SHEAR CAPACITY OF STEEL FIBRE REINFORCED CONCRETE COMPOSITE SLAB

MOHD BASRI BIN CHE BAKAR

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

Faculty of Civil Engineering
Universiti Teknologi Malaysia

December, 2010

Especially dedicated to my beloved mom, dad, sister and younger brother

ACKNOWLEDGEMENT

Praise to Allah S.W.T., this master project entitled "*Shear Capacity of Steel Fibre Reinforced Concrete Composite Slab*" is finally completed within the allocated time.

Major thanks to my supervisor, Dr. Izni Syahrizal Ibrahim, who always there to provide me guidance and honest feedback on my project. His patience and immeasurable contribution is the key to generate this project, I would have not completing my thesis without him.

I would like to express my gratitude towards all the lectures and technicians at the Department of Structures & Materials, Faculty of Civil Engineering for their invaluable help and support while conducting this study and to Timuran Engineering Sdn. Bhd. for supplying the steel fibres.

Also, deep appreciation expressed to my parents, siblings and all my friends for their moral support. Lastly, thanks to the people that I do not mention their name for their assistance and encouragement.

ABSTRACT

This thesis present the results of combined bending and shear test on composite slabs with steel fibres (SFs) in-situ concrete topping. Mechanical properties of steel fibre reinforced concrete (SFRC) were first determined by varying the fibres dosage from 0.50% to 1.25%. The test results show that there was not much improvement of the SFRC properties for steel fibres dosage of 1.0% and 1.25%. Apart from that, strong correlations were found between the concrete splitting tensile strength, compressive cube strength and flexural strength of SFRC. Following this, SFRC with 1.0% dosage was cast onto precast slab with different surface roughness. The SFRC replaced the conventional method using cast in-situ reinforced concrete topping. The experimental results on its ultimate shear capacity were further compared with previous research, and a parametric equation was proposed in predicting the interface shear strength using SFRC as concrete topping. The results shows that the ultimate shear capacity were 16.69% and 13.47% higher than the calculated value for the exposed aggregate and longitudinal roughened surface roughness, respectively. However, they were 15.23% and 17.56% lower than the smooth as-cast surface specimen with conventional reinforced concrete topping, respectively. As for the interface shear strength, the surface roughened in the longitudinal direction was the highest with 2.17 N/mm^2. Further comparison was made with BS 8110 and Eurocode 2 and the results show that they were higher than the minimum value provided in both codes. The finding also suggested that surface roughened in the longitudinal direction was better than the other specimens with SFRC topping in terms of interface bonding.

ABSTRAK

Tesis ini membincangkan mengenai keputusan gabungan ujian lenturan dan ricih ke atas papak komposit yang mengaplikasikan konkrit bertetulang besi gentian tuang di-situ sebagai penutup konkrit. Sifat-sifat mekanikal konkrit bertetulang besi gentian ditentukan dahulu dengan menpelbagaikan peratus dos besi gentian bermula dari 0.50% sehingga 1.25%. Keputusan ujian yang dijalankan menunjukkan peratus dos besi gentian di antara 1.0% hingga 1.25% tidak menunjukkan peningkatan yang ketara pada sifat-sifat mekanikal konkrit bertetulang besi gentian itu sendiri. Selain itu, kajian ini telah mendapati konkrit bertetulang besi gentian mempunyai hubungan yang kuat di antara kekuatan tegangan konkrit, kekuatan mampatan konkrit dan juga kekuatan lenturan konkrit. Berikutan itu, konkrit yang ditambah dengan peratus dos besi gentian sebanyak 1.0% dituang di atas papak pratuang yang mempunyai jenis kekasaran permukaan yang berbeza-beza. Keputusan ujian makmal ke atas kapasiti ricih muktamad dibandingkan dengan kajian yang terdahulu dan persamaan parametrik juga diusulkan untuk meramalkan kekuatan ricih permukaan yang mengaplikasikan konkrit bertetulang besi gentian sebagai penutup konkrit. Keputusan ujian menunjukkan permukaan dedahan dengan batuan adalah 16.69% lebih tinggi daripada nilai teori kapasiti ricih muktamad manakala permukaan kekasaran dalam arah pemanjangan adalah 13.47% lebih tinggi daripada nilai teori. Walau bagaimanapun, permukaan dedahan dengan batuan dan permukaan kekasaran dalam arah pemanjangan adalah 15.23% dan 17.56% lebih rendah berbanding spesimen yang dilapisi penutup konkrit bertetulang besi dengan permukaan licin seperti dituang. Dari segi kekuatan ricih permukaan, permukaan kekasaran panjang mempunyai nilai tertinggi sebanyak 2.17 N/mm^2. Perbandingan nilai kekuatan ricih permukaan dengan BS 8110 dan Eurocode 2 menunjukkan semua spesimen papak komposit mempunyai nilai yang lebih tinggi daripada nilai minimum yang dicadangkan oleh kedua-dua kod latihan tersebut. Kajian ini juga mencadangkan permukaan kekasaran dalam arah pemanjangan adalah yang terbaik dari segi ikatan permukaan bersentuhan berbanding semua spesimen papak komposit yang mengaplikasikan konkrit bertetulang besi gentian sebagai penutup konkrit.

TABLE OF CONTENTS

CHAPTER	TITLE		PAGE
	DECLARATION		**ii**
	DEDICATION		**iii**
	ACKNOWLEDGEMENT		**iv**
	ABSTRACT		**v**
	ABSTRAK		**vi**
	TABLE OF CONTENTS		**vii**
	LIST OF TABLES		**x**
	LIST OF FIGURES		**xi**
	LIST OF NOTATIONS		**xvi**
1	**INTRODUCTION**		
	1.1	Background	1
	1.2	Problem Statement	3
	1.3	Objectives	4
	1.4	Scope of Study	4
	1.5	Importance of Study	6
	1.6	Thesis Structure	6
2	**LITERATURE REVIEW**		
	2.1	Introduction	7
	2.2	Steel Fibres (SFs)	8
	2.3	Steel Fibre Reinforced Concrete (SFRC)	9
		2.3.1 Mechanical Properties of Steel Fibre	10

		Reinforced Concrete (SFRC)	
		2.3.1.1 Compressive Strength	12
		2.3.1.2 Tensile Strength	13
		2.3.1.3 Flexural Strength	13
		2.3.1.4 Shear Strength	13
		2.3.1.5 Shrinkage and Creep	14
	2.3.2	Advantages of Steel Fibre Reinforced Concrete (SFRC)	14
	2.3.3	Previous Works Related to Steel Fibre Reinforced Concrete (SFRC)	15
2.4		Shear Capacity at Interface of Composite Slab	24
	2.4.1	Previous Works Related to Shear Strength at Interface of Composite Slab	28
2.5		Surface Roughness	33
2.6		Bonding Strength at Interface	39
2.7		Summary	42
3		**RESEARCH METHODOLOGY**	
3.1		Introduction	44
3.2		Test Specimens	45
3.3		Experimental Works on Static Mechanical Properties of Steel Fibre Reinforced Concrete (SFRC)	46
	3.3.1	Concrete Compressive Cube Strength Test	49
	3.3.2	Cylinder Splitting Tensile Strength Test and Static Modulus of Elasticity in Compression	50
	3.3.3	Concrete Flexural Strength Test	51
3.4		Specimens Preparation and Casting Procedure	52
	3.4.1	Casting of Precast Concrete Slab Specimens	54
	3.4.2	Casting of Concrete Topping	57
	3.4.3	Wet Curing Condition	59
3.5		Combined Bending and Shear Test	59
	3.5.1	Testing Procedures	62
4		**EXPERIMENTAL RESULTS**	
4.1		Introduction	63

	4.2	Experimental Results on the Mechanical Properties of Steel Fibre Reinforced Concrete (SFRC)	64
		4.2.1 Specimens Failure	65
		4.2.2 Concrete Cube Compressive Strength	67
		4.2.3 Concrete Splitting Tensile Strength	68
		4.2.4 Concrete Flexural Strength	69
		4.2.5 Static Modulus of Elasticity in Compression	71
	4.3	Experimental Results for Bending and Shear Test On Steel Fibre Reinforced Concrete Composite Slab (SFRCCS)	74
		4.3.1 Specimen Cracking Mode	75
		4.3.2 Load versus Mid-span Deflection Relationship	77
		4.3.3 Load versus Strain Relationship	79
		4.3.4 Load versus Interface Slip Relationship	84
5	**ANALYSIS AND DISCUSSION**		
	5.1	Introduction	88
	5.2	Relationships between Mechanical Properties of Steel Fibre Reinforced Concrete (SFRC)	88
	5.3	Shear Force and Mid-span Deflection Relationship	91
	5.4	Interface Shear Strength Analysis	92
6	**CONCLUSION AND RECOMMENDATION**		
	6.1	Conclusion	97
	6.2	Recommendation	99
REFERENCES			100
APPENDIX A – Determination of P_{ult}			103
APPENDIX B – Concrete Mix Design for SFRC			105
APPENDIX C – Concrete Mix Design for Precast Slab			106
APPENDIX D – Calculation of Interface Shear Strength,			107
APPENDIX E – Calculation of Interface Shear Strength,			110

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Design ultimate horizontal shear strength at the interface (N/mm^2)	24
2.2	*c* and factors depending on the roughness at the interface	28
2.3	Comparison of horizontal shear strengths of BS 8110 and Eurocode 2	34
3.1	Mix proportions for SFRC mixes	48
3.2	Numbers of specimens tested on determining the static mechanical properties of SFRC	52
3.3	Mix proportions design for composite slab specimens	53
3.4	Specimen details and parameters studied	56
4.1	Average mechanical properties for concrete with different SFs volumetric percentages	64
4.2	Composite slabs concrete properties	74
4.3	Ultimate load and mid-span deflection on composite slabs in bending and shear test	78
5.1	Interface shear strength results	96

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.1	Applications of precast concrete structures in a building construction	2
1.2	Horizontal shear along the interface of a composite slab bends under flexural load	3
2.1	Different shapes of steel fibres	8
2.2	Effect of steel fibres alignment using table vibration	11
2.3	Effect on flexural strength of SFRC influenced by direction of casting and type of vibration	12
2.4	Schematic diagram of experimental set up	16
2.5	Regression analysis	18
2.6	Schematic diagram of slab test set up and loading configuration	20
2.7	Average stress-strain relationships determined experimentally for plain and SFA concrete	22
2.8	Test set up for displacement-controlled flexural loading of 150 x 150 x 750 mm prism	22
2.9	Appearances of SFARC 300 x 300 x 2000 mm beams with 60kg/m^3 of SFs in bending experiments on the 4-point beam-loading set up	23

2.10	Test set-up	29
2.11	Load versus mid-span deflection relationships	31
2.12	Typical shear pattern in test beam bent in flexural	33
2.13	Indented construction joint	34
2.14	Graphical determination of R_z values	35
2.15	Dimensions of composite slabs	37
2.16	Schematic of push-off test	37
2.17	Horizontal shear strength versus concrete strength	37
2.18	Horizontal shear strength versus roughness	38
2.19	Substrate bodies with sandblasted interfaces (specimens S1 – S5)	40
2.20	Substrate bodies with smooth interfaces (specimen S6)	41
2.21	Substrate bodies with notched interfaces (specimen S7)	42
3.1	Type of steel fibres used	47
3.2	Physical appearance of fresh SFRC in the drum mixer	48
3.3	Specimens curing process until the test day	49
3.4	Arrangement of load and support for flexural strength of concrete test	51
3.5	Precast slab formwork	54
3.6	Concrete drum mixer with capacity of 0.3 m^3/cast	55
3.7	Air Hammer Hand Tool	56
3.8	Difference surface roughness of precast slab	57

3.9	Fresh concrete topping after casting	58
3.10	Composite slab after dismantle the formwork	58
3.11	Specimens were wet cured covered with wet burlap	59
3.12	Position of Demec Pips fixed to specimens	60
3.13	Demec Gauge	61
3.14	Combined bending and shear test setup	61
4.1	Cubes failure in compression	66
4.2	Cylindrical splitting tensile failure	66
4.3	Flexural failure of beams specimens	67
4.4	Relationship between concrete cube compressive strength (f_{cu}) and steel fibre percentage (%)	68
4.5	Relationship between concrete splitting tensile strength (f_{ct}) and steel fibre percentage (%) at 28-days	69
4.6	Relationship between concrete flexural strength (f_t) and steel fibre percentage (%)	70
4.7 (a)	Compressive stress-strain curves in determining the Modulus of Elasticity for plain concrete	71
4.7 (b)	Compressive stress-strain curves in determining the Modulus of Elasticity for SFRC with 0.50% SFs dosage	72
4.7 (c)	Compressive stress-strain curves in determining the Modulus of Elasticity for SFRC with 0.75% SFs dosage	72
4.7 (d)	Compressive stress-strain curves in determining the Modulus of Elasticity for SFRC with 1.00% SFs dosage	73
4.7 (e)	Compressive stress-strain curves in determining the Modulus of Elasticity for SFRC with 1.25% SFs dosage	73

4.8	Compressive stress-strain curves in determining Modulus of Elasticity for precast unit	75
4.9 (a)	Pattern cracking failure for specimen with smooth as-cast surface	76
4.9 (b)	Pattern cracking failure for specimen with surface roughness in transverse direction	76
4.9 (c)	Pattern cracking failure for specimen with surface roughness in longitudinal direction	76
4.9 (d)	Pattern cracking failure for specimen with surface roughness by exposed aggregate	77
4.10	Load versus mid-span deflection relationship for four differences surface roughness	79
4.11 (a)	Load versus strain relationship for specimen with surface roughness smooth as-cast	80
4.11 (b)	Load versus strain relationship for specimen with surface roughness in transverse direction	80
4.11 (c)	Load versus strain relationship for specimen with surface roughness in longitudinal direction	81
4.11 (d)	Load versus strain relationship for specimen with surface roughness by exposed aggregate	81
4.12 (a)	Strain distribution diagram for specimen with smooth as-cast surface	82
4.12 (b)	Strain distribution diagram for specimen with transverse roughened surface	83
4.12 (c)	Strain distribution diagram for specimen with longitudinal roughened surface	83
4.12 (d)	Strain distribution diagram for specimen with surface roughened by exposed aggregate	84
4.13	Strain distribution diagram	85
4.14	Interface slip for specimen with smooth as-cast surface up to 1.0 mm	86

4.15	Interface slip for specimen with surface roughened in transverse direction up to 1.0 mm	86
4.16	Interface slip for specimen with surface roughened in longitudinal direction up to 1.0 mm	86
4.17	Interface slip for specimen with surface roughened by exposed aggregate up to 1.0 mm	87
5.1 (a)	Relationship between concrete splitting tensile strength (f_{ct}) and concrete cube compressive strength (f_{cu})	89
5.1 (b)	Relationship between concrete flexural strength (f_t) and concrete cube compressive strength (f_{cu})	89
5.1 (c)	Relationship between concrete splitting tensile strength (f_{ct}) and concrete flexural strength (f_t)	90
5.2	Shear force and mid-span deflection relationship	92

LIST OF NOTATIONS

A_s	-	area of the tension reinforcement
A_i	-	area of the joint
b	-	full breadth of the precast unit
b_i	-	width of the interface
b_v	-	width of the contact interface
d/l	-	inverse of fibre aspect ratio
$E_{precast}$	-	Elastic Modulus of precast unit
$E_{topping}$	-	Elastic Modulus of concrete topping
E_{steel}	-	Elastic Modulus of steel reinforcement
F	-	maximum load
F_v	-	horizontal shear force
f_{cu}	-	concrete cube compressive strength
f_{ct}	-	concrete splitting tensile strength
f_t	-	flexural concrete strength
f_{ctk}	-	characteristic axial tensile strength of concrete
h_p	-	precast slab depth
I_{comp}	-	second moment of area
I_g	-	gross moment of inertia
L_z	-	distance between the points of min. and max. bending moment

l - span length

l/d - aspect ratio

n_1 - transformation factor for precast unit width to be transformed

n_2 - transformation factor for area of tension reinforcement to be transformed

PWc_{crit} - critical percentage of fibres (by weight of mix)

R_z - surface roughness

SG_f - specific gravity of fibres

SG_c - specific gravity of concrete matrix

V - minimum shear force

V_{Ed} - transverse shear force

V_f - volume percentage of steel fibres

V_v - vertical magnification of the profile record

v - strength reduction factor

v_{ave} - average shear strength at the cross-section of the interface considered at ultimate limit state

v_{Edi} - design value of the shear strength in the interface

v_{Rdi} - design shear resistance at the interface

w - uniform distributed load

W_a - weight of aggregate fraction (particle size >5 mm)

W_m - weight of mortar fraction (particle size < 5 mm)

X - depth of neutral axis

y_p - distance from the neutral axis of composite section to the centroid of precast slab

y_s - distance from the neutral axis of composite section to the steel centroid in the precast slab

z - lever arm of composite se

β - ratio of longitudinal force in the new concrete area and the total longitudinal force either in the compression zone or tension zone, both calculated for the section considered

ε_{fs} - free shrinkage of the SFRC

ε_{os} - free shrinkage of plain concrete

τ_{EC2} - Eurocode 2 interface shear strength

$\tau_{exp\ shear}$ - Experimental interface shear strength

μ is the coefficient of friction between the fibres and the concrete (range from 0.04 for plain steel fibres to 0.12 for deformed fibres)

γ_c is the partial safety factor for concrete

CHAPTER 1

INTRODUCTION

1.1 Background

Concrete is one of the most important material in the constructions nowadays that promises a lot of advantages. The ability of concrete itself can be cast in any shape, excellent resistant to water and high temperature, required less maintenance are among the obvious advantages. Concrete is also known as an economical material which can reduce the overall project cost. Combination with steel as reinforcement in producing reinforced concrete ends up with other excellent properties to concrete in resisting the compressive and tensile forces. Reinforced concrete can be classified into precast or cast in-situ concrete. Precast concrete is cast and cured with high quality control in the factory before transported to construction site and lifted into position with the aid of lifting equipment controlled by highly skilled worker.

Example of construction that uses the precast concrete structure are bridge deck, tunnel lining and building elements including beam, column, slab and wall as shown in the Figure 1.1. Application of precast concrete structures in the construction stage contribute many advantages which include shorten the

construction period, less labour required and at the same time keep the construction site clean with less formwork. However, only slab structure among the other building elements will be emphasized in this study.

In order to enhance the structural performance of precast concrete slab, it will be levelled with in-situ concrete acting as concrete topping that has specific purpose to create horizontal shear strength between the two contact surfaces i.e. precast unit and concrete topping. This is known as composite slab and will be designed monolithically. Interface shear links are usually provided in which projected from the precast slab into concrete topping to resist the horizontal shear.

Nowadays, some modifications can be made by varying the materials used in the casting of concrete topping. This include an application of steel fibre reinforced concrete (SFRC) as structural topping that is possible in resulting better horizontal shear strength between the precast slab and concrete topping without providing any interface shear links. Hence, by understanding the material properties of SFRC including its overall effect to the strength of composite slab and the development of the horizontal shear strength is the main finding in conducting this study.

Figure 1.1: Applications of precast concrete structures in a building construction

1.2 Problem Statement

Composite slab is designed to act monolithically. Essentially, precast slab will bend together with the concrete topping when flexural load is applied onto the composite slab. The flexural behaviour will automatically generate the sliding movement between the precast slab and concrete topping as illustrated in Figure 1.2. Horizontal shear strength developed between these two types concrete will resist the sliding movement of the contact surfaces. In the code of practice e.g. British Standard and Eurocode 2, it states the minimum value of horizontal shear stress that should be fulfilled when designing a composite slab depending on the certain cases i.e. surface texture of precast slab and grade of concrete topping. Otherwise, all the horizontal force should be carried by additional reinforcement e.g. interface shear reinforcement.

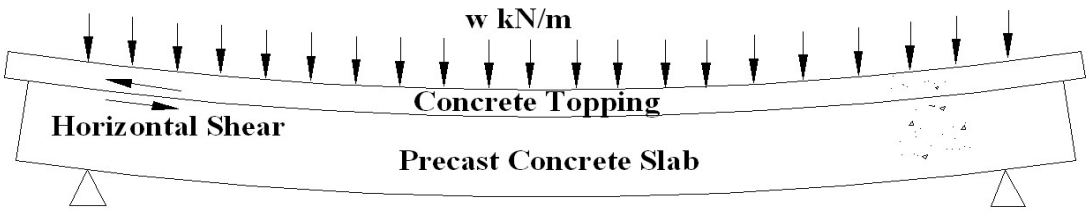

Figure 1.2: Horizontal shear along the interface of a composite slab bends under flexural load

Most precast composite slab structure is designed without providing any shear reinforcement at the interface because it is believed that horizontal shear strength can be carried up by the bonding force between precast slab and in-situ concrete by treating the surface to a certain texture and roughness. The top surface of the precast slab will be brushed either in longitudinal or transverse direction, and exposed aggregate to create the required surface texture. However, most designers prefer the surface to be remained smooth as-cast and according to the FIP [14], they believe smooth surface has better bonding strength compared with the rough ones. Therefore, in this study, it is also important to find out the effect of SFRC application

as concrete topping to the horizontal shear strength based on different surface texture of the precast slab.

Two main parameters will be examined in this study i.e. mechanical properties of SFRC itself as concrete topping and the different types of surface texture of the precast concrete slab that affect the interface shear strength. These two parameters can affect the bonding strength at the interface and thus, affect the flexural behaviour of the precast composite slab.

1.3 Objectives

This study conducted to achieve the following objectives:

i. To study the mechanical properties of SFRC.
ii. To determine the ultimate shear capacity of composite slab with different surface texture under wet curing condition.
iii. To compare the ultimate horizontal shear capacity of composite slab using SFRC and conventional reinforced concrete as concrete topping.
iv. To propose a parametric equation in predicting the ultimate horizontal shear capacity using SFRC as concrete topping.

1.4 Scope of Study

This study is intended to study the mechanical properties of SFRC prior to the application as concrete topping on existing precast slab. The material properties of SFRC which consists of compressive, splitting tensile and flexural strengths and

Modulus of Elasticity were determined with five different volumetric percentages of 0% (as control specimens), 0.50%, 0.75%, 1.00% and 1.25% by absolute concrete weight of grade C25 (f_{cu} = 25 N/mm^2 at 28 days). The strength developments of the SFRC specimens were observed for 7, 14 and 28 days depending on the tests conducted. SFRC with particular volumetric percentage selected from five different volumetric percentages of SFRC specimens whichever give the best results in those mechanical properties was cast as structural concrete topping of composite slab.

Later on, the ultimate shear capacity of SFRC composite slab was determined by carrying out combined bending and shear test. The slab was designed to have 1100 mm length, 500 mm width and 175 mm overall depth i.e. 100 mm depth precast slab with 75 mm concrete topping. The experimental result was compared with the previous study [1] using the same dimensions and concrete properties so that the significant result at the end of this study can be obviously represented.

The surface of precast slabs were treated in four different ways; smooth as-cast, roughened in longitudinal and transverse direction and roughened by exposed aggregate. Therefore, four specimens of SFRC composite slabs were prepared and wet cured until the test day by covering them using wet gunny sacks to avoid the specimens from being exposed to the surrounding environment. Since the previous study [1] claimed that wet cured sample has better interface bond, this was used as the preferred choice to cure the specimens.

A pair of point load was applied until failure of the specimen. The point load was located at 1.5H from the support where H is the overall depth of the SFRC composite slab. During the test conducted, end-span interface slip, mid-span deflection and concrete strains were recorded simultaneously. Following the full scale test, a parametrical equation was proposed in this study to determine the interface shear strength using SFRC as concrete topping.

1.5 Importance of Study

This study conducted to determine the suitability of SFRC as a replacement to the conventional reinforced concrete as concrete topping. An appropriate bonding and interface shear strength can reduce maximum deflection and at the same time increase the loading capacity of SFRC composite slab. The success of this research can reduce labour cost and time in the construction of precast building structure.

1.6 Thesis Structure

The thesis structure presents an outline of all contents as listed below:

a) Chapter 1 described an introduction throughout the study conducted.
b) Chapter 2 described a review of the literature convincing the objectives of the study.
c) Chapter 3 clarifies the samples of SFRC specimens and composite slabs preparation as well as experimental setup for testing combined bending and shear test.
d) Chapter 4 interprets the experimental results.
e) Chapter 5 presents analysis and discussion of the results.
f) Chapter 6 concludes the thesis contents with several conclusions and recommendation for further investigation in the future.

REFERENCES

1. Oh Teck Yee. *The Effect of Surface Roughness and Curing Condition on The Ultimate Shear Capacity of Composite Slab*. Master Thesis. Universiti Teknologi Malaysia; 2009.

2. Arnon Bentur & Sidney Mindess. *Fibre Reinforced Cementitious Composites.* Elsevier Science Publishers Ltd. 1990.

3. Ali R. Khaloo & Majid Afshari. Cement & Concrete Composites. *Flexure Behaviour of Small Steel Fibre Reinforced Concrete Slabs*. 2005. 27 (1): 141-149.

4. B. W. Xu & H. S. Shi. Construction and Building Materials. *Correlations among Mechanical Properties of Steel Fiber Reinforced Concrete.* 2009. 23 (12): 3468-3474.

5. British Standard Institution. *Structural Use of Concrete, Part 1: Code of Practice for Design and Construction*. London, BS 8110. 1997.

6. Kim S. Elliot. *Precast Concrete Structures.* Jordan Hill, Oxford: Elsevier Butterworth-Heinemann. 2002.

7. European Committee for Standardization. *Eurocode 2: Design of Concrete Structures – Part 1: General Rules and Rules for Building.* London, BS EN 1992-1-1. 2004.

8. British Standard Institution. *Assessment of Surface Texture, Part 1: Methods and Instrumentation.* London, BS 1134. 1988.

9. Mitchell Gohnert. Cement & Concrete Composites. *Horizontal Shear Transfer Across a Roughened Surface.* 2003. 25 (3): 379-385.

10. British Standard Institution. *Testing Hardened Concrete, Part 3: Compressive of Test Specimens.* London, BS EN 12390. 2009.

11. Ulf Arne Girhammar and Matti Pajari. Construction and Building Materials. *Test and Analysis on Shear Strength of Composite Slabs of Hollow Core Units and Concrete Topping*. 2008. 22 (8): 1708-1722.

12. Mitchell Gohnert. Cement & Concrete Composites. *Proposed Theory to Determine the Horizontal Shear Between Composite Precast and In Situ Concrete*. 2000. 22 (6): 469-476.

13. Jeffery R. Roesler, David A. Lange, Salah A. Altoubat, Klaus-Alexander Rieder and Gregory R. Ulreich. Journal of Materials in Civil Engineering. *Fracture of Plain and Fibre-Reinforced Concrete Slabs Under Monotonic Loading*. 2004.16 (5): 452-460.

14. Federation Internationale de la Precontrainte (FIP). *FIP Guide to Good Practice - Shear at the Interface of Precast and In-situ Concrete*. Wrexham Springs. 1982.

15. H. Beushausen and M.G. Alexander. Magazine of Concrete Research. *Bond Strength Development Between Concretes of Different Ages*. 2008. 60 (1): 65-74.

16. Fatih Altun, Tefaruk Haktanir, Kamura Ari. Construction and Building Materials. *Effects of Steel Fiber Addition on Mechanical Properties of Concrete and RC Beams*. 2007. 21 (3): 654-661.

17. RILEM TC162-TDF. *Test and Design Methods for Steel Fibre Reinforced Concrete: σ-ε Design Method.* Mater Struct: 2000; 33 (March): 75-81.

18. RILEM TC162-TDF. *Test and Design Methods for Steel Fibre Reinforced Concrete: Bending Test.* Mater Struct: 2000; 33 (January-February): 3-5.

19. D C Teychenné, R E Franklin, H C Erntroy. *Design of Normal Concrete Mixes.* Department of the Environment. HMSO. 1988.

20. British Standard Institution. *Testing Hardened Concrete, Part 6: Tensile Splitting Strength of Test Specimens.* London, BS EN 12390. 2009.

21. British Standard Institution. *Testing Concrete, Part 121: Method for Determination of Static Modulus of Elasticity in Compression.* London, BS 1881. 1983.

22. British Standard Institution. *Testing Hardened Concrete, Part 5: Flexural Strength of Test Specimens.* London, BS EN 12390. 2009.

23. Z. L. Wang, J. Wu and J.G. Wang. *Experimental and Numerical Analysis on Effect of Fibre Aspect Ratio on Mechanical Properties of SFRC.* Construction and Building Materials. 2010. 24 (4): 559-565.

24. Ibrahim I.S., Elliott K.S. and Copeland S. *Bending Capacity of Precast Prestressed Hollow Core Slabs with Concrete Topping.* Malaysian Journal of Civil Engineering. 2009. 20 (2): 260-283.

25. Hibbeler R.C. *Mechanics of Materials.* Sixth Edition. Prentice Hall Inc. 2005.

26. Ariffin R. *Allowable Interface Slip of Composite Slab to Achieve Full Interactive Behaviour*. Master Thesis. Universiti Teknologi Malaysia. 2009.