EFFECT OF CRUMB RUBBER INCORPORATION ON THE BEHAVIOUR OF CONCRETE BEAM SUBJECTED TO IMPACT LOAD

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2013

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by

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Thesis submitted in fulfillment of the requirement for the degree of Doctor Philosophy

2013

بسم الله الرحمن الرحيم

(قُلْ إِنَّ صَلَاتِي وَنُسُكِي وَمَحْيَايَ وَمَمَاتِي لِلَّهِ رَبِّ الْعَالَمِينَ , لَا شَرِيكَ لَهُ وَبِذَلِكَ أُمِرْتُ وَأَنَا أَوَّلُ الْمُسْلِمِينَ) (الأنعام:162-163)..

عن أمير المؤمنين أبي حفص عمر بن الخطاب رضي الله عنه قال سمعت رسول الله صلى الله عليه وسلم يقول "إنما الأعمال بالنيات , وإنما لكل امرئ ما نوى , فمن كانت هجرته إلى الله ورسوله فهجرته إلى الله ورسوله , ومن كانت هجرته إلى دنيا يصيبها و امرأة ينكحها فهجرته إلى ما هاجر إليه " متفق عليه

DEDICATION

To my loving parents Maher and Sabah Al-Tayeb who supported me at all the way; to my wife Heba Al-Tayeb for her unlimited love, patience and encouragement; to my children whose innocent energy was and still a source of inspiration; to all my sisters; to all my family members; to all of my friends and colleagues who stood beside me with great commitment; I dedicate this work hoping that I made all of them proud.

Mustafa Maher Altayeb

ACKNOWLEDGEMENTS

First of all, Alhamdulillah I praised to Allah S.W.T for the blessing granted to us……

I would like to give my deepest gratitude and appreciation to my supervisor Professor Badorul Hisham bin Abu Bakar, not only for his support and motivation during the research ,but also for his high humanity feelings with his students and other people and to my co-supervisors; Professor Hanafi bin Ismail and Professor Hazizan bin Md bin Akil for guided and advised me in this study.

Thank you very much goes to the School of Civil Engineering and Universiti Sains Malaysia for science and financial support. A farther debt of gratitude is due to the Ministry of Higher Education of Malaysia for the Malaysia International Scholarship (MIS).

Thank you very much goes to the staff and lab technicians of School of civil, Materials & Mineral Resources Engineering and Mechanical Engineering at Universiti Sains Malaysia.

Finally, I would like to express my sincere appreciation to brothers, friends and all the people who helped me throughout this research.

TABLE OF CONTENTS

	Page
Dedication	ii
Acknowledgements	iii
Table of Contents	iv
List of Tables	x
List of Figures	xii
List of Symbols	xxiii
List of Abbreviations	xxvii
Abstrak	xxviii
Abstract	xxx
CHAPTER ONE - INTRODUCTION	
1.1 General introduction	1
1.2 Classification of scrap-rubber	4
1.2.1 Slit tires	4
1.2.2 Shredded/chipped tires	4
1.2.3 Ground rubber	5
1.2.4 Crumb rubber	5
1.3 Cement and concrete history	7
1.4 Rubberized concrete and impact load	8
1.5 Finite element analysis	9
1.6 Problem statement	10
1.7 Objectives	12
1.8 Scope of work	13
1.9 Thesis Outline	14

Page

CHAPTER TWO - LITERATURE REVIEW

2.1 Introduction 16

2.2 Rubberized concrete 17

2.2.1 Properties of fresh rubberized concrete 17

2.2.1.1 Concrete Density 17

2.2.1.2 Air content 19

2.2.1.3 Workability 20

2.2.2 Properties of hardened rubberized concrete 21

2.2.2.1 Compressive and tensile stress 21

2.2.2.2 Flexural strength 25

2.2.2.3 Modulus of elasticity 26

2.2.2.4 Fracture toughness, ductility and Stiffness 28

2.2.2.5 Fatigue 30

2.2.2.6 Shrinkage crack 31

2.2.2.7 Ultrasonic wave test 31

2.2.2.8 Microstructures 32

2.3 Impact load 35

2.3.1 General definition of Impact load 36

2.3.2 Impact tests 36

2.3.2.1 Drop-weight impact test 36

2.3.2.2 Pendulum impact test 37

2.3.2.3 Split-Hopkinson pressure bar test 37

2.3.2.4 Projectile impact 37

Page

2.4 Concrete performance under impact load 37

2.5 Concrete with rubber under high loading rate 45

2.6 Hybrid structure 49

2.7 Impact analysis of concrete structure by FEM 50

2.8 Summary 59

CHAPTER THREE - EXPERIMENTAL WORK

3.1 Introduction 61

3.2 Materials 61

3.2.1 Cement 61

3.2.2 Aggregates 63

3.2.3 Crumb rubber 67

3.3 Preparing of concrete samples 70

3.3.1 Plain concrete 70

3.3.2 Concrete with crumb rubber 70

3.3.3 Concrete with fine crumb rubber 71

3.3.4 Concrete with powder crumb rubber 72

3.4 Testing 76

3.4.1 Slump test 76

3.4.2 Compression test 76

3.4.3 Splitting-tensile test 77

3.4.4 Fracture test 77

3.4.5 Impact and static flexural test 81

3.4.5.1 Preliminary impact test 81

Page

3.4.5.2 Instrumented static and impact flexural test 83

a. Static test 83

b. Instrumented impact test 84

3.5 Analysis of instrumented impact test results 89

3.5.1 Inertial and bending load 89

3.6 Summary 93

CHAPTER FOUR- RESULTS AND DISCUSSION -2

4.0 Introduction 94

4.1 Slump test 94

4.1.1 Concrete with crumb rubber 94

4.1.2 Concrete with fine crumb rubber 95

4.1.3 Concrete with rubber powder 96

4.2 Compressive stress and modulus of elasticity 97

4.2.1 Concrete with crumb rubber 97

4.2.2 Concrete with fine crumb rubber 99

4.2.3 Concrete with rubber powder 101

4.3 Splitting-tensile stress 102

4.3.1 Concrete with crumb rubber 102

4.3.2 Concrete with fine crumb rubber 103

4.3.3 Concrete with rubber powder 105

4.4 Fracture Toughness 106

4.4.1 Concrete with crumb rubber 106

4.4.2 Concrete with fine crumb rubber 110

4.4.3 Concrete with rubber powder 112

Page

4.5 Impact test 113

4.5.1 Concrete with crumb rubber 113

4.5.1.1 Preliminary (qualitative) impact test 113

4.5.1.2 Instrumental impact load (flexural) 116

4.5.1.2.1 Rubberized concrete beams (Cr) 116

4.5.1.2.2 Hybrid crumb rubber concrete beams (CrT) 122

4.5.1.2.3 Comparison of instrumental impact and static test results 128

4.5.2 Concrete with fine crumb rubber 130

4.5.2.1 Preliminary (qualitative) impact test 130

4.5.2.2 Instrumental impact load (flexural) 134

4.5.2.2.1 Rubberized concrete beams (Fr) 134

4.5.2.2.2 Hybrid crumb rubber concrete beams (FrT) 139

4.5.2.2.3 Comparison of instrumental impact and static test results 144

4.5.3 Concrete with rubber powder 148

4.5.3.1 Preliminary (qualitative) impact test 148

4.5.3.2 Instrumental impact load (flexural) 150

4.5.3.2.1 Rubberized concrete beams (Pr) 150

4.5.3.2.2 Hybrid crumb rubber concrete beams (FrT) 156

4.5.3.2.3 Comparison of instrumental impact and static test results 160

4.4 Summary 163

CHAPTER FIVE- NONLINEAR FINITE ELEMENT MODEL AND VALIDATION

Page

5.1 Introduction 165

5. 2 LUSAS software 165

5.3 Boundary conditions 167

5.4 Validation of finite element simulation 170

5.4.1 Plain concrete 170

5.4.2 Crumb rubber concrete beams (Cr) 174

5.4.3 Hybrid crumb rubber concrete beams (CrT) 180

5.4.4 Fine crumb rubber concrete beams (Fr) 186

5.4.5 Hybrid fine crumb rubber concrete beams (FrT) 189

5.4.6 Rubber powder concrete beams (Pr) and hybrid structure (PrT) 191

5.5 Summary 194

CHAPTER SIX- CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions 196

6.2 Recommendation of future works 199

REFERANCES 201

LIST OF PUBLICATIONS 211

APPENDIX A 214

APPENDIX B 220

APPENDIX C 227

LIST OF TABLES

		Page
Table 3.1	Chemical compositions of cement	63
Table 3.2	Sieve analysis of coarse aggregates	64
Table 3.3	Sieve analysis of fine aggregate	66
Table 3.4	Mix proportions of plain concrete	70
Table 3.5	Mix proportions of crumb rubber concrete	71
Table 3.6	Mix proportions of fine crump rubber concrete	71
Table 3.7	Mixture proportions of powder rubber concrete	72
Table 3.8	Numbers of samples for each required mix and test	75
Table 4.1	Reduction of compressive stress and modulus of elasticity with crumb rubber content	98
Table 4.2	Reduction of compressive stress and modulus of elasticity with fine crumb rubber content	99
Table 4.3	Reduction of compressive stress and modulus of elasticity with rubber powder content	101
Table 4.4	Reduction of splitting-tensile stress of plain and crumb rubber concrete	102
Table 4.5	Reduction of splitting-tensile stress of plain and fine crumb rubber concrete	103
Table 4.6	Reduction of splitting-tensile stress of the plain and rubber powder concrete	105
Table 4.7	Fracture toughness factors of plain and crumb rubber concrete	108

		Page
Table 4.8	Fracture toughness factors of plain and fine crumb rubber concrete	111
Table 4.9	Fracture toughness factors of plain and rubber powder concrete	112
Table 4.10	Preliminary impact test results for plain and crumb rubber concrete	115
Table 4.11	Comparison of experimental static and impact bending test results	129
Table 4.12	Preliminary impact test results for plain and fine crumb rubber concrete	131
Table 4.13	Comparison of experimental static and impact bending test results	145
Table 4.14	Preliminary impact test results for plain and rubber powder concrete	149
Table 4.15	Comparison of experimental static and impact bending test results	161
Table 5.1	Experimental and predicted deflection for different types of rubberized and hybrid rubber concrete	195

LIST OF FIGURES

		Page
Fig. 1.1	Piling yard of abandoned tires in Thailand	2
Fig. 1.2	Flow chart of destination of scrap tires	3
Fig. 1.3	Fire accident due to wasted tires in Stanislaus County	3
Fig. 1.4	Shredded/chipped tires	4
Fig. 1.5	Ground rubber	5
Fig. 1.6	Crumb rubber	6
Fig. 1.7	Romans Pantheon dome	7
Fig. 2.1	Effect of tire content on the unit weight of the concrete	18
Fig. 2.2	Effect of aggregate replacement ratio on air content of rubberized concrete	19
Fig. 2.3	Effect of rubber content on the workability of concrete	20
Fig. 2.4	Effect of fine (0-1 mm) and coarse (1-4 mm) rubber content on the compressive stress	22
Fig. 2.5	Effect of chipped and ground rubber content on the compressive stress	24
Fig. 2.6	Effect of rubber content on the tensile stress	25
Fig. 2.7	Effect of rubber content on the modulus of elasticity	27
Fig. 2.8	Lateral buckling deflection	30
Fig. 2.9	SEM image of cement specimen with 10% tire rubber	33
Fig. 2.10	SEM image of cement specimen with 10% treated tire rubber	34

		Page
Fig. 2.11	Strain rates associated with different types of loading	35
Fig. 2.12	Stress-strain diagrams for two type of concretes at different rates of straining	39
Fig. 2.13	The relationship between maximum stress and loading rate under different curing conditions	41
Fig. 2.14a	Tensile stress-strain behaviour of mortar	42
Fig. 2.14b	Tensile stress-strain behaviour of concrete	43
Fig. 2.14	Tensile stress-strain behaviour under static and dynamic load	43
Fig. 2.15	The elastic dynamic modulus with volume ratio of rubber	47
Fig. 2.16	Effect of aggregate replacement ratio on impact energy of rubberized concrete	48
Fig. 2.17	Base isolated hybrid structure	49
Fig. 2.18	Hybrid structure (Concrete incorporating scrap rubber tire particles in bottom and plain concrete in top)	49
Fig. 2.19	Experimental and model crack pattern	52
Fig. 2.20	Fragment and target with damaged zones after 20 μs of impact	53
Fig. 2.21	Failure modes and energy balance for Impact velocity of (a) 2 m/s. (b) 4 m/s. (c) 6 m/s. (d) 8 m/s	57
Fig. 2.22	Finite element mesh of specimens	58
Fig. 3.1	Summary of methodology of the present work	62
Fig. 3.2	Sieve Analysis for Coarse Aggregates	65
Fig. 3.3	Sieve Analysis for Fine Aggregates	66

		Page
Fig. 3.4	Crumb rubber of particle size 1 mm	67
Fig. 3.5	Fine crumb rubber of particle size 0.4–0.9 mm	68
Fig. 3.6	Particle size distribution of fine crumb rubber	68
Fig. 3.7	Rubber powder of particle size 0.15–0.6 mm	69
Fig. 3.8	Particle size analysis of rubber powder	69
Fig. 3.9	Hybrid concrete beam	73
Fig. 3.10	Specimen used in the fracture test	78
Fig. 3.11	Test rig of fracture test	80
Fig. 3.12	Preliminary impact tes	82
Fig. 3.13	Static flexural test	83
Fig. 3.14	The instrumented impact flexural test rig	85
Fig. 3.15	Cylinders supported and load cell	86
Fig. 3.16	Accelerometer and tup location on the beam	87
Fig. 3.17	Accelerometer and load cell setup	88
Fig. 3.18	Inertial load	90
Fig. 3.19	Bending load	90
Fig. 2.20	Computation of the generalized inertial load	91
Fig. 4.1	Effect of aggregate replacement ratio on slump of crumb rubber concrete	95
Fig. 4.2	Effect of aggregate replacement ratio on slump of crumb rubber concrete	96

		Page
Fig. 4.3	Effect of aggregate replacement ratio on slump of rubber powder concrete	97
Fig. 4.4	Compressive stress against volume fraction of different rubber types in concrete	100
Fig. 4.5	Splitting-tensile stress against volume fraction of different rubber types in concrete	104
Fig. 4.6	Load against deflection for plain and crumb rubber concrete notched beam	107
Fig. 4.7	Load against CMOD for plain and crumb rubber concrete notched beam	109
Fig. 4.8	Load against deflection for plain and fine crumb rubber concrete notched beam	110
Fig. 4.9	Load against CMOD for plain and crumb rubber concrete notched beam	112
Fig. 4.10	Tup load history of crumb rubber concrete	116
Fig. 4.11	The acceleration history of plain and crumb rubber concrete	117
Fig. 4.12	The deflection history of plain and crumb rubber concrete	118
Fig. 4.13a	Histories of Tup, inertial, and bending loads of Plain concrete	119
Fig. 4.13b	Histories of Tup, inertial, and bending loads of Cr 5%	119
Fig. 4.13c	Histories of Tup, inertial, and bending loads of Cr 10%	120
Fig. 4.13d	Histories of Tup, inertial, and bending loads of Cr 20%	120
Fig. 4.13	Histories of Tup, inertial, and bending loads	120

		Page
Fig. 4.14	Impact bending load against deflection	121
Fig. 4.15	Tup load history of hybrid crumb rubber concrete beam	122
Fig. 4.16a	Histories of Tup, inertial, and bending loads of CrT 5%	123
Fig. 4.16b	Histories of Tup, inertial, and bending loads of CrT 10%	123
Fig. 4.16c	Histories of Tup, inertial, and bending loads of CrT 20%	124
Fig. 4.16	Tup, inertial, and bending loads history	124
Fig. 4.17a	Histories of tup loads of Plain, Cr 5%, CrT 5%	125
Fig. 4.17b	Histories of tup loads of Plain, Cr 10%, CrT 10%	125
Fig. 4.17c	Histories of tup loads of Plain, Cr 20%, CrT 20%	126
Fig. 4.17	Tup load history of plain, crumb rubber and Hybrid crumb rubber concrete beams	126
Fig. 4.18a	Impact bending load against deflection for Plain, Cr 5%, CrT 5%	126
Fig. 4.18b	Impact bending load against deflection for Plain, Cr 10%, CrT 10%	127
Fig. 4.18c	Impact bending load against deflection for Plain, Cr 20%, CrT 20%	127
Fig. 4.18	Impact bending load against deflection	127
Fig. 4.19	First crack impact resistance against volume fraction of rubber	132
Fig. 4.20	First crack impact energy against volume fraction of rubber	132
Fig. 4.21	Failure impact resistance against volume fraction of rubber	133
Fig. 4.22	Failure impact energy against volume fraction of rubber	133

		Page
Fig. 4.23	Tup load history of fine crumb rubber concrete	134
Fig. 4.24	The acceleration history of plain and fine crumb rubber concrete	135
Fig. 4.25	The deflection history of plain and fine crumb rubber concrete	136
Fig. 4.26a	Histories of Tup, inertial, and bending loads of Fr 5%	137
Fig. 4.26b	Histories of Tup, inertial, and bending loads of Fr 10%	137
Fig. 4.26c	Histories of Tup, inertial, and bending loads of Fr 20%	138
Fig. 4.26	Histories of Tup, inertial, and bending loads	138
Fig. 4.27	Impact bending load against deflection	139
Fig. 4.28	Tup load history of Hybrid fine crumb rubber concrete beam	140
Fig. 4.29a	Histories of Tup, inertial, and bending loads of FrT 5%	141
Fig. 4.29b	Histories of Tup, inertial, and bending loads of FrT 10%	141
Fig. 4.29c	Histories of Tup, inertial, and bending loads of FrT 20%	142
Fig. 4.29	Tup, inertial, and bending loads history	142
Fig. 4.30a	Tup load history of Plain, Fr 5%, FrT 5% concrete	143
Fig. 4.30b	Tup load history of Plain, Fr 10%, FrT 10% concrete	143
Fig. 4.30c	Tup load history of Plain, Fr 20%, FrT 20% concrete	144
Fig. 4.30	Tup load history of plain, fine crumb rubber and Hybrid fine crumb rubber concrete	144
Fig. 4.31a	Impact bending load against deflection for Plain, Fr 5%, FrT 5% concrete	146

		Page
Fig. 4.31b	Impact bending load against deflection for Plain, Fr 10%, FrT 10% concrete	146
Fig. 4.31c	Impact bending load against deflection for Plain, Fr 20%, FrT 20% concrete	147
Fig. 4.31	Impact bending load against deflection	147
Fig. 4.32	Tup load history of powder rubber concrete	151
Fig. 4.33	The deflection history of plain and crumb rubber concrete	152
Fig. 4.34a	Histories of tup, inertial, and bending loads of Pr 5%	153
Fig. 4.34b	Histories of tup, inertial, and bending loads of Pr 10%	153
Fig. 4.34c	Histories of tup, inertial, and bending loads of Pr 20%	154
Fig. 4.34	Histories of tup, inertial, and bending loads	154
Fig. 4.35	Impact bending load against deflection for rubber powder concrete	155
Fig. 4.36	Tup load history of Hybrid rubber powder concrete beam	156
Fig. 4.37a	Tup, inertial and bending loads history of PrT 5%	157
Fig. 4.37b	Tup, inertial and bending loads history of PrT 10%	157
Fig. 4.37c	Tup, inertial and bending loads history of PrT 20%	158
Fig. 4.37	Tup, inertial and bending loads history	158
Fig. 4.38a	Tup load history of Plain, Pr 5%, PrT 5% concrete	159
Fig. 4.38b	Tup load history of Plain, Pr 10%, PrT 10% concrete	159
Fig. 4.38c	Tup load history of Plain, Pr 20%, PrT 20% concrete	160

		Page
Fig. 4.38	Tup load history of plain, rubber powder and Hybrid rubber powder concrete beams	160
Fig. 4.39a	Impact bending load against deflection for Plain, Pr 5%, PrT 5% concrete	162
Fig. 4.39b	Impact bending load against deflection for Plain, Pr 10%, PrT 10% concrete	162
Fig. 4.39c	Impact bending load against deflection for Plain, Pr 20%, PrT 20% concrete	163
Fig. 4.39	Impact bending load against deflection	163
Fig. 5.1a	Finite element models for Plain concrete	167
Fig. 5.1b	Finite element models for Rubberized concrete	168
Fig. 5.1c	Finite element models for Hybrid concrete	168
Fig. 5.1	Finite element models for three types of specimens	168
Fig. 5.2	Experimental and predicted impact load against deflection for plain concrete	170
Fig. 5.3a	Stress Distribution Contour at 200μs	171
Fig. 5.3b	Stress Distribution Contour at 400μs	171
Fig. 5.3c	Stress Distribution Contour at 600μs	172
Fig. 5.3d	Stress Distribution Contour at 800μs	173
Fig. 5.3e	Stress Distribution Contour at 1 ms	174
Fig. 5.3	Stress Distribution Contour for plain concrete beam	174

		Page
Fig. 5.4a	Experimental and predicted impact load against deflection for Cr 5%	175
Fig. 5.4b	Experimental and predicted impact load against deflection for Cr 10%	175
Fig. 5.4c	Experimental and predicted impact load against deflection for Cr 20%	176
Fig. 5.4	Experimental and predicted impact load against deflection for crumb rubber concrete	176
Fig. 5.5a	Stress Distribution Contour at 200μs	177
Fig. 5.5b	Stress Distribution Contour at 400μs	178
Fig. 5.5c	Stress Distribution Contour at 600μs	179
Fig. 5.5d	Stress Distribution Contour at 800μs	180
Fig. 5.5	Stress Distribution Contour for crumb rubber concrete	180
Fig. 5.6a	Experimental and predicted impact load against deflection for CrT 5%	181
Fig. 5.6b	Experimental and predicted impact load against deflection for CrT 10%	181
Fig. 5.6c	Experimental and predicted impact load against deflection for CrT 20%	182
Fig. 5.6	Experimental and predicted impact load against deflection for Hybrid crumb rubber concrete beam	182
Fig. 5.7a	Stress Distribution Contour at 200μs	183

		Page
Fig. 5.7b	Stress Distribution Contour at 400μs	184
Fig. 5.7c	Stress Distribution Contour at 600μs	185
Fig. 5.7d	Stress Distribution Contour at 800μs	186
Fig. 5.7	Stress Distribution Contour for Hybrid crumb rubber concrete beam	186
Fig. 5.8a	Experimental and predicted impact load against deflection for Fr 5%	187
Fig. 5.8b	Experimental and predicted impact load against deflection for Fr 10%	188
Fig. 5.8c	Experimental and predicted impact load against deflection for Fr 20%	188
Fig. 5.8	Experimental and predicted impact load against deflection for fine crumb rubber concrete beam	188
Fig. 5.9a	Experimental and predicted impact load against deflection for FrT 5%	189
Fig. 5.9b	Experimental and predicted impact load against deflection for FrT 10%	190
Fig. 5.9c	Experimental and predicted impact load against deflection for FrT 20%	190
Fig. 5.9	Experimental and predicted impact load against deflection for Hybrid fine crumb rubber concrete beam	190
Fig. 5.10a	Experimental and predicted impact load against deflection for Pr 5%	191

Page

Fig. 5.10b	Experimental and predicted impact load against deflection for Pr 10%	192
Fig. 5.10c	Experimental and predicted impact load against deflection for Pr 20%	192
Fig. 5.10	Experimental and predicted impact load against deflection for rubber powder concrete beam	192
Fig. 5.11a	Experimental and predicted impact load against deflection for PrT 5%	193
Fig. 5.11b	Experimental and predicted impact load against deflection for PrT 10%	193
Fig. 5.11c	Experimental and predicted impact load against deflection for PrT 20%	194
Fig. 5.11	Experimental and predicted impact load against deflection for Hybrid rubber powder concrete beam	194

LIST OF SYMBOLS

A	Area of cross section
a_o	Notch depth of the beam
$[B_i]$	Strain- deflection matrix
b	width of the beam
C_i	Initial compliance
D	Diameter of cylinder
$[D]^{-1}$	Isotropic elasto-plastic matrices
d	Depth of the beam
E	Young's modulus
E_b	Fracture energy
E_f	Fracture Young's modulus
$F_{i1}(t)$	Equivalent force for the distributed forces inside the support
$F_{i2}(t)$	Equivalent force for the distributed forces outside the support
$\{f\}$	Loading vector
$f(\alpha)$	Geometry correction for bending load
G	Modulus of rigidity
g	Gravitational acceleration
H	Drop height
$[K]$	Stiffness matrix
K_{IC}	Stress intensity factor
L	Length of the beam
L_c	Length of cylinder
l	Span length of the beam

[M]	Mass matrix
M_c	Moment at the center
m	Mass of the hammer
[*N*]	Element shape function array
n	Number of bows
$P_b(t)$	Generalized bending load history
P_c	Compression load
$P_i(t)$	Generalized point inertial load history
P_{max}	Maximum bending load
P_T	Tensile load
$P_t(t)$	Total tup load history
R(t)	Reaction at the support
U	Total impact energy
{u}	Deformation vector at any location over the element
$\{u_i\}$	Deformation vector at the specified node of the element
u_i	Displacements of the point in the directions of the Cartesian x axes
$u_c(t)$	Time history of the central deflection
u(x, t)	Deflections history of the portion of the beam inside the supports
u(y, t)	Deflection s history of the portions of the beam outside the supports
$\ddot{u}_c(t)$	Time history of the central accelerations
ü(x, t)	Acceleration history of the portion of the beam inside the supports
ü(y, t)	Acceleration history of the portions of the beam overhanging the supports
δu(x)	Virtual deflections of the portion of the beam inside the supports
δu(y)	Virtual deflections of the portion of the beam inside the supports

v	Velocity of the hammer immediately before the contact
v_i	Displacements of the point in the directions of the Cartesian y axes
W	Self-weight of the beam
w_i	Displacements of the point in the directions of the Cartesian z axes
α	a_0/d
ΔE	Kinetic energy lost by the hammer
ε	Normal strains
{ε}	Strain vector
γ	Tangential strains
ρ	Mass density
[ρ]	Density matrix
σ_c	Compression stress
σ_T	Tensile stress
σ_x	Normal stresses on the x plane
σ_y	Normal stresses on the y plane
σ_z	Normal stresses on the z plane
τ_{xy}	Shearing stresses on the x plane and y direction
τ_{xz}	Shearing stresses on the x plane and z direction
τ_{yz}	Shearing stresses on the y plane and z direction
υ	Poisson's ratio
ξ	Local coordination in the directions of the Cartesian x axes
ξ_i	Displacements of the node in the directions of the Cartesian ξ axes
η	Local coordination in the directions of the Cartesian y axes

η_i Displacements of the node in the directions of the Cartesian η axes

ζ Local coordination in the directions of the Cartesian z axes

ζ_i Displacements of the node in the directions of the Cartesian ζ axes

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
CMOD	Crack Mouth Opening Displacement
Cr	Concrete with replacement of sand volume by percentage of crumb rubber
CrT	Hybrid concrete beams in case of casting the top layer of the beam by rubberized concrete with percentage of crumb rubber
EN	European Union standard
Fr	Concrete with replacement of sand volume by percentage of fine crumb rubber
FrT	Hybrid concrete beams in case of casting the top layer of the beam by rubberized concrete with percentage of fine crumb rubber
ITZ	Interfacial Transition Zone
MS	Malaysian Standard
OPC	Ordinary Portland Cement
Pr	Concrete with replacement of sand volume by percentage of rubber powder
PrT	Hybrid concrete beams in case of casting the top layer of the beam by rubberized concrete with percentage of rubber powder
SEM	Scanning Electron Microscopy

KESAN PENAMBAHAN CEBISAN GETAH TERHADAP SIFAT RASUK KONKRIT DI KENAKAN BEBAN HENTAMAN

ABSTRAK

Konkrit yang mengandungi cebisan getah di dalamnya telah diketahui umum menambahbaik sifat keanjalannya serta kemampuan untuk menyerap tenaga. Walau bagaimana pun, tenaga lentur sebenar di bawah beban hentaman masih dipertikai dan diperdebatkan. Tambahan pula tingkah laku hibrid (getahan di atas-konkrit biasa dibawah) struktur konkrit hibrid di bawah beban hentaman atau dalam keadaan beban statik masih dikaji. Oleh itu dalam kajian ini, eksperimen dan analisis tak linear dinamik konkrit dengan penambahan cebisan getah dikaji. Penambahan cebisan getah (5%, 10% dan 20%) berasaskan isipadu pasir atau simer dilakukan terhadap konkrit. Tiga saiz cebisan getah yang berbeza digunakan cebisan getah (1 mm), cebisan getah halus (0.4-0.9 mm) dan serbuk cebisan getah (0.15-0.6 mm). Tiga jenis spesimen iaitu konkrit biasa, konkrit berlapis getah, dan konkrit lapisan berganda disediakan dan dilakukan ujian hingga gagal menggunakan mesin hentaman beban jatuh seberat 20 N dari ketinggian 300 mm, dan tiga lagi spesimen yang sama telah digunakan untuk ujian beban statik. Dalam kedua-dua ujian, beban-pesongan dan keretakan setiap spesimen telah dikaji. Simulasi unsur terhingga telah juga dilakukan untuk mengkaji tingkah laku dinamik sampel dengan menggunakan perisian LUSAS V.14. Rasuk dimodelkan sebagai elemen heksagon dan mempunyai lapan nod. Bahan elastoplastik telah digunakan untuk memodelkan kedua-dua struktur konkrit biasa dan konkrit bergetah tersebut. Skim dinamik tak tersirat telah digunakan untuk menentukan peningkatan pesongan dengan masa. Secara umum keputusan menunjukkan beban impak semakin meningkat dengan peningkatan dalam

peratusan getah. Pemerhatian menunjukkan bahawa kesan ini adalah lebih ketara untuk spesimen lapisan berganda. Secara umum, kekuatan dan tenaga keupayaan menyerap konkrit berlapis getah adalah lebih baik di bawah pembebanan hentaman daripada pembebanan statik. Beban simulasi terhadap tingkah laku pesongan semua sampel telah disahkan oleh keputusan eksperimen.

EFFECT OF CRUMB RUBBER INCORPORATION ON THE BEHAVIOUR OF CONCRETE BEAM SUBJECTED TO IMPACT LOAD

ABSTRACT

It is well known that concrete containing crumb rubber would enhance the elastic properties of concrete as well as ability to absorb energy. However, the actual flexural energy under impact load is still questionable and debatable. Moreover, the behavior of hybrid (rubberized top-plain bottom) concrete structures under impact or static load conditions are yet to be investigated. In this study, experimental and nonlinear dynamic analysis of rubberized concrete under impact load was investigated. Rubberized concrete samples were prepared by partial substitution (5%, 10% and 20 % replacements by volume) of sand or cement by two size of crumb or powder rubber respectively, and tested under impact three-point bending load, as well as static load. Three types of specimens namely, plain concrete, rubberized concrete, and double layer concrete were loaded to failure in a drop-weight impact machine by subjecting to 20N weight from a height of 300mm, and another three similar specimens were used for the static load test. In both tests, the load-deflection and fracture energy of each specimen were investigated. Finite-element simulations were also performed to study the dynamic behaviours of the samples, by using LUSAS V.14 software. The concrete beam was modeled to be built with eight node hexahedron elements and elasto-plastic material was used to model both plain and rubberized concrete structures. Explicit nonlinear dynamic scheme was used to determine the deflection increments for each time step.In general the result was noticed that, the impact loads increased with the increase in the percentage of rubber. It was interesting to observe that these effects were more significant in the double layer specimen. In general, the strength and energy absorbing capability of

rubberized concrete was better under impact loading than under static loading. The simulated load against deflection behaviours of all the samples were validated by the experimental results.

CHAPTER ONE

INTRODUCTION

1.1 General introduction

Concrete is the most commonly used construction material. In the context of the current construction requirements, the properties of concrete in terms of its flexibility, toughness, energy absorption and impact resistance needs further improvement (Topcu, 1995 and Wang et al., 2000). On the other hand disposal of waste rubber is a serious environmental issue all around the globe, on account of its health hazard and difficulty in land filling. The high cost of disposal and the requirement of large landfill area often result in random and illegal dumping of waste rubber (Siddique and Naik, 2004) and over 281 million scrap tires are generated in United States every year (Baker et al., 2003). According to "Markets for Scrap Tires"1991 edition, published by the US Environmental Protection Agency (EPA), only 7% of the tires are recycled into new products and about 11% are converted into energy. Over 77.6%, or about 218 million tires per year, are land filled, stockpiled, or illegally dumped and the remaining 5% are exported. In Malaysia, a number of project involving a huge investment in waste rubber recycling has been monitored. For instance, in 2002 a project totaling RM4.47 billion was approved by Malaysian Industrial Development Authority (MIDA) to proceed with the recycling project of scrap tires to manufacture synthetic rubber powder and thermoplastic elastomer (TPE) (Awang, 2008).

Figure 1.1 shows one such dump yard in Thailand reflecting the gravity of the problem. Figure 1.2 shows that the flow chart detailing the distribution of the scrap tire.

Landfilling of scrap tires in open piles causes a number of problems such as degradation of the landscape, health diseases vectored by mosquito, and serious open tire fires which is difficult and need long time to extinguish (See Figure 1.3). Moreover it has serious impact on health and the environment due to dangers of air emissions via black and carbon smoke and also contamination of water and soil due to the run-off water and pyrolytic oil released from the burning tires (EPA, 1991 and Siddique and Naik, 2004). Due to the high cost of disposal and the requirement of large landfill area for waste rubber, the issue of random and illegal dumping is alarming (Siddique and Naik, 2004).

Fig. 1.1: Piling yard of abandoned tires in Thailand (Sukontasukkul and Chaikaew, 2006)

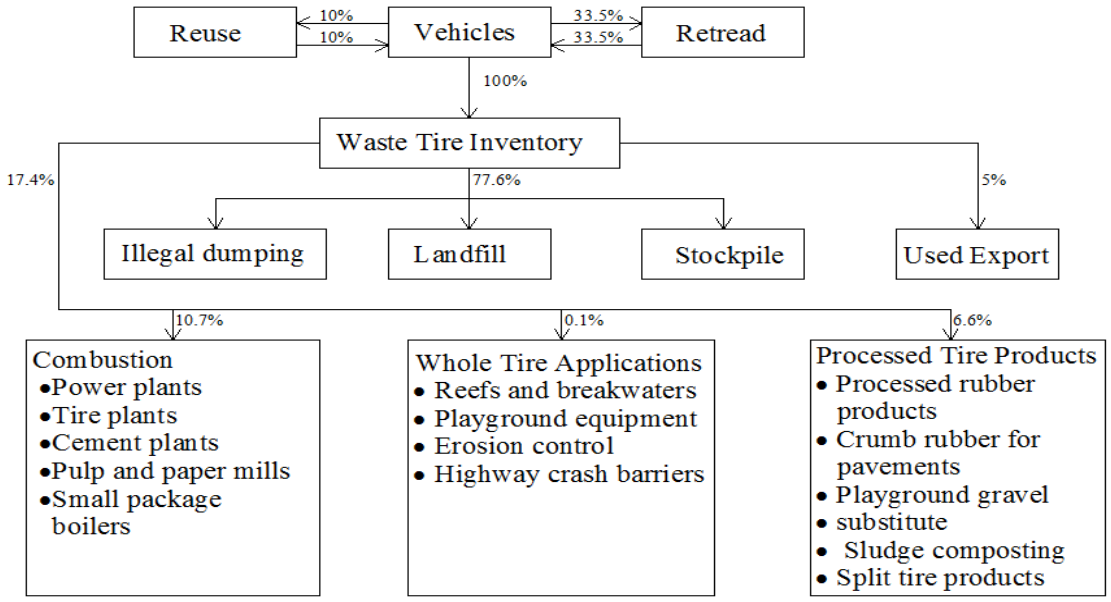

Fig. 1.2: Flow chart of destination of scrap tires (EPA, 1991).

Fig. 1.3: Fire accident due to wasted tires in Stanislaus County, CA. (Sukontasukkul and Chaikaew, 2006)

Driven by this situation, efforts are on, to identify alternative solutions to reuse the waste rubber, and its use in concrete as partial substitutes for sand. This partial replacement of rubber in cement has been proven to be one of the promising options.

1.2 Classification of scrap-rubber

According to Siddique and Naik (2004), scrap-rubber can be classified into four types with regard to their particle size:

1.2.1 Slit tires

The tires are produced by separating the sidewalls from the thread of the tires or cutting the tire into two halves. This process was carried out in large amount of scrap tires in the factory (Siddique and Naik, 2004).

1.2.2 Shredded/chipped tires

It is produced by shredding tire into shreds or chips that vary from 300 to 460 mm long, 100 to 230 mm wide, and 100–150 mm length in the primary process. Production of tire chips, usually sized from 76 to 13 mm requires both primary and secondary shredding to achieve reduction of volume. Figure 1.4 shows the appearance of shred tire (Khaloo et al., 2008).

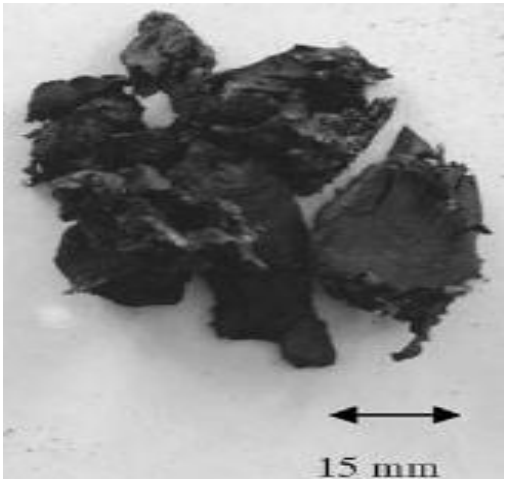

Fig. 1.4: Shredded/chipped tires (Khaloo et al., 2008)

1.2.3 Ground rubber

The two process involved in ground rubber are magnetic separation and screening process. Normally the size of ground rubber varies from 19 mm to 0.15 mm depending on the size of reduction, equipment and envisioned usage. Figure 1.5 shows the appearance of ground rubber (Khaloo et al., 2008).

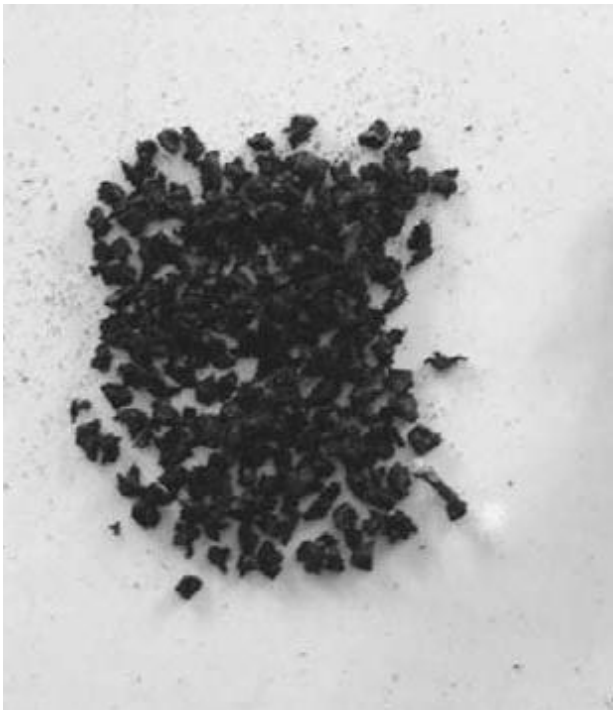

Fig. 1.5: Ground rubber (Khaloo et al., 2008)

1.2.4 Crumb rubber

The typical process in making crumb as in Figure 1.6 involves three stages. First, the scrap tire is reduced to particles ranging from 5 to 0.075 mm size shreds by reducing the size of tire rubber. This is generally accomplished by passing the material between rotating corrugated steel drums or the cracker mill process which tears it apart. Second,

the screen and gravity separators are used to remove metal. And finally, aspiration equipment is used to remove fibers (Son et al., 2011).

Fig. 1.6: Crumb rubber (Son et al., 2011)

In this research three different sizes of crumb rubber which are crumb rubber of 1 mm particle size, fine crumb rubber of particle size 0.4–0.9 mm and powder crumb rubber of particle size 0.15–0.6 mm will be added to concrete. The mechanical properties of the concrete will then be investigated.

1.3 Cement and concrete history

Cement is defined as adhesive and cohesive material having capability to bond fragment or masses of solid material (Lea and Hewlett, 1998). The use of cementing materials can be dated back to very ancient times. The ancient Egyptians used lime mortar in the pyramid construction. The Greeks and Etruscans also used cement limestone. The first concrete in history was developed by Romans who improved the mortar properties by adding sand and crushed stone or brick and broken tiles to lime and water (Neville, 1995). One of the most remarkable examples of the concrete works is the Pantheon dome as seen in Figure 1.7 (Wilkins, 2004).

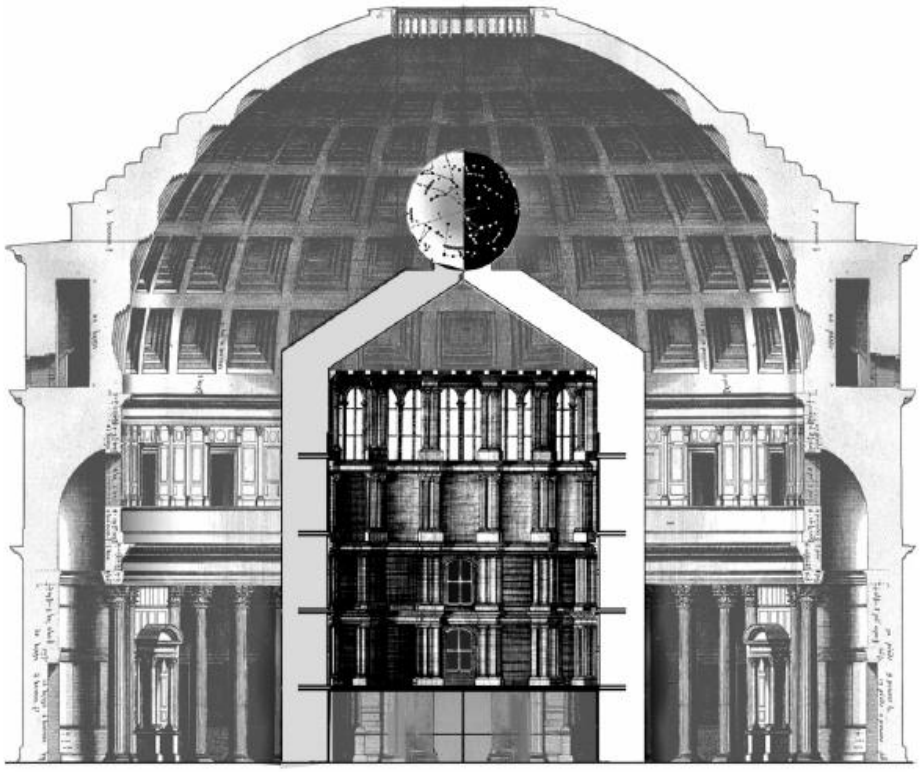

Fig. 1.7: Romans Pantheon dome (Wilkins, 2004)

The Romans discovered that lime mortar does not harden under water, so they milled lime and volcanic ash or finally ground burnt clay tiles to produce pozzolanic cement

referring to village of Pozzuoli, near Vesuvius. Modern concrete technology took shape in the late 18th century. In 1756, it was discovered that the best mortar could be produced by mixing limestone with pozzolana which contains high production of clayey material. It was only in 1824, Joseph Aspdin discovered the Portland cement. This cement is formed by heating finely divided clay with ground limestone in a furnace until CO_2 has been driven off. Isaac Johnson in 1845 discovers the prototype of modern cement by burning its raw materials to clinkering temperatures in order to satisfy the reaction necessary for creating strong cementing compounds (Neville, 1995).

1.4 Rubberized concrete and impact load

Recently many researchers have carried out investigations on the ability of tire rubber in concrete as a replacement for sand or aggregates to improve the properties of concrete and to reduce the waste material dumping problems by utilizing these waste materials as raw material.

The ability to reuse rubber as partial replacement in concrete was studied by Eldin and Senouci (1993), in which they used two groups of rubberized mixes. In the first group, part of sand was substituted by crumb rubber in the range of 25, 50, 75 and 100 percentages. In the second group, a portion of coarse aggregate was substituted by chip rubber in similar percentage as in the first group. The result observed using 100% of crumb rubber as sand replacement leads to losses of up to 65% of the compressive stress and up to 50% of the tensile stress in the first group. However the study also concludes that the ductility of concrete was improved which makes rubberized concrete suitable for structure subjected to dynamic or impact loading. Topcu (1995) also demonstrated

that using waste tire in concrete improves the toughness value and the plastic energy capacities. He concluded that high ductility of rubberized concrete leads to high strains under static and impact load.

The impact resistance of rubberized concrete was studied by Topcu and Avcular (1997) for highway barriers. They determined that the presence of rubber tire particles yields significant enhancement in the impact resistance. Similarly,Taha et al. (2008) observed enhancement in the impact resistance of concrete beams by adding crumb or chipped tire rubber particles. Nevertheless, almost all the previous studies investigated the impact resistance of rubberized concrete qualitatively by counting the numbers of blows that result in cracking or failure of the structure. However, this method was improved by Banthia (1985) method which is not followed by Taha et al (2008) to measure the load, deflection and acceleration of concrete beam under impact energy.

1.5 Finite element analysis

There are several difficulties in analyzing normal or rubberized concrete structures under dynamic load because of the nonlinear behaviour of structure and the nonlinear dynamic load with time. New approaches of nonlinear structural analysis have been introduced in the recent times owing to the development of powerful computers, where the structural response can be investigated in terms of the total loading range. The finite element approach is one of such important method which solves the numerical equations that govern the problems found in nature. The finite element method improved in the field of structural engineering where dimensional element to analyzed the stresses in continuous bars and beams was developed. Then the shape functions defined over

triangular regions in the applied mathematics was developed. Then treatment of two-dimensional elements was developed by derived the stiffness matrix for triangular and rectangular elements in plane stress. After that matrix structural analysis was driven from the stiffness matrix of a plane stress rectangular panel. The formulations of element stiffness matrices by early investigators were not based on the field equations of the entire elastic continuum (Huebner et al. 2008).

In 1967 Zienkiewicz published the first book describing applications of the method in the analysis of material behaviour. After that the finite element method became one of the most important methods used in the engineering analysis and design. And it has become indispensable to analyzing structural problems with complex material behaviours and complicated boundary conditions (Oñate, 2009).

1.6 Problem statement

Disposal of waste rubber is a serious environmental issue all around the globe, on account of its health hazard and difficulty in land filling. The high cost of disposal and the requirement of large landfill area often result in random and illegal dumping of waste rubber (Siddique and Naik, 2004). This serious environmental and health issues associated with rubber demands urgent attention to develop alternative solutions for their reuse in other applications. In Malaysia, a number of projects involving a huge investment in waste rubber recycling have been observing. For instance, in 2002 a project total RM 4.47 billion was approved by Malaysian Industrial Development Authority to proceed with the recycling project of scrap tires to manufacture synthetic rubber powder and thermoplastic elastomer (Awang, 2008). On the other hand, normal

concrete exhibits limited properties such as small resistance to cracking, low ductility, and low impact energy absorption (Wang et al., 2000). However, it was established that adding the waste tire to concrete would enhance its ability of crack resistance ductility and energy absorption (Topcu 1995).

According to the literature, no study has been reported on the static fracture toughness of concrete with assessment of crack resistance for rubberized concrete using crack mouth opening displacement (CMOD).

However, only Reda-Taha et al. (2008) investigated the effect of crumb and fine crumb rubber in the bending impact resistance to a rectangular beam. In this work, the impact energy was reported qualitatively by calculating the impact energy from a number of drops until failure. It was noted that there is no instrumented impact test using load cell and accelerometer to investigate the accurate impact load causing the failure or deformation of the rubberized concrete beams. Furthermore, previous investigations did not measure the actual fracture energy of the rubberized concrete beam under impact bending load.

Moreover, the nonlinear finite element dynamic analysis of rubberized concrete structures which is a promising contribution to facilitate realistic predictions the behaviour of rubberized concretes beams. Also, investigations into the behaviour of hybrid (rubberized top-plain bottom) concrete structures under impact or static load conditions are yet to be accomplished by any researcher. Thus, there are several gaps in the previous research, which needs to be addressed to arrive at a mix of concrete having best possible impact properties of concrete.

1.7 Objectives

The overall objective of the project is to investigate the feasibility of improving the impact resistance of concrete bream. This research will investigate the feasibility of used of waste rubber tire in concrete subjected to impact load and to investigate its properties of energy absorption and ductility.

Thus the main objectives of this work are:

i. To study the suitable size of rubber, its mixed proportion and material properties of rubberized concrete.

ii. To determine the static fracture toughness of rubberized concrete with assessment of crack resistance using crack mouth opening displacement (CMOD).

iii. To investigate the effect of crumb rubber incorporation on the impact tup, inertial load and bending load of rubberized concrete and hybrid beam experimentally.

iv. To analyze the impact energy and behaviour of rubberized concrete and hybrid structure beam subjected to impact load.

v. To verify finite element model for simulating the behaviour of rubberized and hybrid concrete beams based on the measured data.

1.8 Scope of work

In the present work, the impact load and displacement, and dynamic fracture energy are investigated for concrete beams containing fine crumb rubber, crumb rubber and powder rubber. The crumb rubber particle size 1 mm and fine crumb rubber particle size 0.4–0.9 mm are used in replacement ratio of 5%, 10%, and 20% by volume of sand and the same proportions of powder rubber 0.15–0.6 mm is added to the concrete with proportional decrease in the volume of cement.

Alongside this, double layer beam with rubberized top and plain bottom (hybrid structure), are tested under impact three-point bending load to investigate its impact behaviour and to improve its ability to absorb the impact energy. Numerical simulations are carried out to study the dynamic behaviour of all the samples. LUSAS V.14 tool is used to simulate the behaviour of rubberized concrete beams under impact load. In order to determine the properties of rubberized concrete, experiments has been carried out to study the material behaviour under compressive and tensile loadings. The concrete beam is assumed to be made of eight node hexahedron elements. And to substantiate the present finite element model, the predicted impact behaviour is compared with the experimental results.

In order to further accomplish the objectives of the present study, the fracture properties such as stress intensity factor (K_{IC}), Young's modulus (E), critical energy release rate (G_{IC}), and crack resistance using crack mouth opening displacement (CMOD) are investigated as preliminary test for the three group of rubberized concrete.

1.9 Thesis Outline

The present thesis is organized into five chapters. A brief outline of each chapter is given hereunder:

- Chapter one presents general information about the problems due to waste tire rubber, concrete, rubberized concrete and effect of rubber on the impact behaviour of the concrete. And also general finite element history is presented. This chapter also focuses on the problem statement, objectives, and the scope of work.

- The review of literature is presented in chapter two. This review focuses on the previous study that has been carried out on the rubberized concrete and discusses its properties. It also presents the most relevant studies with respect to the impact loading and its effect on the concrete behaviour.

- Chapter three is divided into two main parts. Part one covers the methodology for experimental works and describes the materials and laboratory investigations that are carried out to fulfill the objectives of the research. Part two describes the finite element formulation model of material and scheme of analysis for plain, rubberized and hybrid concrete beams subjected to bending impact load.

- Chapter four presents the analysis and discussion on the results obtained from the experimental tests. Comparisons between three types of rubberized concrete, between rubberized and hybrid structure and also between static and dynamic results were studied.

- Chapter five nonlinear analysis model of concrete subjected to impact load by using finite element method. Comparison is carried out between experimental and computational results.

- Chapter six provides the conclusions drawn from the result of both experimental work and finite element model. Finally the recommendations for the future work are also presented in this chapter.

CHAPTER TWO

LITERATURE SURVEY

2.1 Introduction

Cement consumption is increasing day by day owing to its wide use as construction material. The increased use of cement poses an environmental challenge because 5% to 8% of the global anthropogenic CO_2 emissions originate from cement production (Scrivener and Kirkpatrick, 2008). Another major problem haunting environmentalist is the increased generation of waste rubber all over the world. For example, in the United States alone, every year more than 281 million scrap-tires are produced, out of which over 77%, are landfilled, stockpiled, or illegally dumped (Baker et al., 2003). In Malaysia, a number of projects involving a huge investment in waste rubber recycling have been observing. For instance, in 2002 a project total RM4.47 billion was approved by Malaysian Industrial Development Authority to proceed with the recycling project of scrap tires to manufacture synthetic rubber powder and thermoplastic elastomer (Awang, 2008). The problem with this indiscriminate accumulation of waste tires is that it is dangerous and hazardous on account of its potential fire risks which generally demands longer time to extinguish. These fires are major source of the air, soil, and water pollution and have direct bearing on the surrounding communities (Sukontasukkul and Chaikaew, 2006).

This serious environmental and health issues associated with rubber demands urgent attention to develop alternative solutions for their reuse in other applications, and in this regard concrete has been identified as one of the feasible options.

2.2 Rubberized concrete

Recently many researchers have carried out experimental studies to identify the best suitable application of recycled rubber in the field of concrete technology. The primary objective of their study was to reduce the waste material dumping problems by utilizing these materials as raw material in concrete mixes and thereby improve their properties. In this chapter the works related to utilization of waste tire rubber in concrete is reviewed.

2.2.1 Properties of fresh rubberized concrete

2.2.1.1 Concrete Density

Concrete density is one of the important properties of concrete. The fresh and hardened dry unit weight of aerated cement composites containing shredded rubber waste was determined by Benazzouk et al. (2006). Aerated cement composites mixes were prepared with replacements of cement volume in the range of 0% to 50% using shredded waste rubber. The absolute density of the shredded waste rubber is approximately 430 kg/m^3. They found that addition of shredded waste rubber will cause significant reduction in the fresh and hardened dry unit weight of the mixtures. In a similar work carried by Khaloo et al. (2008), they investigated the effect of replacing coarse aggregate and sand with chips and crumb rubber on the properties of concrete. They found that addition of waste tire in concrete significantly reduced the density of the concrete (see Figure 2.1).

The effect of addition of waste automobile tires on the unit weight of concrete was experimentally investigated by Topçu and Sarıdemir (2008). They also employed the

artificial neural networkand fuzzy logic techniques ability to predict the unit weight of the concrete under study. In their study concrete without rubber and having15, 30 and 45% rubberized concrete were developed. The results showed that unit weight of concrete decreased with the increasing crumb rubber content.

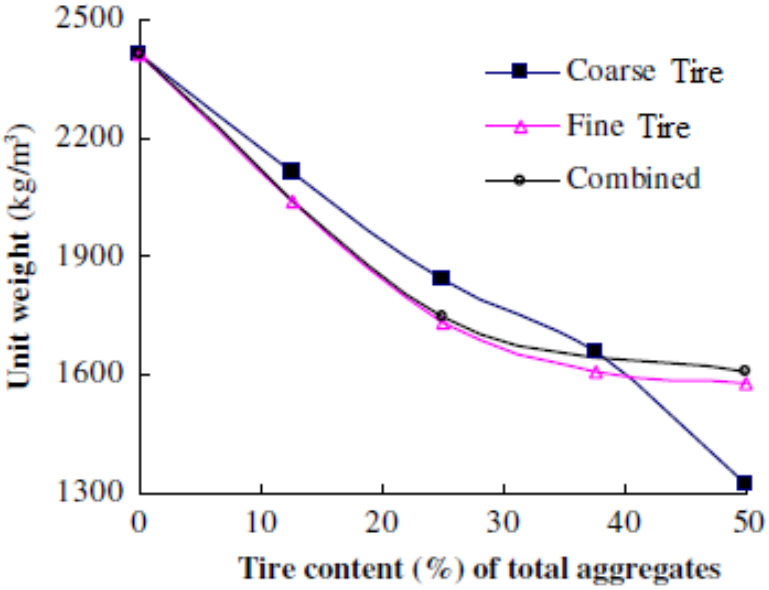

Fig. 2.1: Effect of tire content on the unit weight of the concrete (Khaloo et al., 2008)

Similarly, Pelisser et al. (2010) investigated the effect of replacing sand with recycled tire rubber on the density of concrete mix. The recycled rubber with maximum particles size of 4.8 mm was washed with sodium hydroxide (NaOH) to increase the hydrophilicity of the rubber particle surface. Further, silica fume (microsilica) was added (15% mass fraction) to the recycled rubber as a surface modifier.

The combination of the rubber treatment by sodium hydroxide followed by the addition of silica fume was favorable for the porosity reduction in the interface of these aggregates. This contributed to the recovery of the concrete strength and a lower permeability.

2.2.1.2 Air content

The effect of chipped and crumbed tire rubber particles as replacement of coarse and fine aggregates on the air content of concrete mix have also been studied Taha et al. (2008). They found that increase in the content of tire waste rubber increased the air content of the concrete mix (Figure 2.2). Several other researchers have also demonstrated that using waste tire in concrete increases the level of air content in the mix (Benazzouk et al., 2003; Khatib and Bayomy, 1999).

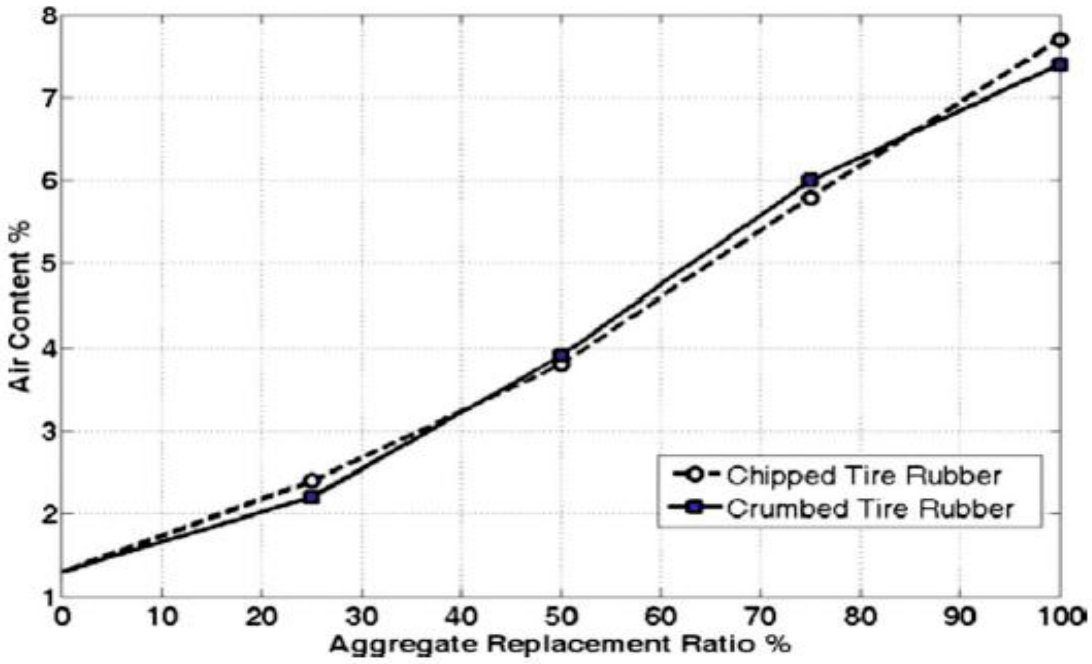

Fig. 2.2: Effect of aggregate replacement ratio on air content of rubberized concrete (Taha et al., 2008)

2.2.1.3 Workability

In order to study the workability of rubberized concrete, chipped and crumbed tire rubber particles as replacement of coarse and fine aggregates were used in the study by Khatib and Bayomy (1999). The result (see Figure 2.3) showed that the presence of crumb or chipped tire rubber particles decreased the workability of the concrete. Whereas, for the concrete mix with sand replacement, the slump increased with increase in rubber percentage and reached a maximum value when the rubber percentage was 15%, which on subsequent increase in rubber percentage the slump decreases.

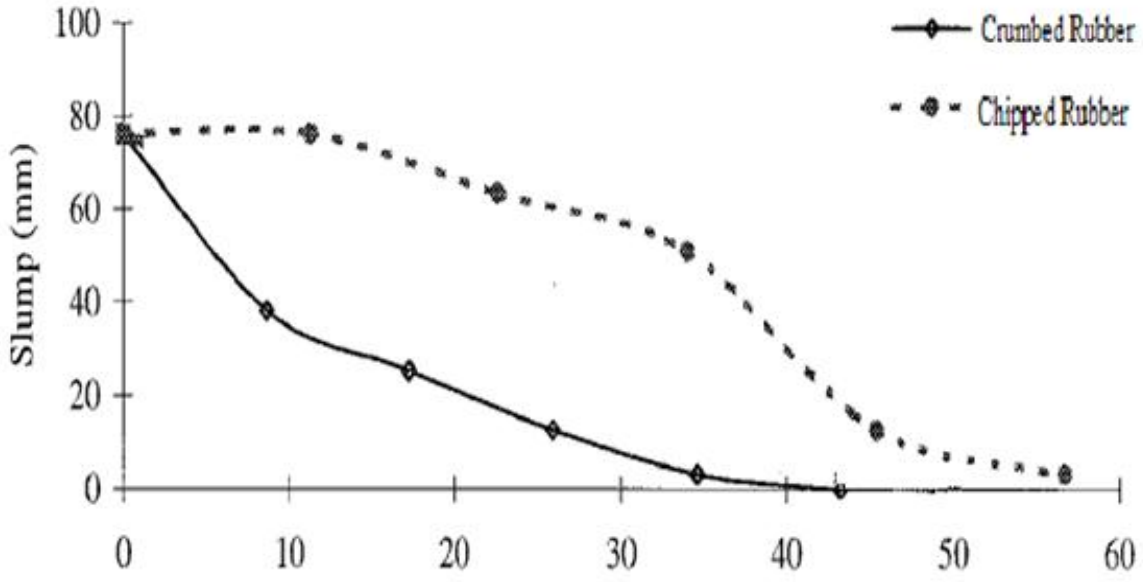

Fig. 2.3: Effect of rubber content on the workability of concrete (Khatib and Bayomy, 1999)

In a similar work carried out by Raghavan et al. (1998), the effect of adding shredded automobile and truck tires on the workability of mortar was investigated. The result showed that addition of rubber shreds improves the workability of the mortar. In another

work by Albano et al. (2005), they observed that the values of slump decreased from a value of 8 cm for the controlled concrete mix to a value of 1 cm (88% slump reduction) for the scrap rubber concrete having 5 wt% rubber with 0.29 and 0.59 mm particle sizes. The value for 10 wt% rubber with 0.29 and 0.59 mm particle sizes was 0.5 cm (94% slump reduction). This reduction is due to the decrease on blend flow, because of the presence of a high portion of rubber particles, which have a very low density, hence greater volume.

2.2.2 Properties of hardened rubberized concrete

2.2.2.1 Compressive and tensile stress

The compressive and splitting-tensile stress in terms of different particle size and amount of rubber in concrete mixture was studied byTopcu (1995). Two particle sizes of rubber 0-1 mm (fine) and 1-4 mm (coarse) were added to concrete mixes in varying percentages of 15, 30 and 45 %. As shown in Figure 2.4, the compression stress decreased approximately by 36, 43, and 56% when fine aggregate was replaced with fine rubber aggregate of 15, 30, and 45% volume, respectively. Whereas, for the case of using chipped tire rubber particles to replace the same percentage of aggregate the reduction in compressive stress was 50, 69, and 80%, respectively for similar volumetric additions.

For the splitting-tensile test, the plain concrete yielded at 3.21MPa, and it reduced to 32, 52, and 65% when replaced with fine aggregates having 15, 30 and 45 % of fine rubber and, 53, 67, and 74% when replaced with the coarse rubber chips.

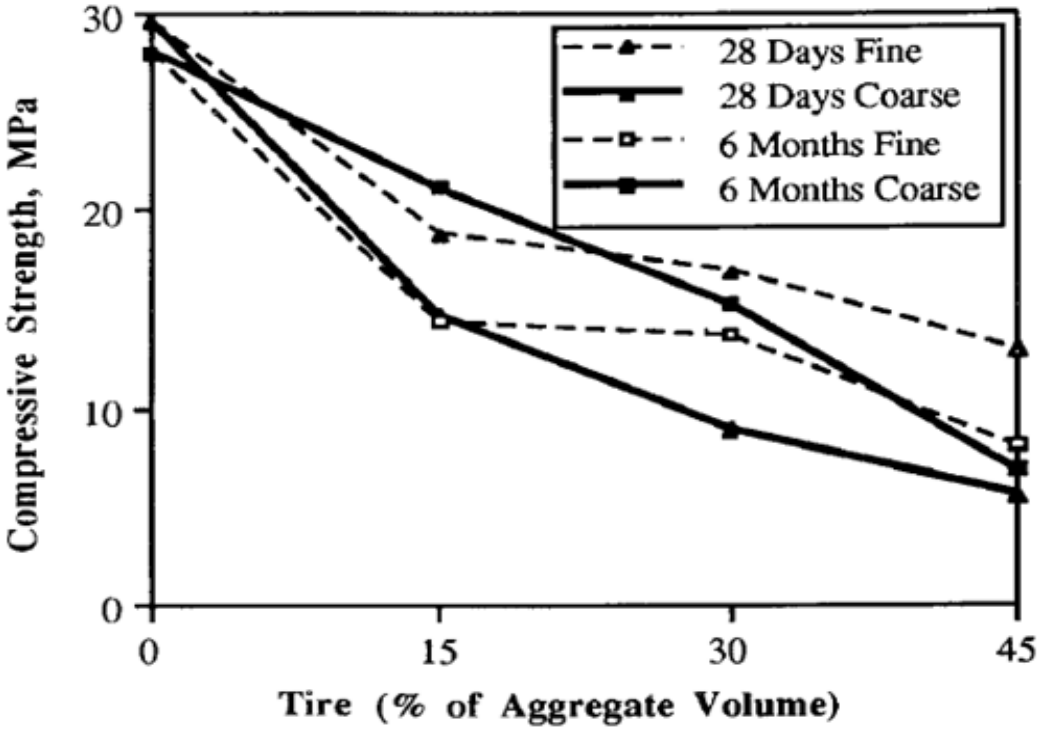

Fig. 2.4: Effect of fine (0-1mm) and coarse (1-4mm) rubber content on the compressive stress (Topcu, 1995)

Crumb rubber of particle size 0.15–4.75 mm was used by Batayneh et al. (2008) as partially replacement of sand in various percentages of 20%, 40%, 60%, 80%, and 100% to investigate the effect of rubber in the performance of concrete. The results indicate that the compressive stress for different rubber contents reduced from 10% to 75% of the control specimen, while the tensile stress decreased from 8% to 65% of the control specimen.

The mechanical properties of concrete containing high volume of tire rubber was investigated by Khaloo et al. (2008). Chipped, crumbed, and a combination of tire rubber particles were used to replace coarse and fine aggregate with different volume replacement levels. Natural sand and coarse aggregate were substituted by fine rubber and coarse rubber with 25, 50, 75 and 100%, respectively. The result showed that

compression stress decreased by approximately 80% when sand was replaced with 25 % whereas, the ultimate stress for coarse replacement was slightly higher than that of sand replacement for rubber concentrations lower than 25%. This higher stress was attributed to the existence of fibers in coarse tire–rubber particles. Ultimate stresses of combined specimens appeared somewhere in between the ultimate stress of concrete with sand and coarse aggregate replacement, but it was found closer to concrete with sand replacement. They suggested replacement ratio not exceeding 25% of aggregate by tire rubber.

A new approach to predict the effect of tire rubber on the stress of concrete using a mathematical model was introduced by Vieira et al. (2010). Design of the model depends on study of the composition stress of concrete in a multivariate form using a completely random experimental design. The variables of model were grouped into two groups of variables, mixture variables (the properties of the mixture constituents such as aggregates, water and cement) and process variables (Tire rubber percentage and size in the concrete). In this study three different particle sizes of truck tires rubber (from 1.2 to 2.4 mm, from 2.4 to 4.8 mm, and greater than 4.8 mm) were used with the weight fraction of rubber 2.5–5.0–7.5%. The truck tires rubber was added to concrete mixes as a substitute for fine aggregate. The results show that by adding 2.5% rubber substitute having fine aggregate with 2.4 mm particle size, can account for the optimum stress of the concrete. Moreover, the result showed that a concrete having a compressive stress above 20 MPa for 28 days can be obtained. This indicates that these mixtures can be used in structures as well as pavements, dividers and other applications in civil engineering.

Another study by Ganjian et al. (2009), investigated the stress of concrete mixtures by incorporating 5%, 7.5% and 10% of discarded tire rubber as aggregate and cement replacements. Figure 2.5 shows that there is no major change in the compressive stress with 5% replacement of aggregate or cement by rubber. The significant reduction in compressive stress was with respect to 7.5-10% replacement by aggregates and cement leading to reduction of stress by about 10–23% and 20–40% in case of cement replacement.

Moreover, tensile stress of concrete was reduced with the increase in the percentage of rubber replacement in concrete as shown in Figure 2.6. It was also found that the reduction in the tensile stress of concrete containing powdered rubber was lower than that of concrete containing chipped rubber.

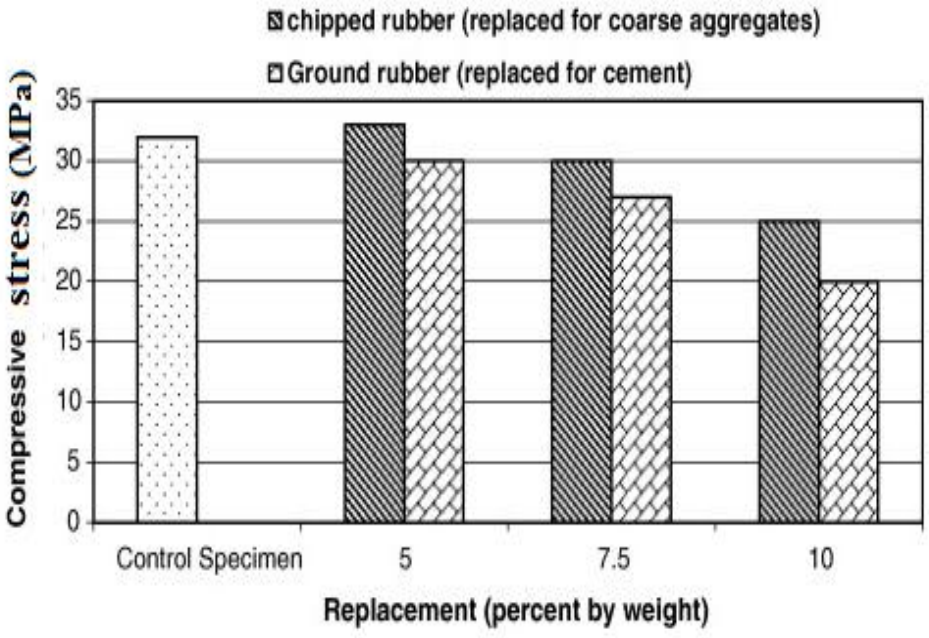

Fig. 2.5: Effect of chipped and ground rubber content on the compressive stress (Ganjian et al., 2009)