

THE MECHANICAL PROPERTIES AND STRUCTURAL PERFORMANCE OF  
HYBRID FIBRE REINFORCED CONCRETE COMPOSITE

FAEZAH ASMAHANI BINTI OTHMAN

A thesis submitted in fulfillment of the  
requirements for the award of the degree of  
Master of Engineering (Structure and Material)

Faculty of Civil Engineering  
Universiti Teknologi Malaysia

AUGUST 2014

*...Dedicated to...*

*My beloved Father and Mother*

*Othman Bin Che Mat and Che Wan Asma' Binti Khalid*

*My Brothers and Sisters*

*Thank You from the Bottom of My Heart for Being My*

*Inspirations..*

*My Supervisor*

*Dr. Izni Syahrizal Ibrahim*

*For Being Patient and Give Me A Lot of Knowledge*

*And Lastly To All My Dear Friends*

*Thank You for Supporting Me.*

## ACKNOWLEDGEMENT

All praise is to Allah the all Mighty and peace is upon the holy Prophet Muhammad S.A.W.

Herewith,

I would like to lay a special tribute and profound gratitude to my supervisor, Dr. Izni Syahrizal Bin Ibrahim upon his profoundly guidance, support, and advice throughout the period of my study. He contributes constructive suggestions since early stage, valuable feedback till I successfully reached the final stage of my course.

I too, wished to pronounce my deepest gratitude to the staffs of the Structure and Materials Laboratory. Their sincere help and generosity by sharing experience and knowledge have helped me a lot in completing my project. Last but not least, I wished to thank my beloved family for their steadfast love and undivided support. Wassalam.

## ABSTRACT

Fibres in concrete provide a mean of preventing crack growth. Short discontinuous fibres have the advantage of being uniformly mixed and dispersed throughout the concrete. In this research, the mechanical properties of hybrid fibre reinforced concrete composite (HyFRCC) were investigated by combining polypropylene fibre (PP) with steel fibre (ST). PP fibre is good in preventing micro cracks while steel fibre is reliable in preventing macro cracks in concrete. Specimens incorporated with ST and PP fibres were in the mix proportion of 100-0%, 75-25%, 50-50%, 25-75%, and 0-100% at volume fraction of 0.5%, 1.0%, and 1.5%. Compression test, flexural test, splitting tensile test, flexural toughness, and Young's Modulus were carried out to determine the mechanical properties of HyFRCC. By combining these two fibres in concrete, the crack growth reduced where PP fibre was found to improve the tensile strain capacity, while ST fibre contributed to the improvement on the ultimate tensile strength. HyFRCC specimens also delayed the failure phenomena due to the different tensile strength of PP and ST fibres compared with the sudden failure experienced by plain concrete. The experimental test results found that HyFRCC with the combined mix proportion of 75% ST fibre + 25% PP fibre at volume fraction of 1.5% can be adjudged as the optimum percentage. This optimum percentage was then applied in reinforced concrete beams to study the structural performance in flexural of shear. In conclusion, HyFRCC beam is tougher and stronger compared with the control beam based on the load-deflection relationship. Crack pattern of HyFRCC beam shows that the crack width and crack spacing reduces compared with the control beam. The effect of combining ST and PP fibres in concrete enhances the tensile strength, the concrete strain hardening and flexural toughness.

## ABSTRAK

Gentian di dalam konkrit menyediakan pencegahan pertumbuhan retak. Gentian pendek tidak berterusan mempunyai kelebihan keseragaman bercampur dan tersebar di seluruh konkrit. Dalam kajian ini, sifat mekanikal gentian hibrid komposit konkrit bertetulang (HyFRCC) dikaji dengan menggabungkan gentian polypropylene (PP) dan keluli (ST). Gentian PP bagus dalam mencegah keretakan mikro manakala gentian ST dipercayai dalam mencegah keretakan makro di dalam konkrit. Spesimen digabungkan dengan gentian ST dan PP pada kadar campuran daripada 100-0%, 75-25%, 50-50%, 25-75%, dan 0-100% pada pecahan isipadu sebanyak 0.5%, 1.0%, dan 1.5 %. Ujian mampatan, ujian lenturan, ujian tegangan, kekuatan lenturan, dan Modulus Young dijalankan untuk menentukan sifat-sifat mekanik HyFRCC. Dengan menggabungkan kedua-dua gentian dalam konkrit, pertumbuhan retak berkurangan di mana gentian PP didapati meningkatkan keupayaan terikan tegangan, manakala gentian ST menyumbang kepada peningkatan kekuatan tegangan muktamad. Spesimen HyFRCC juga melambatkan fenomena kegagalan disebabkan kekuatan tegangan yang berbeza gentian PP dan ST berbanding dengan kegagalan secara tiba-tiba yang dialami oleh konkrit biasa. Keputusan ujian eksperimen mendapati HyFRCC dengan nisbah campuran gabungan 75% ST + 25% PP pada pecahan isipadu sebanyak 1.5% boleh diputuskan sebagai peratusan optimum. Peratusan optimum ini kemudiannya diaplikasikan pada rasuk konkrit bertetulang untuk mengkaji prestasi struktur dalam lenturan dan ricih. Kesimpulannya, rasuk HyFRCC adalah lebih tahan lasak dan lebih kuat berbanding dengan rasuk kawalan berdasarkan hubungan beban-lenturan. Corak retak rasuk HyFRCC menunjukkan lebar dan jarak retak berkurangan berbanding rasuk kawalan. Kesan daripada penggabungan gentian ST dan PP di dalam konkrit meningkatkan kekuatan tegangan, pengerasan terikan konkrit dan kekuatan lenturan.

## TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	<b>DECLARATION</b>	ii
	<b>DEDICATION</b>	iii
	<b>ACKNOWLEDGEMENTS</b>	iv
	<b>ABSTRACT</b>	v
	<b>ABSTRAK</b>	vi
	<b>TABLE OF CONTENTS</b>	vii
	<b>LIST OF TABLES</b>	xii
	<b>LIST OF FIGURES</b>	xiv
	<b>LIST OF ABBREVIATIONS</b>	xix
	<b>LIST OF SYMBOLS</b>	xxi
<b>1</b>	<b>INTRODUCTION</b>	1
	1.1 Background	1
	1.2 Problem Statement	4
	1.3 Objectives of the Research	7
	1.4 Scope of Study	7
	1.5 Significance of Study	8
	1.6 Thesis Organisation	9
<b>2</b>	<b>LITERATURE REVIEW</b>	10
	2.1 General	10
	2.2 Steel Fibre	14
	2.2.1 Steel Fibre Reinforced Concrete	18

	2.2.2	Mechanical Properties of Steel Fibre Concrete at Fresh and Hardened State	20
	2.2.2.1	Compressive Strength	23
	2.2.2.2	Flexural Strength	24
	2.2.2.3	Load-deflection Relationship	25
	2.3	Polypropylene Fibre	27
	2.3.1	Mechanical Properties of Polypropylene Fibre Concrete at Fresh and Hardened State	29
	2.3.1.2	Compressive Strength	30
	2.3.1.3	Flexural Strength and Tensile Strength	31
	2.3.1.4	Toughness	32
	2.4	Steel-Polypropylene Hybrid Fibre Reinforced Composite Concrete	33
	2.5	Hybrid Fibre Reinforced Composite Concrete in Beam	36
	2.6	Summary	40
<b>3</b>		<b>METHODOLOGY</b>	41
	3.1	Introduction	41
	3.2	Materials	43
	3.2.1	Steel Fibre	43
	3.2.2	Polypropylene Fibre	47
	3.2.3	Cement	49
	3.2.4	Coarse Aggregate	50
	3.2.5	Fine Aggregate	51
	3.2.6	Water	53
	3.2.7	Superplasticizer	54
	3.3	Mould Preparation	55

3.4	Mixing Process	56
3.5	Compaction Process	57
3.6	Concrete Curing	58
3.7	Tests on Fresh Concrete	60
	3.7.1 Slump Test	60
3.8	Tests for Hardened Concrete	61
	3.8.1 Compression Test	61
	3.8.2 Flexural Tensile Test	63
	3.8.3 Splitting Tensile Test	64
	3.8.4 Toughness Test on Prism Specimen	65
	3.8.5 Young's Modulus Test	69
3.9	Bending Test on Hybrid Fibre Reinforced Composite Concrete Beam	72
	3.9.1 Materials Preparation	73
	3.9.2 Strain Gauge Installation on the Reinforcement Steel Bar	74
	3.9.3 Demec Disc Installation	76
	3.9.4 Flexural Test on Beam Specimen	79
	3.9.5 Concrete Strain Measurement	81
	3.9.6 Crack Width Measurement	82
3.10	Summary	83

## 4

	<b>RESULTS AND DISCUSSIONS ON THE MECHANICAL PROPERTIES OF HyFRCC</b>	85
4.1	Introduction	85
4.2	Density and Slump Results	86
4.3	Compressive Strength Results	90
	4.3.1 Crack Pattern on Cube Specimen	93
4.4	Flexural Test Results	94
	4.4.1 Crack Pattern on Prism Specimen	97
4.5	Tensile Strength Results	99



	4.5.1	Crack Pattern on Cylinder Specimen	102
	4.6	Toughness Results	103
	4.6.1	Crack Pattern on Prism Samples for the Toughness Test	110
	4.7	Young's Modulus Results	111
	4.7.1	Crack Pattern on Cylinder Samples under Young's Modulus Test	114
	4.8	Discussion on the Optimum Percentage of Fibre Determination	115
	4.9	Summary	118
<b>5</b>		<b>RESULTS AND DISCUSSION ON HyFRCC BEAM</b>	119
	5.1	Introduction	119
	5.2	Density Test Results	120
	5.3	Compressive Strength and Concrete Slump Results	121
	5.4	Flexural Toughness Beam Test Results	123
	5.5	Crack Width Results of the Beam Specimen	126
	5.6	Loads and Steel Reinforcement Strain Relationship	128
	5.7	Loads against Strain for Concrete Results	130
	5.8	Strain Distribution Diagram	131
	5.9	Summary	133
<b>6</b>		<b>CONCLUSION AND RECOMMENDATION</b>	134
	6.1	Conclusion	134
	6.2	Recommendation for Future Work	137

<b>REFERENCES</b>	139
Appendix A (Results on Density Test for ST Fibre)	144
Appendix B (Mix Design (DoE) Method)	145
Appendix C (Results on Density Test for PP Fibre)	146
Appendix D (Sieve Analysis Results)	147
Appendix E (Beam Design)	148

## LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Effects of different fibres on concrete properties	11
2.2	Properties of steel fibre	15
2.3	Properties of hooked-ends ST fibre	22
2.4	Properties of polypropylene fibre	27
3.1	Volume fraction of fibre	42
3.2	Mix design for the concrete batches	46
3.3	Material proportion for the beam specimen	73
4.1	Concrete slump and density results of the cube	
	Specimen	87
4.2	Compressive strength results	91
4.3	Flexural strength test results	95
4.4	Tensile strength results at 28 days	100
4.5	Average tensile strength for single ST and PP fibre	
	at every total volume fraction, $V_f$	101
4.6	Results of the toughness test on toughness indices	105
4.7	The Modulus of Elasticity for all concrete batches	
	at 28 days	112
5.1	Density results for the concrete beam specimens	120
5.2	Concrete slump and compressive strength results	122
5.3	Toughness indices for beam samples	125
5.4	Crack width of the beam specimen at the selected	
	load	126

5.5

Crack width at ultimate load

128

## LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.1	Polypropylene fibre	2
1.2	Industrialised steel fibre	3
1.3	Crack on slab	5
2.1	(a) 30 mm length hooked-end ST fibre (b) 12 mm length non-metallic recron'3s fibre	12
2.2	Cracking pattern and failure mechanism for: (a) plain concrete, (b) polypropylene fibre concrete, and (c) Steel fibre concrete	13
2.3	Type and shape of steel fibre	15
2.4	Steel fibre with 60 mm length	16
2.5	Bundled of steel fibre	17
2.6	Single fibre when in contact with water	17
2.7	Fibre reinforced concrete aircraft parking	19
2.8	Tunnel lining process	20
2.9	Fibre "balling effect" in concrete	21
2.10	Effect of fibre content on workability	22
2.11	Slump test results	23
2.12	Effect of fibre content on the compressive strength	24
2.13	Flexural strength relationship	25
2.14	Load-deflection curves with different volume fraction (A) hooked-ends ST fibre (B) waved ST fibre	26
2.15	Polypropylene fibre (Mega Mesh II)	27

2.16	Length measurement of PP fibre	28
2.17	Effects of PP fibre volume fraction on slump	30
2.18	Effect of different of PP fibre length on compressive strength, $f_{cu}$ at $V_f = 0.4\%$	31
2.19	(a) Flexural strength (b) split tensile strength at different volume fraction, $V_f$	32
2.20	Typical stress –strain curves for fibre reinforced concrete	33
2.21	Ductility index	39
3.1	Steel fibre	43
3.2	(a) Balance setup for density test (b) Holder for non-floating solids	44
3.3	(a) Weight of solid in air (b) Weight of solid in liquid	45
3.4	Polypropylene (PP) fibre	47
3.5	Rolled cotton ball PP fibre for the density test	47
3.6	(a) Weight of PP fibre in air (b) Weight of PP fibre in liquid	48
3.7	Ordinary Portland cement	49
3.8	Drying process of coarse aggregate	50
3.9	Drying process of fine aggregate	51
3.10	Sieve shaker for the sieve analysis	52
3.11	Water used in mixing	53
3.12	Superplasticizer as water reducing agent	54
3.13	Mould preparation before casting is carried out	56
3.14	Drum mixer used in the mixing process	57
3.15	Poker vibrator used for the compaction work	58
3.16	Concrete curing process	59
3.17	Wet gunny sacks used for curing for the beam specimens	59
3.18	Slump test equipment and measuring technique	60
3.19	Compression test on cube sample	62
3.20	Weighing scale used to weigh the cube sample	62
3.21	Flexural test on the prism specimen	63
3.22	Splitting test on the cylinder specimen	64

3.23	Toughness test equipment	65
3.24	Schematic diagram toughness test setup	66
3.25	Example of parameter calculations when (a) peak load equal to first-peak load (b) peak load is greater than first-peak load	68
3.26	Compression test on cylinder sample	70
3.27	Installation of the strain gauges on the cylinder specimen	71
3.28	Concrete strain gauges used in the Young's Modulus test	71
3.29	Cyanoacrylate (CN) adhesive used to glue the strain gauges	72
3.30	Reinforcement arrangement in the beam specimen	74
3.31	Steel strain gauges used in the research	75
3.32	(a) Coating material (b) Bitumen sealant to cover the strain gauge from being in contact with water	75
3.33	Installation of strain gauges on the steel reinforcement bar	76
3.34	(a) Position of Demec discs, and (b) measurement of Demec disc installation, in mm	77
3.35	Calibration bar to maintain a 150 mm distance between the Demec discs	78
3.36	Rapid setting time epoxy adhesive	78
3.37	Flexural beam test set up	79
3.38	LVDTs position, equipments and illustration of the test setup	80
3.39	Reference bar	81
3.40	Strain meter to measure the displacement between the two Demec discs	82
3.41	Crack meter device to measure crack width	82
3.42	Summary flow chart of the research methodology	84
4.1	The relationship between concrete density and fibre mix Proportion at (a) 3 days, (b) 7 days, and (c) 28 days	88
4.1	(Continued) The relationship between concrete density and fibre mix proportion at (a) 3 days, (b) 7 days, and (c) 28 days	89
4.2	Relationship between concrete slump and fibre mix	

	proportion	90
4.3	Compressive strength relationship on cube specimens (a) 3 days, (b) 7 days, and (c) 28 days	92
4.4	Cracking pattern of the cube specimens for every HyFRCC batches	93
4.4	(Continued) Cracking pattern of the cube specimens for every HyFRCC batches	94
4.5	Flexural strength relationships of the prism specimens at (a) 7 days (b) 28 days	96
4.6	Honeycomb occurred on the prism sample for (0 ST – 100 PP) fibre at $V_f = 1.5\%$	97
4.7	Crack pattern of the prism specimen at failure	98
4.8	ST and PP fibre bridge the crack growth to avoid sudden failure of the prism specimen	99
4.9	Tensile strength relationships of the cylinder specimens	100
4.10	Crack pattern of the cylinder specimen at failure during the splitting test	102
4.10	(Continued) Crack pattern of the cylinder specimen at failure during the splitting test	103
4.11	Load against deflection relationship for all specimens	106
4.11	(Continued) Load against deflection relationship for all Specimens	107
4.12	Toughness value at $T_{150}$	108
4.13	Toughness value at $T_{600}$	109
4.14	Crack pattern on prism samples under the toughness test	110
4.14	(Continued) Crack pattern on prism samples under the toughness test	111
4.15	Stress–strain relationship	112
4.16	The relationship between the Modulus of Elasticity and the fibre mix proportion	113
4.17	Crack pattern on the cylinder specimens at failure	114



4.17	(Continued) Crack pattern on the cylinder specimens at failure	115
4.18	Combination of load-deflection relationship under toughness test	116
4.19	Combination of flexural and tensile strengths relationship at $V_f = 1.5\%$	117
4.20	Modulus of Elasticity and fibre mix proportion relationship at $V_f = 1.5\%$	118
5.1	Relationship between density and the percentage of mix proportion of the beam specimens	121
5.2	The relationship between the concrete slump and the percentage of mix proportion of the beam specimens	122
5.3	Compressive strength relationship of the beam specimens	123
5.4	Load-deflection relationship of the beam specimen	124
5.5	Crack pattern of the beam specimens	127
5.6	Relationship between load and steel strain	129
5.7	Relationship between load and concrete strain	131
5.8	Strain distribution diagram	132

**LIST OF ABBREVIATIONS**

ACI	-	American Concrete Institute
ASTM	-	American Society for Testing and Materials
BMD	-	Bending Moment Diagram
BS	-	British Standard
C-S-H gel	-	Calcium Silicate Hydrate
CN	-	Cyanoacrylate
DoE	-	Department of Environment
EN	-	European Standard
FBD	-	Free Body Diagram
FRC	-	Fibre Reinforced Concrete
GFRP	-	Glass Fibre Reinforced Polymer
HyFRCC	-	Hybrid Fibre Reinforced Composite Concrete
ISO	-	International Organization for Standardization
LVDT	-	Linear Variable Displacement Transducer
MOE	-	Modulus of Elasticity
MOR	-	Modulus of Rupture
N.A	-	Neutral Axis
OPC	-	Ordinary Portland Cement
PE	-	Polyethylene
PP	-	Polypropylene
prEN	-	Draft for European Standard
RC	-	Reinforced Concrete
SFD	-	Shear Force Diagram
SFRS	-	Steel Fibre Reinforced Shortcrete

SP - Superplasticizer  
ST - Steel

## LIST OF SYMBOLS

$A$	-	Weight of the solid in air
$A_a$	-	Area of Tension Reinforcement
$a_v$	-	Distance From Support To Load
$B$	-	Weight of the solid in the distilled water
$b$	-	Width of Section Average/ Width of The Specimen at The Fracture
$d$	-	Effective Depth/ Average Depth of The Specimen at The Fracture
$D, \emptyset$	-	Diameter
$E$	-	Modulus of Elasticity
$F_{cc}$	-	Internal Force From Concrete
$F_{st}$	-	Internal Force From Steel
$f_{600}$	-	Flexural Strength at 1/600
$f_{150}$	-	Flexural Strength at 1/150
$f_{ck}$	-	Characteristic Strength of Concrete
$f_{cu}$	-	Compressive Strength
$f_{ct}$	-	Tensile Strength
$f_t$	-	Flexural Strength
$f_{yk}$	-	Characteristic Strength of Steel
$h$	-	Overall Depth
$L$	-	Span Length
$l/d$	-	Aspect ratio
$M$	-	Moment of Resistance
$P, V$	-	Applied Load
$P_{600}$	-	Load at 1/600

$P_{150}$	-	Load at 1/150
$P_1$	-	First-peak Load
$P_p$	-	Peak Load
$S$	-	Ultimate Stress
$s$	-	Depth of Stress Block/ Spacing
$T_{600}$	-	Toughness at 1/600
$T_{150}$	-	Toughness at 1/150
$V_{Ed}$	-	Design Shear Force
$V_{Ed, Max}$	-	Concrete Strut Capacity
$V_f$	-	Volume Fraction
$V_{min}$	-	Shear Resistance of Minimum Links
$x$	-	Depth of Stress Block
$z$	-	Lever Arm
$\rho$	-	Density of solid
$\rho_o$	-	Density of the distilled water at the given temperature
$\theta$	-	Angle

**LIST OF APPENDICES**

<b>APPENDIX</b>	<b>TITLE</b>	<b>PAGE</b>
A	Results on Density Test for ST Fibre	144
B	Results on Density Test for PP Fibre	145
C	Sieve Analysis Results	146
D	Mix Design (DoE Method)	147
E	Beam Design	148

## **CHAPTER 1**

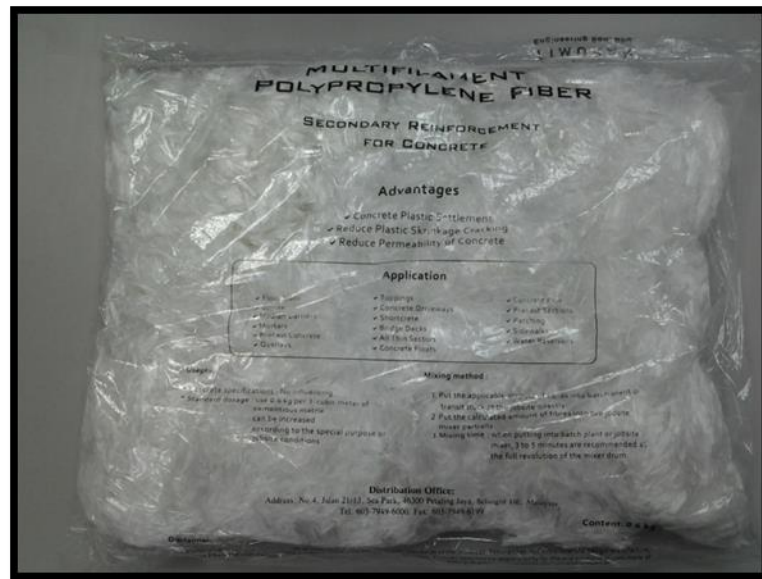
### **INTRODUCTION**

#### **1.1 Background**

Fibres in concrete provide a medium of arresting crack growth. Short discontinuous fibre have the advantage of being uniformly mixed and dispersed in concrete. According to Parameswaran (1991), composites reinforced with steel, polypropylene and natural fibres have a wider social development to country with low-cost and low-energy construction. Nowadays, the application of fibre in structure components has spread widely throughout the world especially for single fibre. Furthermore, when mixing fibres in plain concrete, it needs to be done properly to avoid failure in the structure components. In order to produce better concrete and to overcome some weaknesses of single fibre in concrete, hybrid fibre is introduced in this study.

This research will explore the potential for achieving balanced improvements in the performance characteristics of composite concrete materials by combining different types of fibre. This combination is known as hybrid fibre. Such efforts can potentially lead to the development of fibrous composite concrete that will provide superior performance under severe loading and environmental effects at a reasonable cost. In this

research, polypropylene (PP) fibre (Figure 1.1) is combined with steel (ST) fibre (Figure 1.2) and mix in concrete with various volume fractions. The study is to observe the macro and micro cracking growth development. Application to structural elements such as beam and slab should be able to reduce crack growth and provide additional resistance to the tensile and flexural strengths.



**Figure 1.1:** Polypropylene fibre





**Figure 1.2:** Industrialised steel fibre

The use of PP fibre as a reinforcing medium can only be made in cement matrices. Their natural abundance, wide range and type of fibres, immeasurable source and relative cheapness point to the direction of their development for housing and many related construction. However, their inherent weaknesses such as low Elastic Modulus, high water absorption and low fire resistance contributed to their relatively poor performance for workability and durability (Sharma, 2013). Therefore, it is necessary to carry out development work by mixing together with ST fibre with regards to the choice of fibres and fabrication process. While for ST fibre, it is known to increase the flexural and tensile strengths of the concrete. The wide used of ST fibre concrete in construction has proved its ability in improving the brittle failure of the concrete. ST fibre has higher tensile strength compared to PP fibre. Therefore, the combination of high and low tensile strength of the fibre is used in this study.

Hybrid fibre reinforced composite concrete can be applied in slab, beam, and also column. In this study, application to the structural beam is selected. This is because concrete is good in compression but weak in tension. Therefore, the application in

structural beam will study in detailed the fibre effects in both compression and tension zones. This will be done after obtaining the optimum percentage for hybrid fibre reinforced composite concrete, it will be applied in the structural beam.

Mostly, the application of fibre is established on ground slab and road pavement. However, they are also applied on structural beam and column for its function and reaction in concrete to resist tensile stress. Application of fibre in the infrastructure work is widely used in the airport zone because of the heavy loading capacity. Besides that, fibre is also applied in tunnel construction for its segmental lining.

## **1.2 Problem Statement**

Concrete due to its brittle behaviour has little ability to resist tensile stress and strain. Therefore, discontinuous fibres are added in concrete to improve energy absorption capacity and cracking resistance (Singh et. al., 2010).

Plain concrete is known to have a brittle behaviour with lower flexural strength and tensile strength. To improve the behaviour, fibre reinforced concrete is introduced which is by adding single type of fibre in concrete. There are many types of fibre available in the market such as steel, glass and even natural. Recycled steel fibres are also an alternative where they can be obtained from used tyres.

Hybrid fibre reinforced composite concrete is introduced in this study. By having two or more types of fibre and mixed in concrete can increase the flexural and tensile

strength than the one with single fibre. Furthermore, the presence of fibres in concrete bridged the crack growth thus increase the ultimate loading capacity of the structural elements.

Figure 1.3 shows crack occurred on ground slab at precast yard, Ulu Tiram, Johor Bahru where monofilament polypropylene fibre is applied in the slab. The figure shows cracking occurred because of the single fibre application in the slab which can only prevent micro cracking. In an open wide surface area, concrete experiencing rapid loss of water, thus hydration process cannot take place completely. Expansion and contraction process of the concrete occurred too fast and produce long crack across the slab. Therefore, additional bonding constituent is needed to bond the concrete particles to control the expansion and contraction process and then to overcome crack problem. The tiny cracks need to be prevented at the early stage of concrete setting to avoid additional tiny cracks to further developed into large crack.



**Figure 1.3:** Crack on slab

Therefore, in this study ST fibre is combined with PP fibre and mixed in concrete. Each fibre have their own characteristic in order to improve the strength. Plain concrete experienced sudden failure at ultimate load. For HyFRCC the failure development is in the sequence of exceeding the limit of the PP fibre, followed by pull-out of ST fibre before the concrete fails.

In this study, both hybrid combination methods are considered to produce a better concrete. The used of stronger, stiffer, and long ST fibre with 60 mm length is to prevent macro crack and absorb more energy before the concrete fails, while flexible and short PP fibre with 12 mm length will improve toughness by bridging micro cracking. Positive responses produced by this two combination will increase flexural strength of the concrete.

According to A. Bentur et al. (1990) and G. Xu et al. (1998), there are two methods to combine two types of fibres in concrete. The first method is based on fibre constitutive response. One type of fibre is stronger, stiffer, and provides reasonable first crack strength and ultimate strength, while the second type of fibre is relatively flexible and leads to improve toughness and strain capacity in the post-crack zone. The second method is hybrid combination based on fibre dimension. One type of fibre is smaller, so that it bridge micro cracking and therefore control the growth and delays coalescence. This leads to higher tensile strength of the material. The second fibre is larger and is intended to arrest the propagation of macro cracks and therefore results in a substantial improvement in the fracture toughness of the material.

### **1.3 Objectives of the Research**

This study embarks on the following objectives:

- 1) To investigate the mechanical properties of hybrid fibre reinforced composite concrete at fresh and hardened state.
- 2) To investigate the toughness and ductility response of hybrid fibre reinforced composite concrete.
- 3) To determine the optimum percentage of volume fractions of hybrid fibre reinforced composite concrete.
- 4) To investigate the effect of hybrid fibres on the flexural performance of concrete beams.

### **1.4 Scope of Study**

To achieve the objective of the study, experimental work is carried out in three stages. In the first stage, the mechanical properties of both steel (ST) and polypropylene (PP) fibres is justified by carrying out tensile and density test. Mega Mesh II type polypropylene fibre and group 1- cold drawn wire, hooked end steel fibre are used in this research. Both fibres are supplied by Timuran Engineering Sdn. Bhd. The concrete strength is fixed at 30 N/mm<sup>2</sup>. The second stage of the reseach is to justify the mechanical properties of hybrid fibre reinforced composite concrete (HyFRCC). To

achieve the objectives of the study, compression, flexural, tensile splitting, toughness, and Young's Modulus test of HyFRCC are carried out. The volume fraction,  $V_f$  are taken as 0.5%, 1.0%, and 1.5%. For every volume fraction, the ST-PP fibre mix proportion by volume in percentage are varied for 100-0, 75-25, 50-50, 25-75, and 0-100. For compression test, cube with dimensions of  $150 \times 150 \times 150$  mm is used. Prism with dimensions of  $100 \times 100 \times 500$  mm is used for the flexural test where as prism with dimensions of  $100 \times 100 \times 350$  mm is used for the toughness test. Cylinder with dimensions of 150 mm diameter  $\times$  300 mm high is used for the Young's Modulus and tensile splitting test. The specimens are tested at 3, 7, and 28 days. Therefore, for every concrete batch, 9 cubes, 6 prisms with size of  $100 \times 100 \times 500$  mm, 3 prisms with size of  $100 \times 100 \times 350$  mm, and 5 cylinders are prepared. All together, 16 batches of HyFRCC are produced including 1 batch of plain concrete as control. The final stage of the research is applying the optimum percentage proportion of ST-PP fibre obtained from the second stage work in 150 mm wide  $\times$  200 mm high  $\times$  2200 mm long beam. All beams undergone flexural testing to investigate the structural performance for its deflection, strain pattern and failure mode.

### **1.5 Significance of Study**

The significant of the study is to improve the existing fibre reinforced concrete properties by mixing PP together with ST fibre in concrete. In the structural field, PP fibre is used in mortar while ST fibre is widely used in concrete. Also in this study, the optimum percentage of volume fraction of HyFRCC that is suitable for industrial purposes is justified so that it can be widely used in Malaysia. PP fibre in concrete will help to delay micro cracks while steel fibre delays the macro cracks. Theoretically, combining both fibres in concrete will enhance the concrete strength compared with single fibre alone or even the plain ones.

Combination of two types of fibre can enhance the flexural strength of the concrete. Good combination of different type, size, and length of the fibres which is ST and PP fibre, can increase the flexural strength and improve the durability of the concrete. Both fibres must be uniformly mixed throughout the concrete and randomly oriented to make sure that they are well functional as bridging elements in delaying crack growth and automatically enhance the flexural strength of the beam.

## **1.6 Thesis Organisation**

This thesis will discuss on mechanical properties of HyFRCC and its structural performance. Background of the study, problem statement, objectives, scope and significance of study are discussed in Chapter 1. Some literature reviews from previous study on PP fibre concrete, ST fibre concrete, and HyFRCC are discussed in detailed in Chapter 2. Various combination of different fibre type and dimension are used by previous researchers and this is highlighted in this chapter. Chapter 3 discussed on methodology of the study by experimental work. Sample calculation on hybrid fibre used, the amount of volume fractions and materials compositions and the laboratory tests conducted to determine the mechanical properties of HyFRCC are also discussed. The beam test method is also discussed in this chapter to study the flexural performance. Chapter 4 revealed the test results together with the discussions on the mechanical properties of HyFRCC to determine the optimum percentage of volume fraction to be applied in the structural beam. Meanwhile, Chapter 5 revealed the test results and discussions on the fibre reinforced structural beam together with the comparison with the control beam. The structural performance of the beams are then investigated for its deflection, strain pattern and failure mode. Lastly, Chapter 6 discussed the conclusions of the study and recommendations for future works are also given in this chapter.

## REFERENCES

- Acikgenc, M., Alyamac, K. E., & Ulucan, Z. C. (2013). Fresh and Hardened Properties of Steel Fiber Reinforced Concrete Produced with Fibers of Different Lengths and Diameters. Pp 23–25.
- Ahmed, S. F. U., Maalej, M., & Paramasivam, P. (2007). Flexural Responses of Hybrid Steel–Polyethylene Fiber Reinforced Cement Composites Containing High Volume Fly Ash. *Construction and Building Materials*. 21(5): Pp 1088–1097.
- Ahmed, S. F. U., & Maalej, M. (2009). Tensile Strain Hardening Behaviour of Hybrid Steel-Polyethylene Fibre Reinforced Cementitious Composites. *Construction and Building Materials*. 23: Pp 96 – 106.
- American Society for Testing and Materials (2012). C 1609/C 1609M. American: American Concrete Institute Committee. Standard Test Method for Flexural Performance of Fibre Reinforced Concrete (Using Beam With Third-Point Loading).
- American Concrete Institute Committee (2009). ACI 544.4R-88. American: American Concrete Institute Committee.
- American Society for Testing and Materials (2008). C 1609/C 1609M. American: American Concrete Institute Committee. Standard Test Method for Flexural Performance of Fibre Reinforced Concrete (Using Beam With Third-Point Loading).
- American Society for Testing Method and Material (2008). D3289. American: American Concrete Institute Committee. Standard Test Method for Density of Semi-Solid and Solid Bituminous Materilas (Nickel Crucible Method).
- American Society for Testing and Materials (1992). C 1018/C 1018M. American: American Society for Testing and Materials. Standard Test Method for Flexural Performance of Fibre Reinforced Concrete (Using Beam With Third-Point Loading).



- Banthia, N., & Gupta, R. (2004). Hybrid Fiber Reinforced Concrete (HyFRC): Fiber Synergy in High Strength Matrices. *Materials and Structures* 37(10): Pp 707–716.
- Banthia N., & Nandakumar, N. (2003). Crack Growth Resistance of Hybrid Fiber Reinforced Cement Composites. *Cement and Concrete Composite*. 25: Pp 3-9.
- Bentur, A., & Mindess, S. (1990). Fiber Reinforced Cementitious Composites. Elsevier Applied Science, London.
- Behbahani, H. P. (1985). Flexural Behaviour of Steel Fiber Reinforced Concrete Beams. M.Sc. Thesis. Universiti Teknologi Malaysia, Skudai.
- British Standards Institution (2000). BS EN 12350-2. London: British Standards Institution. Testing Fresh Concrete - Part 2: Slump Test.
- British Standards Institution (2009). BS EN 12390-3. London: British Standards Institution. Testing Hardened Concrete - Part 3: Compressive Strength of Test Specimens.
- British Standards Institution (2009). BS EN 12390-5. London: British Standards Institution. Testing Hardened Concrete - Part 5: Flexural Strength of Test Specimens.
- British Standards Institution (2009). BS EN 12390-6. London: British Standards Institution. Testing Hardened Concrete - Part 6: Tensile Splitting Strength of Test Specimens.
- British Standards Institution (2012). prEN 12390-13 (E). London: British Standards Institution. Testing Hardened Concrete - Part 13: Determination of Secant Modulus of Elasticity in Compression.
- British Standards Institution (1989). BS 1796-1. London: British Standards Institution. Test Sieving - Part 1: Methods Using Test Sieves of Woven Wire Cloth And Perforated Metal Plate.
- British Standards Institution (2007). BS EN ISO 12680-1. London: British Standards Institution. Method of Test for Refractory Products - Part 1: Determination of Dynamic Young's Modulus (MOE) by Impulse Excitation of Vibration.
- Brown, R., Shukla, A., Natarajan, K. R., & Hall, C. (2002). Fiber Reinforcement of Concrete Structures.
- Correia, J. R., Branco, F. A., & Ferreira, J. G. (2005). Structural Behaviour of GFRP-Concrete Hybrid Beams.

- Daniel, J. I., Ahmad, S. H., Arockiasamy, M., Ball, H. P., Batson, G. B., Criswell, M. E., Dorfmueller, D. P., et al. (2002). State-of-the-Art Report on Fiber Reinforced Concrete Reported by ACI Committee 544, 96 (Reapproved).
- Fatima, S. (2013). Report Mechanical Properties of Polypropylene Fibre Reinforced Concrete (PPFRC) and Structural Applications.
- Goh, K. L., Aspden, R. M., Mathias, K. J., & Hukins, D. W. L. (1999). Effect of Fibre Shape on The Stresses Within Fibres in Fibre- Reinforced Composite Materials. Pp 3351–3361.
- Ibrahim, I.S., & Che Bakar, M. B. (2011). Effects of Mechanical Properties of Industrialised Steel Fibres addition to Normal Weight Concrete. *Procedia Engineering*. 14: Pp 2616 – 2626.
- Jiang, Z., & Banthia, N. ( 2010). Size Effects in Flexural Toughness of Fibre Reinforced Concrete. *Journal of testing and Evaluation*. Vol 38: Pp 1-7.
- Johnston C. D., & Skarendahl, A. (1992). Comparative Flexural Performance Evaluation of Steel Fibre-Reinforced Concrete According to ASTM C1018 Shows Importance of Fibre Parameters. *Rilem Publication Barl*. Vol 25: Pp. 191-200.
- Labib, W., & Eden, N. (2004). An Investigation Into the Use of Fibres in Concrete Industrial Ground-Floor Slabs.
- Mansour F.R., Parniani S., & Ibrahim I.S. (2011). Experimental Study on the Effects of Steel Fibre Volume on the Mechanical Properties of SFRC. *Advanced Materials Research*. 214: Pp 144 – 148.
- Neville, A. M (2002). *Properties Of Concrete*. Pearson Prentice Hall. Vol. 4
- Othman, F. A. (2013). The Mechanical Properties of Hybrid Fibre Reinforced Concrete Composite.
- Parameswaran, V. S. (1991). Fibre Reinforced Concrete: A Versatile Construction Material. *Building and Environment*. 26 (3): Pp 301-305.
- Patel, P. A., Desai, A. K., & Desai, J. A. (2012). Evaluation of Engineering Properties for Polypropylene Fibre Reinforced Concrete. *International Journal of Advanced Engineering Technology*. Vol. 3: Pp 42-45.
- Qian, C. X., & Stroeven, P. (2000). Development of Hybrid Polypropylene-Steel Fibre-Reinforced Concrete. 30: Pp 63–69.
- Ramadevi, K.. (2012). Flexural Behavior of Hybrid ( Steel-Polypropylene ) Fibre Reinforced Concrete Beams. 70(1): Pp 81–87.

- Richardson, A . (2007). Post Crack Flexural Toughness in Steel Fabric and Fibre Reinforced Concrete Beams.
- Sarbini, N. N., Ibrahim, I. S., & Saim, A. A. (2012). The Mechanical Performance of Steel Fibre Reinforced Concrete Using Fibres Geometrical. Pp 1–12.
- Sekar, C. C., & Ramamoorthy, N. V. (2013). Flexural Behaviour Of Solo And Hybrid Fibre Concrete-A Comparative Study. 2(7): Pp 2148–2157.
- Sekar, D. A. S. S., & Kesavan, D. (2011). Performance of Hybrid Fibre Reinforced Concrete Under Compression and Flexure.
- Sharmila, S., & Nadu, T. (2013). Behavior of Reinforced Concrete Flexural Member With Hybrid Fibre Under Cyclic Loading. 2(4): Pp. 725–734.
- Shende, A. M., Pande, A. M., & Pathan, M. G. (2012). Experimental Study on Steel Fiber Reinforced Concrete for M-40 Grade, 1(1): Pp 43–48.
- Singh, S. P., Singh, A. P., & Bajaj, V. (2010). Strength and Flexural Toughness of Concrete Reinforced With Steel-Polypropylene Hybrid Fibres. 11(4): Pp 495–507.
- Soulioti, D. V., Barkoula, N. M., Paipetis, a., & Matikas, T. E. (2011). Effects of Fibre Geometry and Volume Fraction on the Flexural Behaviour of Steel-Fibre Reinforced Concrete. *Strain*, 47, Pp e535–e541.
- Sorelli, L., Banthia, N., & Plizzari, G. A. (2011). Crack Growth Resistance of Thin Mortar Layers with Hybrid Fiber Reinforcement. Pp 161–178.
- Wafa, F. F. (1990). Properties and Applications of Fiber Reinforced Concrete. 2: Pp 49–63.
- Wafa, L., & Nick, E. (2004). An Investigation Into The Use of Fibres In Concrete Industrial Ground-Floor Slabs.
- Wang, P., Huang, Z., Jiang, J., & Wu, Y. (2012). Performances of Hybrid Fiber Reinforced Concrete with Steel Fibers and Polypropylene Fibers. Pp 458–461.
- Xu, G., Magani, S., & Hannant, D.J. (1998). Durability of Hybrid Polypropylene-Glass Fiber Cement Corrugated Sheets. *Cement and Concrete Composites*. Vol. 20: Pp 79-84.
- Yi, S. T., & Cho, S. G. (2013). Effect of Hybrid Fibre Reinforcement on Capacity of Reinforced Concrete Beams. *ICE - Structures and Buildings*. 166(10): Pp 537–546.

Yusof, M. A., Nor, N. M., Ismail, A., Peng, N. C., Sohaimi, R. M., & Yahya, M. A. (2013). Performance of Hybrid Steel Fibers Reinforced Concrete Subjected to Air Blast Loading.