

EFFECT OF KENAF FIBER ON THE MECHANICAL PROPERTIES OF
REINFORCED CONCRETE STRUCTURES

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To my beloved family and friends

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ABSTRACT

There is currently a great deal of interest in developing technology using natural organic fiber materials in cement composites. Kenaf is one of the organic fiber that has potential to be used in concrete. Kenaf fiber has many advantages such as affordability, renewability, recyclability, and biodegradability. Its tensile properties are comparable to those of other natural fibers, such as jute, flax and bamboo. Fiber reinforced concrete (FRC) was introduced to the industry to improve concrete properties and to prevent the cracking of reinforced concrete members. Nevertheless, the limited use of FRC in load-bearing structures seems to be due to a lack of accepted design mixes and guidelines. This study investigates the physical and mechanical properties of Kenaf fiber reinforced concrete (KFRC) and its structural behaviour as concrete beam under static loads. This study was carried out mainly by experiment. The experiments were conducted according to relevant American Standards (ASTM) and British Standards (BS), as well as recommended methods from past researchers. A number of parameters were observed from the experiment, such as physical properties (colour, fiber distribution in concrete, surface morphology, density, aspect ratio, weight loss and water absorption), properties of fresh KFRC (slump, compacting factor and vebe time), properties of hardened KFRC (ultrasonic pulse velocity, rebound hammer, density, compressive strength, splitting tensile strength, flexural strength, static modulus of elasticity and equivalent compressive strength) and performance of KFRC when used as beams under flexural loadings (ultimate load, deflection, cracking, steel strain, concrete strain, bonding between concrete and steel reinforcement and neutral axis). A total of 1300 concrete specimens (cube, cylinder and prism) and 7 beam specimens were casted and tested in this study. A theoretical model for the analysis and design of Kenaf fiber reinforced concrete materials and structural beam elements was proposed and evaluated. Results show that the presence of Kenaf fiber in concrete improved the properties such as splitting tensile strength, flexural strength and ultimate load of beam. However, it reduced the concrete properties if the fiber used was over the limit, the properties such as density, slump, compacting factor, vebe time, ultrasonic pulse velocity, rebound hammer, compressive strength, static modulus of elasticity and equivalent compressive strength. KFRC only can perform well under the suitable fiber to cement volume fractions of up to 0.75%. Fiber length did not affect concrete performance. The performance of KFRC was greatly influenced by the distribution and orientation of Kenaf fibers in concrete. Control and handling during the mixing process of KFRC was a major factor in producing quality concrete. Finally the use of Kenaf fiber as reinforcement in concrete is highly recommended based on improvements in material strength and structural performance.

ABSTRAK

Buat masa ini terdapat banyak faedah dalam membangunkan teknologi dengan menggunakan bahan-bahan gentian semula jadi dalam komposit simen. Kenaf adalah salah satu gentian organik yang mempunyai potensi untuk digunakan dalam konkrit. Gentian kenaf mempunyai banyak kelebihan seperti kemampuan, pembaharuan, kitar semula, dan biodegradability. Sifat tegangan ia adalah setanding dengan gentian semula jadi yang lain, seperti jute, flax dan buluh. Konkrit bergentian (FRC) diperkenalkan kepada industri untuk meningkatkan sifat-sifat konkrit dan juga untuk mengurangkan keretakan struktur konkrit bertetulang. Walau bagaimanapun, penggunaan FRC terhad dalam struktur menanggung beban adalah disebabkan tiada cara reka bentuk dan garis panduan yang diterbitkan setakat ini. Kajian ini mengkaji sifat-sifat fizikal dan mekanikal Kenaf serat konkrit (KFRC) dan tingkah laku strukturnya sebagai rasuk di bawah beban statik. Kajian ini dijalankan terutamanya oleh eksperimen. Kajian ini telah dijalankan dengan mengikuti Piawaian Amerika (ASTM) dan Piawaian British (BS), dan kaedah yang disarankan oleh pengkaji yang terdahulu. Beberapa parameter ditentukan dan diperhatikan dari eksperimen, seperti sifat-sifat fizikal gentian Kenaf (warna, agihan gentian dalam konkrit, permukaan morfologi, ketumpatan gentian, nisbah aspek, penurunan berat gentian selepas dan penyerapan air), sifat-sifat segar KFRC (kemerosotan, faktor mampatan dan masa vebe), sifat-sifat keras KFRC (ultrasonik nadi halaju, pemulihan tukul, ketumpatan, kekuatan mampatan, kekuatan tegangan, kekuatan lenturan, modulus statik keanjalan dan kekuatan mampatan yang setara) dan prestasi bertetulang KFRC yang digunakan sebagai rasuk di bawah beban lenturan (beban muktamad, pesongan, keretakan, ketegangan keluli, terikan konkrit, ikatan antara konkrit dan tetulang keluli dan paksi neutral). Sebanyak 1300 spesimen konkrit (kubus, silinder dan prisma) dan 7 spesimen rasuk telah diuji dalam kajian ini. Model teori untuk analisis dan reka bentuk Kenaf bahan konkrit bergentian dan unsur-unsur rasuk struktur telah dicadangkan. Hasil kajian menunjukkan bahawa Kenaf gentian dalam konkrit menambah baik sifat seperti kekuatan tegangan, kekuatan lenturan dan beban muktamad rasuk. Walau bagaimanapun, ia melemahkan sifat konkrit sekiranya gentian yang digunakan melebihi had, ciri-ciri seperti ketumpatan, kemerosotan, faktor mampatan, masa vebe, ultrasonik nadi halaju, pemulihan tukul, kekuatan mampatan, modulus statik keanjalan dan kekuatan mampatan yang setara. KFRC hanya dapat berfungsi dengan baik di bawah jumlah pecahan gentian untuk simen yang sesuai sehingga 0.75%. Panjang gentian tidak menjejaskan prestasi konkrit. Prestasi KFRC banyak dipengaruhi oleh pengedaran dan orientasi gentian Kenaf dalam konkrit. Kawalan baik dan pengendalian semasa proses pencampuran KFRC merupakan faktor utama untuk menghasilkan konkrit yang berkualiti. Akhirnya, kegunaan gentian Kenaf sebagai tetulang di dalam konkrit amat disyorkan kerana ia dapat meningkatkan kekuatan bahan dan prestasi struktur.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xvi
	LIST OF FIGURES	xviii
	LIST OF ABBREVIATIONS	xxv
	LIST OF SYMBOLS	xxvi
	LIST OF APPENDICES	xxix
1	INTRODUCTION	1
	1.1 Background of the Study	1
	1.2 Problem Statement	3
	1.3 Objectives	6
	1.4 Scope of Study	6
	1.5 Significant of Study	7
	1.6 Outline of Thesis	8
2	LITERATURE REVIEW	10
	2.1 Introduction	10
	2.2 Fibers	11
	2.3 Classification of Fibers	12

2.4	Natural Fibers	15
2.5	Characteristic of Natural Fibers	18
2.6	Kenaf Fiber	19
2.7	Kenaf Plant in Malaysia	21
2.8	Benefits of Kenaf Plant	22
2.9	The Advantages and Disadvantages of Natural Fiber Including Kenaf Fiber	23
2.10	Natural Fiber Pre-treatment and Characteristics	24
2.11	Kenaf Fiber Chemical Treatment (Alkaline Treatment)	25
2.12	History of Fiber Reinforced Concrete (FRC)	26
2.13	Fiber Reinforced Concrete (FRC)	27
2.14	Properties of Fiber Reinforced Concrete (FRC)	28
	2.14.1 Fiber Bridging Action	29
2.15	Factors Affecting Fiber Reinforced Concrete	30
	2.15.1 Fiber Length	31
	2.15.2 Fiber Volume Fraction	31
	2.15.3 Fiber Aspect Ratio	32
	2.15.4 Fiber Distribution	34
	2.15.5 Bonding between Fiber and Cement	34
	2.15.6 Aggregate Size	35
2.16	Mechanical Properties of Fresh Fiber Reinforced Concrete	37
	2.16.1 Workability	37
	2.16.2 Bleeding and Segregation	39
2.17	Mechanical Properties of Hardened Fiber Reinforced Concrete	40
	2.17.1 Compressive Strength	40
	2.17.2 Tensile Strength	41
	2.17.3 Flexural Strength	42
	2.17.4 Crack Resistance	42
	2.17.5 Modulus of Elasticity	43
2.18	Limitations of Fiber Application in Concrete	44

2.19	Standard Mix Design	45
2.20	Preparation of Fiber Reinforced Concrete	46
	2.20.1 Mixing of Fibers	46
	2.20.2 Placing, Finishing and Curing	47
2.21	Theoretical Principles of Fiber Reinforced Concrete Beam in Flexure	47
	2.21.1 Load-Deflection	48
	2.21.2 Strain Diagram and Neutral Axis	49
2.22	Summary	50
3	METHODOLOGY	53
3.1	Introduction	53
3.2	Laboratory Test Framework	54
3.3	Materials and Preparation	55
	3.3.1 Ordinary Portland Cement (OPC)	55
	3.3.2 Aggregate	57
	3.3.2.1 Coarse Aggregate	57
	3.3.2.2 Fine Aggregate	58
	3.3.3 Water	59
	3.3.4 Distilled Water	60
	3.3.5 Kenaf Fiber	60
	3.3.6 Sodium Hydroxide (NaOH)	61
	3.3.7 Admixture - Superplasticizer	62
3.4	Laboratory Works	63
3.5	Kenaf Fiber Properties Tests	63
	3.5.1 Preparation of Kenaf Fiber	63
	3.5.2 Alkaline Treatment of Kenaf Fiber	64
	3.5.3 Alkaline Treatment Process	65
	3.5.4 Cutting Process for Kenaf Fiber	65
	3.5.5 Storage of Kenaf Fiber	66
	3.5.6 Physical and Mechanical Property Tests on Kenaf Fibers	66
	3.5.6.1 Density Test	66

3.5.6.2	Weight Loss Test	68
3.5.6.3	Water Absorption Test	68
3.5.6.4	Microscopic Tests	69
3.6	Kenaf Fiber Reinforced Concrete (KFRC)	
	Property Tests	70
3.6.1	Concrete Mix Design	70
3.6.2	Testing Specimens	72
3.6.2.1	Compressive Strength Test, Splitting Tensile Strength Test and Flexural Strength Test	72
3.6.2.2	Static Modulus of Elasticity of Concrete in Compression Test	73
3.6.2.3	Modulus of Rupture Test on KFRC (Three-Point Loading)	73
3.6.3	Mixing Procedure	74
3.6.4	Casting and Compacting Process	76
3.6.5	Curing Process	76
3.7	KFRC Laboratory Tests	77
3.7.1	Sieve Analysis	77
3.7.2	Test on Fresh Concrete	78
3.7.2.1	Slump Test	78
3.7.2.2	Vebe Time Test	79
3.7.2.3	Compacting Factor Test	80
3.7.3	Test on Hardened Concrete	81
3.7.3.1	Ultrasonic Pulse Velocity (UPV) Test	81
3.7.3.2	Rebound Hammer Test	82
3.7.3.3	Hardened Concrete Density Test	83

3.7.3.4	Compressive Strength Test	84
3.7.3.5	Splitting Tensile Strength Test	85
3.7.3.6	Flexural Strength Test	86
3.7.3.7	Modulus of Rupture Test for KFRC (Three-Point Loading)	87
3.7.3.8	Equivalent Compressive Strength Test for Prism Broken in Modulus of Rupture Test for KFRC (Three-Point Loading)	88
3.7.3.9	Static Modulus of Elasticity in Compression Test	89
3.8	Performance Tests on Kenaf Fiber Reinforced Concrete (KFRC) Beam	90
3.8.1	Beam Design and Detailing	90
3.8.2	Beam Testing Setup	91
3.8.3	Steel Reinforcement Design	91
3.8.4	Preparation of Formwork	92
3.8.5	Preparation and Fabrication of Steel Reinforcement	93
3.8.6	Preparation of Concrete	93
3.8.7	Casting of Beam	94
3.8.8	Curing of Beam	94
3.8.9	Installation of Strain Gauges	95

	3.8.10 Installation of Demec Disc	97
	3.8.11 Four-Point Bending Beam Test	97
	3.9 Summary	98
4	RESULTS OF KENAF FIBER PROPERTIES AND CONCRETE TRIAL MIXES	99
	4.1 Introduction	99
	4.2 Properties of Kenaf Fibers	99
	4.2.1 Physical Appearance: Colour of Kenaf Fiber	100
	4.2.2 Surface Morphology of Kenaf Fibers	100
	4.2.3 Density of Kenaf Fibers	103
	4.2.4 Aspect Ratio of Kenaf Fibers	104
	4.2.5 Weight Loss of Kenaf Fibers after Treatment	105
	4.2.6 Water Absorption Properties	107
	4.3 Summary	109
5	RESULTS OF KENAF FIBER REINFORCED CONCRETE PROPERTIES	110
	5.1 Introduction	110
	5.2 Properties of Fresh Concrete	111
	5.2.1 Sieve Analysis on Aggregate	111
	5.2.2 Result of Slump Test	113
	5.2.3 Result of Compacting Factor	116
	5.2.4 Result of Vebe Time	117
	5.3 Properties of Hardened Concrete	118
	5.3.1 Result of Ultrasonic Pulse Velocity (UPV) Test	118
	5.3.2 Result of Rebound Hammer Test	120
	5.3.3 Result of Concrete Density	121
	5.3.3.1 Result of Density Test on Cube	122

5.3.3.2	Result of Density Test on Cylinder	124
5.3.3.3	Result of Density Test on Prism	126
5.3.3.4	Discussion on the Density of KFRC	129
5.3.4	Result of Compressive Strength	129
5.3.4.1	Discussion on the Compressive Strength of KFRC	132
5.3.5	Result of Splitting Tensile Strength	134
5.3.5.1	Discussion on the Splitting Tensile Strength of KFRC	137
5.3.6	Result of Flexural Strength	138
5.3.6.1	Discussion on the Flexural Strength of KFRC	141
5.3.7	Relationship between Compressive Strength, Splitting Tensile Strength and Flexural Strength to the Water/Cement (W/C) ratio and Fiber Volume Fraction	143
5.3.8	Result of Static Modulus of Elasticity	152
5.3.9	Result of Modulus of Rupture of KFRC	156
5.3.10	Result of Equivalent Compressive Strength Test for Prism Broken in Modulus of Rupture of KFRC	159
5.4	Summary	160
6	PERFORMANCE OF KFRC BEAM STRUCTURES UNDER FLEXURAL LOADS AND THEORETICAL ANALYSIS	162
6.1	Introduction	162
6.2	Flexural Strength Test for Reinforced Concrete Beam	163

6.3	Ultimate Load	166
6.4	Load-Deflection Behaviour	167
6.5	Mode of Failure	171
6.6	Cracking Behaviour	173
6.7	Steel Strain	176
6.8	Concrete Strain	178
6.9	Bonding between Concrete and Steel Reinforcement	178
6.10	Changes of Neutral Axis	181
6.11	Theoretical Analysis	185
6.11.1	Theoretical Formula for Deflection	186
6.11.2	Theoretical Formula for Effective Moment of Inertia	186
6.11.3	Analytical Models of Calculating Moment of Inertia of Cross Section for Uncracked Beams	188
6.11.3.1	Plain Concrete (No Fiber)	189
6.11.3.2	Full Depth of Fiber Dispersion	190
6.11.3.3	Half Depth of Fiber Dispersion	191
6.11.3.4	Quarter Depth of Fiber Dispersion	192
6.11.4	Analytical Models of Calculating Moment of Inertia of Cross Section for Cracked Beams	193
6.11.4.1	Plain Concrete (No Fiber)	196
6.11.4.2	Full Depth of Fiber Dispersion	197
6.11.4.3	Half Depth of Fiber Dispersion	198
6.11.4.4	Quarter Depth of Fiber Dispersion	198

6.11.5	Theoretical Formula for Cracking Moment	199
6.11.6	Analytical Models of Calculating the Ultimate Moment	200
6.11.6.1	Plain Concrete (No Fiber)	201
6.11.6.2	Full Depth of Fiber Dispersion	203
6.11.6.3	Half Depth of Fiber Dispersion	204
6.11.6.4	Quarter Depth of Fiber Dispersion	205
6.11.7	Comparison of Experimental and Predicted Deflections	206
6.11.7.1	Effect of Kenaf fibers on Moment of Inertia	206
6.11.7.2	Effect of Kenaf fibers on Ultimate Moment	207
6.11.7.3	Deflections	208
6.12	Summary	209
7	CONCLUSIONS AND RECOMMENDATIONS	211
7.1	Conclusions	211
7.2	Detailed Conclusions	212
7.2.1	Objective (i)	212
7.2.2	Objective (ii)	213
7.2.1	Objective (iii)	214
7.2.1	Objective (iv)	215
7.2.1	Objective (v)	215
7.3	Recommendations	216
	REFERENCES	218
	Appendices A - B	228 - 239

LIST OF TABLES

TABLE NO.	TITLE	PAGE
2.1	Typical Properties of Some Fiber Type	14
2.2	Description of Some Fiber Type	14
2.3	Mechanical Properties of Natural Fiber	16
2.4	Classification of Fibers according to its Origin	17
2.5	Characteristic of Some Natural Fiber Type	19
2.6	Advantages and Disadvantages of Natural Fibers	23
2.7	Aspect Ratio of the Fiber	33
3.1	Types of Laboratory Test	53
3.2	General Chemical Composition of Ordinary Portland Cement	56
3.3	Chemical Composition of Kenaf Fiber	61
3.4	Example of Mix Design Proportions (Grade 30)	71
3.5	Concrete Mixtures Specimens for Compressive Strength, Splitting Tensile Strength and Flexural Strength Test	72
3.6	Concrete Mixture Specimens for Static Modulus of Elasticity Test	73
4.1	The Aspect Ratios (l/d) of the Kenaf Fiber	105
4.2	Weight Loss of the Kenaf Fibers after Alkaline Treatment	106
5.1	UPV Test Results for Concrete Prisms	119
5.2	Rebound Hammer Test Results for Concrete Prisms	120
5.3	Relationship between W/C ratio, Fiber Volume Fraction and Compressive Strength at 28 days (25 mm Fiber Length)	143
5.4	Relationship between W/C ratio, Fiber Volume Fraction and Compressive Strength at 28 days (50 mm Fiber Length)	144

5.5	Constant Value for Compressive Strength Equation	146
5.6	Relationship between W/C ratio, Fiber Volume Fraction and Splitting Tensile Strength at 28 days (25 mm Fiber Length)	146
5.7	Relationship between W/C ratio, Fiber Volume Fraction and Splitting Tensile Strength at 28 days (50 mm Fiber Length)	147
5.8	Constant Value for Splitting Tensile Strength Equation	149
5.9	Relationship between W/C ratio, Fiber Volume Fraction and Flexural Strength at 28 days (25 mm Fiber Length)	149
5.10	Relationship between W/C ratio, Fiber Volume Fraction and Flexural Strength at 28 days (50 mm Fiber Length)	150
5.11	Constant Value for Flexural Strength Equation	152
5.12	Compressive Strength Results for Cylinders	152
5.13	Flexural Strength and Deflection Results for Prism	157
5.14	Equivalent Compressive Strength Test Results	159
6.1	Results of Compressive Strength of Concrete Mix for RC beam	165
6.2	Ultimate Load Results for All Beam Specimens	166
6.3	Ultimate Load Results Compared to Designed Ultimate Load	166
6.4	Deflection of Beams at Mid Span	168
6.5	Failure Modes of the Beam Specimens	172
6.6	Characteristic of the Crack Length	174
6.7	Characteristic of the Crack Width	174
6.8	The Different between the Laboratory and Theoretical Neutral Axis of Beams	182
6.9	Computed Moment of Inertia for all the Beams	207
6.10	Computed Ultimate Moment for all the Beams	207
6.11	Comparison of Measures and Predicted Deflections for all Beams	208

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
2.1	Fiber Classification	13
2.2	Kenaf Seed V36	21
2.3	Kenaf Bast and Core	21
2.4	Kenaf Plant	21
2.5	Kenaf Fibers	21
2.6	Structure of Natural Fiber	25
2.7	Fiber Reinforcement Before and After the Creation of a Macro-Crack (Left) and Crack Bridging by Fibers (Right)	30
2.8	Effect of Fiber Aspect Ratio on V-B time of Fiber Reinforced Mortar	33
2.9	Fiber Distribution with Different Aggregate Size	36
2.10	Effect of Aggregate Size on the Vebe Time of Concrete with Different Fiber Content	36
2.11	Effect of Fiber Aspect Ratio on the Compacting Factor of Concrete	39
2.12	Load-Deflection Curves for Plain Concrete and Steel Fiber Reinforced Concrete	49
2.13	Comparison of Typical Stress-strain Responses in Tension of High Performance Fiber Reinforced Concrete and Conventional FRC	50
3.1	Schematic Diagram Showing the Laboratory Test Flow Chart	54
3.2	Ordinary Portland Cement – Tasek Cement	56

3.3	Granite Aggregate	58
3.4	Sand/Fine Aggregate	59
3.5	Distillation Machine	60
3.6	Bast Kenaf Fibers	61
3.7	Sodium Hydroxide (NaOH)	62
3.8	Rheobuild 1100 HG	62
3.9	Washing Fibers with Tap Water	64
3.10	Air Dry under the Sun	64
3.11	Alkaline Treatment	65
3.12	Air Dry at Room Temperature	65
3.13	Cut Kenaf Fibers	66
3.14	Analytical Balances	67
3.15	Kenaf Samples for Density Test	67
3.16	Kenaf Fiber Immersed in Distilled Water	69
3.17	MS Analytical Balance	69
3.18	SEM Instrument	70
3.19	Section Details for Concrete Prism Specimens	74
3.20	Water Curing Process	77
3.21	Mechanical Siever for Sieve Analysis	78
3.22	Types of Slump	79
3.23	Slump Cone Test Set	79
3.24	Vebe Consistometer	80
3.25	Compaction Factor Apparatus	81
3.26	UPV Test Apparatus	82
3.27	Rebound Hammer	83
3.28	Weighing of Concrete Specimen for Density Test	84
3.29	Cube Test	85
3.30	Splitting Tensile Strength Test	86
3.31	Flexural Strength Test	87
3.32	Modulus of Rupture for Beam Setup	88
3.33	Equivalent Compressive Strength Test	88
3.34	Static Modulus of Elasticity Test	89
3.35	RC Beams Detailing	90

3.36	RC Beam Testing Setup	91
3.37	Cross Section of RC Beams	92
3.38	Formwork for RC Beams	92
3.39	Steel Reinforcement for RC Beams	93
3.40	Beam Cover by Wet Gunny Sack	94
3.41	Strain Gauges Installed in Concrete	96
3.42	Strain Gauges Installed in Steel Bars	96
3.43	Arrangement of Demec Disc on Beam	97
3.44	100 mm Demec Strain Gauge	97
3.45	Four-point Bending Beam Testing Setup	98
4.1	Changing in Colour of Kenaf Fibers after Treatment Process	100
4.2	Untreated Kenaf Fiber	101
4.3	Kenaf Fiber Treated with pH 8	101
4.4	Kenaf Fiber Treated with pH 9	102
4.5	Kenaf Fiber Treated with pH 10	102
4.6	Kenaf Fiber Treated with pH 11	102
4.7	Kenaf Fiber Treated with pH 12	102
4.8	Kenaf Fiber Treated with pH 13	102
4.9	Kenaf Fiber Treated with pH 14	102
4.10	Treated Kenaf Fiber after 3 Months	103
4.11	Treated Kenaf Fiber after 6 Months	103
4.12	Treated Kenaf Fiber after 1 Years	103
4.13	Treated Kenaf Fiber after 2 Years	103
4.14	Density Test Results for Kenaf Fibers	104
4.15	Average Weight Loss versus Various pH Value	106
4.16	Water Absorption Percentage of Kenaf Fiber at Different Time Interval	107
4.17	Water Absorption Test Results for 3 Batches of Kenaf Fiber	107
5.1	Sieve Analysis for Coarse Aggregate	112
5.2	Sieve Analysis for Fine Aggregate	113
5.3	Slump Test Results for 25 mm Fiber Length	114

5.4	Slump Test Results for 50 mm Fiber Length	114
5.5	Compacting Factor Test Results for 25 mm Fiber Length	116
5.6	Compacting Factor Test Results for 50 mm Fiber Length	116
5.7	Vebe Time Test Results for 25 mm Fiber Length	117
5.8	Vebe Time Test Results for 50 mm Fiber Length	118
5.9	Density Test Results on Cube for 25 mm Fiber Length at 7 days	122
5.10	Density Test Results on Cube for 50 mm Fiber Length at 7 days	122
5.11	Density Test Results on Cube for 25 mm Fiber Length at 28 days	123
5.12	Density Test Results on Cube for 50 mm Fiber Length at 28 days	123
5.13	Density Test Results on Cylinder for 25 mm Fiber Length at 7 days	124
5.14	Density Test Results on Cylinder for 50 mm Fiber Length at 7 days	125
5.15	Density Test Results on Cylinder for 25 mm Fiber Length at 28 days	125
5.16	Density Test Results on Cylinder for 50 mm Fiber Length at 28 days	125
5.17	Density Test Results on Prism for 25 mm Fiber Length at 7 days	127
5.18	Density Test Results on Prism for 50 mm Fiber Length at 7 days	127
5.19	Density Test Results on Prism for 25 mm Fiber Length at 28 days	128
5.20	Density Test Results on Prism for 50 mm Fiber Length at 28 days	128
5.21	Compressive Strength Results for Cubes at 7 Days of Curing Time (25 mm Fiber Length)	130

5.22	Compressive Strength Results for Cubes at 28 Days of Curing Time (25 mm Fiber Length)	130
5.23	Compressive Strength Results for Cubes at 7 Days of Curing Time (50 mm Fiber Length)	131
5.24	Compressive Strength Results for Cubes at 28 Days of Curing Time (50 mm Fiber Length)	131
5.25	Failure Mode of Cube (Control)	134
5.26	Failure Mode of Cube (KFRC)	134
5.27	Splitting Tensile Strength Results for Cylinders at 7 Days of Curing Time (25 mm Fiber Length)	135
5.28	Splitting Tensile Strength Results for Cylinders at 28 Days of Curing Time (25 mm Fiber Length)	135
5.29	Splitting Tensile Strength Results for Cylinders at 7 Days of Curing Time (50 mm Fiber Length)	136
5.30	Splitting Tensile Strength Results for Cylinders at 28 Days of Curing Time (50 mm Fiber Length)	136
5.31	Failure Mode of Cylinder (Control)	138
5.32	Failure Mode of Cylinder (KFRC)	138
5.33	Flexural Strength Results for Prisms at 7 Days of Curing Time (25 mm Fiber Length)	139
5.34	Flexural Strength Results for Prisms at 28 Days of Curing Time (25 mm Fiber Length)	139
5.35	Flexural Strength Results for Prisms at 7 Days of Curing Time (50 mm Fiber Length)	140
5.36	Flexural Strength Results for Prisms at 28 Days of Curing Time (50 mm Fiber Length)	140
5.37	Failure Mode of Prism (Control)	142
5.38	Failure Mode of Prism (KFRC)	142
5.39	Relationship between W/C ratio, Fiber Volume Fraction and Compressive Strength at 28 days (25 mm Fiber Length)	144
5.40	Relationship between W/C ratio, Fiber Volume Fraction and Compressive Strength at 28 days (50 mm	

	Fiber Length)	145
5.41	Relationship between W/C ratio, Fiber Volume Fraction and Splitting Tensile Strength at 28 days (25 mm Fiber Length)	147
5.42	Relationship between W/C ratio, Fiber Volume Fraction and Splitting Tensile Strength at 28 days (50 mm Fiber Length)	148
5.43	Relationship between W/C ratio, Fiber Volume Fraction and Flexural Strength at 28 days (25 mm Fiber Length)	150
5.44	Relationship between W/C ratio, Fiber Volume Fraction and Flexural Strength at 28 days (50 mm Fiber Length)	151
5.45	Results of Static Modulus of Elasticity Values	154
5.46	Results of Static Modulus of Elasticity Test	154
5.47	Prisms Detailing	157
5.48	Prism before Testing	159
5.49	Prism after Testing	159
6.1	RC Beam Detailing	163
6.2	Failure of PB Beam	163
6.3	Failure of KB1 Beam	164
6.4	Failure of KB2 Beam	164
6.5	Failure of KB3 Beam	164
6.6	Failure of KB4 Beam	164
6.7	Failure of KB5 Beam	164
6.8	Failure of KB6 Beam	165
6.9	The Ultimate Load Results for All Beam Specimens	167
6.10	Load versus Deflection Graph of All Beams	169
6.11	Load at First Crack for All Beam Specimen	172
6.12	Crack of PB Beam	174
6.13	Crack of KFRC Beam	175
6.14	Load versus Steel Strain Curve of All Beams	177
6.15	Load versus Concrete Strain Curve of All Beams	178

6.16	Load versus Strain Curve (PB Beam)	179
6.17	Load versus Strain Curve (KB1 Beam)	179
6.18	Load versus Strain Curve (KB2 Beam)	180
6.19	Load versus Strain Curve (KB3 Beam)	180
6.20	Load versus Strain Curve (KB4 Beam)	180
6.21	Load versus Strain Curve (KB5 Beam)	181
6.22	Load versus Strain Curve (KB6 Beam)	181
6.23	Location of Neutral Axis for PB Beam	182
6.24	Location of Neutral Axis for KB1 Beam	183
6.25	Location of Neutral Axis for KB2 Beam	183
6.26	Location of Neutral Axis for KB3 Beam	183
6.27	Location of Neutral Axis for KB4 Beam	184
6.28	Location of Neutral Axis for KB5 Beam	184
6.29	Location of Neutral Axis for KB6 Beam	184
6.30	Equivalent Cross Section and Reduced Rectangular Cross Section for Uncracked Beam with Plain Concrete (Control)	188
6.31	Equivalent Cross Section and Reduced Rectangular Cross Section for Uncracked Beams with Kenaf Fibers	189
6.32	Equivalent Cross Section and Reduced Rectangular Cross Section for Cracked Beam with Plain Concrete (Control)	195
6.33	Equivalent Cross Section and Reduced Rectangular Cross Section for Cracked Beam with Kenaf Fibers	195
6.34	Strain and Stress Distribution for Cross Section of the Doubly Reinforced Plain Concrete Beam	200
6.35	Design Assumptions for Analysis of Doubly Reinforced Concrete Beams Containing Kenaf Fibers	201

LIST OF ABBREVIATIONS

ACI	-	American Concrete Institute
ASTM	-	American Society for Testing and Materials
BS	-	British Standard
DEMEC	-	Demountable Mechanical Strain
FRC	-	Fiber Reinforced Concrete
H ₂ O	-	Water
KFRC	-	Kenaf Fiber Reinforced Concrete
LVDT	-	Linear Variable Displacement Transducer
NaOH	-	Sodium Hydroxide
O ₂	-	Oxygen
OPC	-	Ordinary Portland Cement
RC	-	Reinforced Concrete
SEM	-	Scanning Electron Microscopic

LIST OF SYMBOLS

A	-	Area
A_{s1}	-	Area of Tensile Steel Reinforcement
A_{s2}	-	Area of Compressive Steel Reinforcement
A_s	-	Area of Tension Reinforcement
A_s'	-	Area of Compression Reinforcement
a	-	Position of Fracture from Near Support
a_2	-	Distance from the Extreme Concrete Fiber to Centroid of Compressive Steel Bar
b	-	Width
b_p	-	Width of Prism
c	-	corresponding deformation (strain difference)
d	-	Distance from the Extreme Concrete Fiber to Centroid of Tensile Steel Bar
d_c	-	Diameter of Cylinder
d_f	-	Fiber Mean Diameter
d_p	-	Depth of Prism
d_t	-	Distance Travelled for Pulse
E	-	Effective Modulus
E_c	-	static modulus of elasticity in compression
E_c^{fib}	-	Modulus of Elasticity of FRC
E_s	-	Modulus of Elasticity of Steel
f	-	stress difference for measurements
f_{cf}	-	Characteristic Strength of Kenaf Fiber Concrete
f_{ck}	-	Characteristic Compressive Strength of Cube
f_{ct}	-	Characteristic Splitting Tensile Strength
f_t	-	Characteristic Flexural Strength

f_r	-	Modulus of Rupture for the Concrete
f_{yk}	-	Characteristic Strength of Reinforcement
h	-	Depth
I_{cr}	-	Cracking Moment of Inertia
I_e	-	Effective Moment of Inertia
I_g	-	Gross Moment of Inertia
I_{ucr}	-	Uncracked Moment of Inertia
L	-	Effective Span of the Beam
L_a	-	Distance from Support to One of the Loads
L_p	-	Span of Prism
l	-	Length
M	-	Moment
M_a	-	Ultimate Moment
M_{cr}	-	First Cracking Moment
m	-	Coefficient for Branson's Formula
m_c	-	Mass of Concrete
P	-	Applied Load
t_s	-	Time Travelled for Pulse
V_f	-	Volume Fraction
v	-	Volume of Concrete
v_b	-	Interfacial Bond Strength for Fiber
y_t	-	Distance from Neutral Axis of Uncracked Cross-section to Extreme Tension Reinforcement
W_a	-	Weight of Fiber in the Air
W_b	-	Weight of Fiber in the Auxiliary Liquid
W_f	-	Weight of Fully Compacted Concrete
W_o	-	Weight of Fibers before Chemical Treatment
W_p	-	Weight of Partially Compacted Concrete
W_t	-	Weight of Fibers after Chemical Treatment
W_1	-	Weight of Dried Fibers
W_2	-	Weight of Kenaf Fibers after Water Absorption
x	-	Neutral Axis Depth
Z_1	-	Depth of Neutral Axis

z	-	Level Arm
ρ_o	-	Density of Auxiliary at the Given Temperature
ρ_c	-	Density of Concrete
ρ_f	-	Density of Fiber
δ	-	Deflection at Mid Span at Ultimate Load
σ	-	Stress
ε	-	Strain
$\alpha_{e,eff}$	-	Modular Ratio for Steel Bar
$\alpha_{f,eff}$	-	Modular Ratio for KFRC
α_{cc}	-	Different between the Bending Strength and the Cylinder Crushing Strength of the Concrete
η	-	Defining the Effective Strength
γ_c	-	Usual Partial Safety Factor for the Strength of Concrete

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Normal Concrete Mix Design Computation and Summary	297
B	KFRC Mix Design Computation and Summary	303

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Concrete is one of the most durable and widely used building materials, and it is expected to continue to be so in the future. It has advantages over other materials such as timber and steel. The energy used to produce cement is lower than steel or plastics. The energy requirements to produce a cubic meter of cement is 22 times lower than a corresponding volume of steel and the energy cost of cement per unit volume is less than one-fifth that of common plastics (Timothy *et al.*, 2013).

Recently, there have been many studies on the development of construction materials in civil engineering. Most researchers investigate and innovate materials based on three aspects, which are availability, environmental compatibility, and financial constraints. This results in the introduction of new construction materials to meet the ever increasing demand for improved mechanical properties and superior workability, in numerous civil and structural engineering applications.

The incorporation of fibers into brittle things as reinforcement has been used since ancient times. 3500 years ago, straw was used in sun-baked bricks and horsehair was used in mortar. Bricks were used to build the 57m high hill of Aqar

Quf near Baghdad (Liew, 2008). In the early 1950s, asbestos fiber began to be used in concrete. However, it was found that asbestos was harmful to human health. In the 1960s, some new fibers were introduced to replace asbestos such as steel, glass, and synthetic fiber, which are still used today (Joshi *et al.*, 2004). A lot of new fibers have potential as reinforcement in concrete and that makes the research of fiber reinforced concrete an interesting topic for researchers. Over the past 40 years, fiber reinforced concrete was used in road and floor slabs, refractory materials, and concrete products (Joshi *et al.*, 2004).

Fiber reinforced concrete contains cement, aggregate, water and discontinuous discrete fibers (Newman and Choo, 2003). Used fiber can be of various shapes and sizes and are classified into metallic, mineral, and organic. The choice of fibers varies from synthetic organic materials such as polypropylene or carbon, synthetic inorganic such as steel or glass, natural organics such as cellulose or sisal to natural inorganic asbestos (ACI, 1986). Currently commercial products are reinforced with steel, glass, polyester, and polypropylene fibers.

Fiber reinforced concrete is an increasingly popular construction material due to its ability to enhance the properties of conventionally reinforced concrete (Isa, 2015). In general, concrete is weak in tension compared to its compression capacity. Normally, steel reinforcement is used to overcome concrete's weakness to tension. However, this weakness can also be solved by the inclusion of a sufficient volume fraction of certain fibers (Dianah, 2014). The idea is to disperse fibers into concrete to improve tensile strength.

According to Romualdi and Baston (1963), the plastic and drying shrinkage cracking of concrete can be controlled by the inclusion of fibers. Randomly distributed fibers in concrete act as a crack arrester, which has superior cracking resistance and crack propagation. Moreover, fibers are able to hold concrete together after excessive cracks. Fibers can lower the permeability of concrete and reduce bleeding in water (Dianah, 2014). Some fibers offer greater abrasion, shatter resistance, and concrete impact. Generally fibers cannot be used to totally replace structural steel reinforcements because some fibers reduce the strength of concrete

(Faezah, 2012). However, compared to plain concrete, fiber reinforced concrete is much tougher and has good impact resistance.

There are several fiber-reinforcing materials available in the market, but for structural applications, steel fiber is used. Most recently, there have been research efforts to utilize natural fibers for the production of low-cost building elements, partly due to the energy crisis (Dianah, 2014). This is due to the properties of natural fibers which are readily available, renewable, and cheap to produce compared to man-made fibers.

However, due to uncertainties in current design practices over the ability of natural fiber to be used as reinforcement in structure, the need for an extensive research programme is necessary. Most research are studies on the use of steel fibers in concrete, and it is rare to find studies on natural fibers, especially kenaf fiber (Lee, 2007; Rabalais, 1992; Aruntas *et al.*, 2008; Mohammadi *et al.*, 2006; Torrijos *et al.*, 2007; Magendran, 2007; Huzaiifa, 2008; Julie, 2012; Isa, 2015). No natural fiber has emerged to dominate the marketplace. In this study, particular interest was paid to the use of kenaf fibers as concrete reinforcement.

1.2 Problem Statement

Sustainability is an important issue today in business and society. Sustainable construction may include element management, energy use, low carbon emissions from the use of concrete alternatives, the optimized use of carbon high materials, proper site planning and construction, and the recycling or reuse of natural resources (Tan, 2012).

In Malaysia, there is increasing demand, in both the private and public sectors to understand sustainable construction practices. In order to promote sustainable concepts, green materials have been developed and have attracted global attention.

There is currently a great deal of interest in developing natural organic fiber materials in cement composites. Among the most promising of such materials are biofibers. Biofibers have many advantages compared to other types of fibers such as their renewability, recyclability, and biodegradability (Hafizah *et al.*, 2011). In order to completely evaluate the potential of biofiber for new applications, a comprehensive and detailed study of their fundamental properties is important.

Cement concrete lends itself to a variety of innovative designs as they can be cast into any desired shape. It possesses many desirable properties like high compressive strength, high stiffness, low thermal conductivity, and low electrical conductivity. However, it also has low tensile strength, limited ductility, and little resistance to cracking (Bergman *et al.*, 2010).

In order to overcome concrete weaknesses, it is essential to use conventional steel reinforcement or the inclusion of a sufficient volume of certain fibers. The randomly distributed fibres in the concrete redistribute tensile force and interrupt the propagation of cracks, improving post-cracking ductility (Faezah, 2012). With this mechanism, concrete becomes ductile and catastrophic failure can be prevented. Natural fibre in reinforced concrete is able to enhance tensile strength, flexural strength, modulus of elasticity, shrinkage, fatigue life and resistance to impact and abrasion (Nurulhuda, 2008). In addition, fibres in the tension zone contribute to flexural stiffness and fibers in the compression zone delay disintegration and enabling beams or columns to develop greater overall ductility during failure, which substantially increases energy absorption capabilities (Sellers *et al.*, 1999). However, fibre reinforced concrete is not meant to be a replacement for steel reinforcement for heavy loading applications. This is because of its inferior strength compared to conventional steel reinforcement bars.

In the 1960s, steel, glass and synthetic fibers such as polypropylene fibers were utilized with concrete, and research into new fiber reinforced concrete continues today. The above statement tells us that the investigation of materials and methods is needed to satisfy community needs.

There is still a lack of applications for natural fiber reinforced concrete in the construction industry. This may be caused by a lack of information on natural fiber reinforced concrete in the construction sector, especially in Malaysia. Consequently, natural fiber reinforced concrete is not popular in civil engineering despite its advantages compared to conventional cast-in-situ concrete. Natural fiber reinforced concrete will be accepted in the construction industry only after its characteristic properties are thoroughly investigated and well understood. (Lim, 2006)

The natural fiber used in this study is kenaf fiber. Kenaf has advantages compared to other cellulosic fiber crops since it has short plantation cycle, flexible environmental requirements, and requires less pesticides and herbicides. Kenaf fiber has superior properties such as high tensile strength, light weight, renewability, biodegradability, and affordability (Elsais *et al.*, 2011). The Malaysian government is interested in replacing tobacco plants with kenaf plants. Kenaf cultivation reveals that natural fibers could reduce CO₂ emissions.

The weaknesses of kenaf fiber as composite reinforcement is that its fibers are hydrophilic attract water, while matrix materials are typically hydrophobic and repel water. This difference in hydrophilicity makes wetting the fiber with a polymer matrix during the fabricating process difficult. The solution to this problem are surfaces treatment that improve interactions between the fibre and matrix material.

In order to assess the effectiveness of alkaline treatment on the kenaf fiber surface as well as the effect of kenaf fiber on the mechanical properties of concrete and reinforced concrete structures, a set of experimental tests were carried out. There is currently, no information about kenaf fiber applications in load-bearing structures. The use of kenaf fibers in a concrete matrix was carried out only for no-structural elements. Kenaf fiber can be used in combination with conventional reinforcing bars to improve concrete properties. Therefore studies on the load-bearing structure behaviour of KFRC beams using through experiments and theoretical analysis might be the best way to collect data in the process of preparing a universal standard for kenaf fiber design and construction. It is necessary to check the properties of the material, to determine the performance of KFRC and the optimum content of kenaf fiber before the material can be broadly used as a building material.

1.3 Objectives

The aim of the study is to investigate Kenaf fiber properties and their performance in concrete and reinforced concrete. There are five objectives for this study:

1. To characterise the physical and mechanical properties of kenaf fibers.
2. To investigate the effects of kenaf fibers on the properties of fresh and hardened concrete.
3. To observe the optimum characteristics of kenaf fiber reinforced concrete for structural applications.
4. To determine the load-deformation behaviour of reinforced concrete beams by employing kenaf fiber reinforced concrete.
5. To evaluate the analytical models of kenaf fiber reinforced concrete for reinforced concrete elements.

1.4 Scope of Study

The study was conducted experimentally to evaluate and develop kenaf fiber reinforced concrete based on requirements for availability, economical, recyclability, energy use, and environmental considerations. Before kenaf fiber reinforced concrete can be introduced to the marketplace and widely used as a building material, the properties of the material and methods used to handle the material must be carefully studied. This study mainly focuses on the development of standard mixtures for kenaf fiber reinforced concrete using various fiber parameters (fiber volume, fiber fraction, and fiber length) based on laboratory testing on fresh and hardened concrete.

The study was divided it into four stages as shown in below:

- Stage I: For kenaf fiber, the tests conducted were density test, water absorption test, weight loss and Scanning Electron Microscope (SEM) test.
- Stage II: For fresh concrete, the tests conducted were slump, compacting factor, and Vebe time test.
- Stage III: For hardened concrete, the tests conducted were compressive strength, splitting tensile strength, flexural strength, static modulus of elasticity in compression, and equivalent of compressive strength.
- Stage IV: For reinforced concrete beam, the test conducted was a four-point bending test.
- Stage V: Analytical models and theoretical analysis of KFRC beams were proposed and evaluated, then compared to experimental results.

1.5 Significance of Study

To develop kenaf fiber reinforced concrete as a material in the construction industry, the significance of this study is as follows:

- i. The development of kenaf fiber reinforced concrete as a sustainable green material would be beneficial for the construction industry.
- ii. The study of kenaf fiber chemical treatments provides information on the properties of kenaf fiber in concrete applications.
- iii. Kenaf fiber reinforced concrete can cause the industry to improve concrete properties and building life time.

- iv. The study of kenaf fiber reinforced concrete on load-bearing structure can provide information for a universal standard for kenaf fiber design and construction.

1.6 Outline of Thesis

There are 7 chapters in this thesis and each chapter gives information related to the research objectives. An outline of this thesis is shown below:

- i. **Chapter 1:** This chapter presents the introduction study background, problem statement, objectives, study scope, and study significance.
- ii. **Chapter 2:** This chapter presents the literature review. It covers brief explanations regarding natural fibers, kenaf fiber, kenaf fiber chemical treatments, and natural fiber reinforced concrete.
- iii. **Chapter 3:** This chapter presents information on material specifications, equipment and the experimental procedures used in this study.
- iv. **Chapter 4:** This chapter describes the results for kenaf fiber properties (physical and mechanical) and concrete trial mixes.
- v. **Chapter 5:** This chapter describes the results for kenaf fiber reinforced concrete. Fresh and hardened concrete properties are discussed.

- vi. **Chapter 6:** This chapter describes the results of the performance of KFRC beam structures under flexural loads and also make a comparison to the theoretical analysis.

- vii. **Chapter 7:** A summary of the major findings of the study together with some recommendations for further work is given in this chapter.

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