors Affecting The Dynamic Modulus of Elasticity of High Strength Concrete. *Cement and Concrete Research*. 25(6), 1246-1256.
- Marzouk, H. and S. Langdon (2003). The Effects of Alkali-aggregate Reactivity On The Mechanical Properties of High and Normal Strength Concrete. *Cement & Concrete Composites*. 25, 549-556.
- Mazloom, M., et al. (2004). Effect of silica fume on mechanical properties of highstrength concrete. *Cement & Concrete Composites*. 26, 347-357.
- Mei, H., et al. (2001). Confinement Effects on High-Strength Concrete. ACI Structural Journal. 98(4).
- Naik, T. R., et al. (1998). Mechanical Properties and Durability of Concrete Made with Blended Fly Ash. *ACI Materials Journal*. 95(4), 454-460.
- Naik, T. R., et al. (1995). Abrasion Resistance of High-Strength Concrete Made with Class C Fly Ash. *ACI Materials Journal*. 92(6), 649-659.
- Nawy, E. G. (1996). Fundamentals of High Performance Concrete UK: Longman.
- Papayianni, I. and E. Anastasiou (2010). Production of High-Strength Concrete Using High Volume of Industrial By-Products. *Construction and Building Materials*. 24, 1412-1417.
- Poon, C. S., et al. (2000). A Study On High Strength Concrete Prepared With Large Volumes of Low Calcium Fly Ash. *Cement & Concrete Research*. 30, 447-455.
- Price, B. (2003). High strength concrete. Advanced Concrete Technology Set. J. Newman and B. S. Choo. Oxford, Butterworth-Heinemann: 1 - 16.

- Rashid, M. A., et al. (2002). Correlations between Mechanical Proporties of High-Strength Concrete. *Journal of Materials in Civil Engineering*. 14(3), 230-238.
- Roller, J. J. and H. G. Russell (1990). Shear Strength of High-Strength Concrete Beams with Web Reinforcement. *ACI Structural Journal*. 87(2), 191-198.
- Sata, V., et al. (2004). Utilization of Palm Oil Fuel Ash in High-Strength Concrete. J. Mat. in Civ. Engrg. 16(6), 623-628
- Setunge, S., et al. (1993). Ultimate Strength of Confined Very High-Strength Concretes. ACI Structural Journal. 90(6), 632-641.
- Shannag, M. J. (2000). High-Strength Concrete Containing Natural Pozzolan and Silica Fume. *Cement & Concrete Composites*. 22, 399-406.
- 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.
- Sivakumar, A. and M. Santhanam (2007). Mechanical Properties of High Strength Concrete Reinforced with Metallic and Non-Metallic Fibres. *Cement & Concrete Composites*. 29, 603-608.
- Song, P. S. and S. Hwang (2004). Mechanical Properties of High-Strength Steel Fiber-Reinforced Concrete. *Construction and Building Materials*. 18, 669-673.
- Swamy, R. N. (1986). Properties of High-Strength Concrete. Journal of Cement, Concrete, and Aggregates. 8(1), 33-41.
- Tangchirapat, W., et al. (2009). Use of Palm Oil Fuel Ash As A Supplementary Cementitious Material for Producing High-Strength Concrete. *Construction* and Building Materials. 23, 2641-2646.
- Taylor, M. R., et al. (1996). Mix proportions for high-strength concrete. Construction and Building Materials. 10, 445-450.
- Thoman, et al. (1934). Ultimate Strength and Modulus of Elasticity of High Strength Portland Cement Concrete. *ACI Journal Proceedings*. 30(3), 231-238.
- Walker, S. and D. L. Bleom (1960). Effects of Aggregate Size on Properties of Concrete. ACI Journal Proceedings. 57(9), 283-298.
- Wu, K.-R., et al. (2001). Effect of coarse aggregate type on mechanical properties of high-performance concrete. *Cement & Concrete Research*. 31, 1421-1425.
- Wu, W., et al. (2010). Optimum Content of Copper Slag As A Fine Aggregate In High Strength Concrete. *Materials and Design*. 31, 2878-2883.

- Yang, E.-I., et al. (2000). Effect of Axial Restraint on Mechanical Behavior of High-Strength Concrete Beams. ACI Structural Journal. 97(5), 751-756.
- Yen, T., et al. (2007). Influence of Class F Fly Ash On The Abrasion-Erosion Resistance of High-Strength Concrete. *Construction and Building Materials*. 21, 458-463.
- Yi, S. T., et al. (2006). Effect of Specimen Sizes, Specimen Shapes, and Placement Directions on Compressive Strength of Concrete. *Nuclear Engineering and Design.* 236, 115-127.
- Zain, M. F. M., et al. (2002). Prediction of splitting tensile strength of highperformance concrete. *Concrete and Cement Research*. 32(1251-1258).
- Zhang, M.-H. and V. M. Malhotra (1996). High-Performance Concrete Incorporating Rice Husk Ash as a Supplementary Cementing Material. ACI Materials Journal. 93(6), 629-636.