

ENGINEERING PROPERTIES OF RUBBERISED CONCRETE INCORPORATING  
PALM OIL FUEL ASH

PARHAM FOROUZANI

A thesis submitted in fulfilment of the  
requirements for the award of the degree of  
Doctor of Philosophy (Civil Engineering)

Faculty of Civil Engineering  
Universiti Teknologi Malaysia

JULY 2016

ENGINEERING PROPERTIES OF RUBBERISED CONCRETE  
INCORPORATING PALM OIL FUEL ASH

PARHAM FOROUZANI

A thesis submitted in fulfilment of the  
requirements for the award of degree of  
Doctor of Philosophy (Civil Engineering)

Faculty of Civil Engineering  
Universiti Teknologi Malaysia

JULY 2016

**To my lovely parents**

who gave me endless love, trust, constant encouragement over the years, their prayers and financial supports

And

**To my lovely wife**

for her love, patience, support, and for enduring the ups and downs during the completion of this thesis.

## ACKNOWLEDGEMENT

First and foremost I wish to glorify almighty Allah the most gracious the most merciful by the saying of ALLHAMDULLILAH RABILALMIN, for the benefit of wisdom and power he has provided without expecting anything in return. These provisions of Allah (SW) have made it possible to come this long in academic pursuit.

I wish to express my sincere and profound gratitude to my supervisor, Professor Dr. Mohammad Ismail for his continuing assistance, the encouragement, guidance, critics and understanding throughout the period of my studies. The trust, patience, great insight, modesty and friendly personality demonstrated by him have always been my source of inspiration.

I wish to express my deepest appreciation to my parent, Abdolrasoul Forouzani and Shahla Ahmadzadeh who supported and encouraged me to complete the study. I remain immensely grateful for the financial support by my parents.

Special thanks to my lovely wife Omolbanin Farahmandpour for all her patience, guidance and support during the execution of this research. In fact, she always gave me immense hope every time I found problems relating to my research and life.

The author is greatly indebted to Faculty of Civil Engineering (FKA) for the support and facilities provided to carry out the experimental work. Finally, the corporation enjoyed by my research colleagues is highly appreciated.

## ABSTRACT

The utilisation of waste materials and by-products is a partial solution to environmental and ecological problems. One important recent development, in the field of concrete technology, is the utilisation of waste materials and by-products in the construction industry, as aggregates in the production of various types of concrete. Agro-waste materials, such as palm oil fuel ash (POFA), show a great potential ability to be utilised as a pozzolanic material in concrete. The problem of the rising costs of construction materials, coupled with evident environmental degradation, and the need to improve concrete properties; especially in terms of acoustic properties, has stimulated the necessity to incorporate tyre-rubber aggregates (TRA) and POFA in concrete. Rubberised Concrete (RC) is produced by replacing a volume percentage of the traditional coarse and/or fine aggregate with tyre-rubber particles. TRA has been utilized in various gradations from used vehicle tyres and POFA has been replaced partially as cementitious material. This research investigates the wide range of physical, mechanical and acoustic properties of concrete containing recycled TRA and POFA to assess its suitability as a construction material. The influence of factors, such as rubber aggregate content, size, shape and type of rubber particle, was also considered. TRA is classified into three groups, namely fine fibre ( $R_1$ ), fine granular ( $R_2$ ) and coarse granular ( $R_3$ ). The concrete mixture is designed based on ACI 211-91. The TRA component of the mixture is replaced in 5% to 30% by volume. The results of this study show that the best proportion of POFA is 20% with a water-binder ratio of 0.38; which improves the 28-day concrete strength. The results show that despite a great loss in strength with increasing TRA replacement, this type of concrete is acceptable for various structural applications requiring medium to low compressive strengths. It is found that for the same volume of rubber (coarse and fine TRA), coarse rubber particles increase air content, decrease compressive, indirect tensile, and flexural strengths, and improve the deformability of concrete, compared to concrete containing fine TRA. Furthermore, the modified rubberised concrete exhibits superior acoustic properties. The results of sound absorption coefficient and sound transmission loss show that the coarse aggregates have more influence on improving the sound-proofing properties by up to 42.5% with 30% TRA incorporation. These attributes make rubberised POFA concrete a potential candidate for application in a promising flooring system that is cost-effective and has increased sound-proof properties. The possible quantities of concrete produced worldwide for such applications would ensure the viability of this product. Therefore, this type of concrete shows promise in becoming an additional sustainable solution for tyre-rubber waste management.

## ABSTRAK

Penggunaan bahan-bahan buangan dan produk sampingan adalah penyelesaian separa kepada masalah alam sekitar dan ekologi. Satu perkembangan penting baru-baru ini dalam bidang teknologi konkrit adalah penggunaan bahan-bahan buangan dan produk sampingan dalam industri pembinaan sebagai agregat dalam pengeluaran pelbagai jenis konkrit. Bahan-bahan sisa agro, seperti abu bahan api kelapa sawit (POFA), menunjukkan potensi besar untuk digunakan sebagai bahan pozzolanic dalam konkrit. Masalah kenaikan kos bahan-bahan binaan, ditambah pula dengan pencemaran alam sekitar yang jelas, dan keperluan untuk meningkatkan sifat-sifat konkrit, terutama dari segi ciri-ciri akustik, telah merangsang keperluan untuk menggabungkan agregat tayar-getah (TRA) dan POFA dalam konkrit. Konkrit Getah (RC) dihasilkan dengan menggantikan peratusan isipadu agregat kasar tradisional dan/atau agregat halus dengan zarah-zarah tayar-getah. TRA telah digunakan dalam pelbagai penggredan daripada tayar terpakai kenderaan dan POFA telah digantikan sebahagiannya sebagai bahan bersimen. Penyelidikan ini menyiasat pelbagai sifat-sifat fizikal, mekanikal dan akustik pada konkrit yang mengandungi TRA yang dikitar semula dan POFA untuk menilai kesesuaiannya sebagai bahan pembinaan. Pengaruh faktor-faktor seperti kandungan agregat getah, dan saiz, bentuk dan jenis zarah getah juga dipertimbangkan. TRA diklasifikasikan kepada tiga kumpulan, iaitu serat halus ( $R_1$ ), butiran halus ( $R_2$ ) dan butiran kasar ( $R_3$ ). Campuran konkrit direka bentuk ACI 211-91. Komponen TRA dalam campuran digantikan sebanyak 5% hingga 30% mengikut isipadu. Keputusan kajian ini menunjukkan bahawa bahagian terbaik POFA adalah 20% dengan nisbah air-pengikat sebanyak 0.38, yang meningkatkan kekuatan konkrit 28 hari tersebut. Keputusan menunjukkan bahawa walaupun sebahagian besar kekuatan kehilangan dengan peningkatan penggantian TRA, konkrit jenis ini boleh digunakan untuk pelbagai aplikasi struktur yang memerlukan kekuatan mampatan yang sederhana hingga rendah. Telah didapati bahawa untuk isipadu getah (TRA kasar dan halus) yang sama, zarah getah kasar meningkatkan kandungan udara, menurunkan kekuatan mampatan, tegangan tidak langsung dan lenturan, dan meningkatkan perubahan bentuk konkrit berbanding dengan konkrit yang mengandungi TRA halus. Tambahan pula, konkrit getah yang diubahsuai mempamerkan sifat-sifat akustik yang unggul. Keputusan pekali penyerapan bunyi dan kehilangan penghantaran bunyi menunjukkan bahawa agregat kasar mempunyai pengaruh yang lebih ke atas peningkatan sifat-sifat kalis bunyi sehingga 42.5% dengan penggabungan TRA sebanyak 30%. Ciri-ciri ini menjadikan konkrit getah POFA calon yang berpotensi untuk aplikasi sistem lantai yang berkesan dari segi kos dan mempunyai sifat-sifat kalis bunyi yang lebih baik. Kuantiti konkrit yang mungkin dihasilkan di seluruh dunia untuk aplikasi begini akan memastikan kebolehlaksanaan produk ini. Oleh itu, jenis konkrit ini berpotensi menjadi penyelesaian tambahan yang mampan bagi pengurusan sisa tayar-getah..

## TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	<b>DECLARATION</b>	<b>ii</b>
	<b>ACKNOWLEDGEMENT</b>	<b>iv</b>
	<b>ABSTRACT</b>	<b>v</b>
	<b>ABSTRAK</b>	<b>vi</b>
	<b>TABLE OF CONTENTS</b>	<b>vii</b>
	<b>LIST OF TABLES</b>	<b>xvii</b>
	<b>LIST OF FIGURES</b>	<b>xix</b>
	<b>LIST OF ABBREVIATIONS</b>	<b>xxx</b>
	<b>LIST OF SYMBOLS</b>	<b>xxxii</b>
	<b>LIST OF APPENDICES</b>	<b>xxxiv</b>
<b>1</b>	<b>INTRODUCTION</b>	<b>1</b>
	1.1 Overview	1
	1.2 Importance of the Study	3
	1.3 Problem statement	4
	1.4 Aim and Research Objective	5
	1.5 Scope and Limitation of the Research	6
	1.6 Significance of the Research	7
	1.7 Thesis Organisation	7
<b>2</b>	<b>LITERATURE REVIEW</b>	<b>11</b>
	2.1 Introduction	11
	2.2 Properties of Tyre Rubber Aggregates	13
	2.3 Classification of the Scrap Tyres Using as Construction Materials	14
	2.3.1 Shredded or Chipped Rubber	15

2.3.2	Ground Rubber	15
2.3.3	Granulated Rubber	15
2.3.4	Crumb Rubber	16
2.3.5	Powder Rubber	16
2.4	Rubberised Concrete	16
2.5	Mix Design of Rubberised Concrete and Procedure of Mixing Operation	17
2.6	Influence of the Rubber Aggregate on Fresh Properties of Rubberised Concrete	18
2.6.1	Workability of Rubberised Concrete	18
2.6.2	Air Content of Rubberised Concrete	21
2.6.3	Unit weight (Fresh Density) of Rubberised Concrete	22
2.7	Influence of the Rubber Aggregate on Hardened Properties of Rubberised Concrete	24
2.7.1	Compressive Strength	24
2.7.2	Tensile Strength	26
2.7.3	Flexural Strength	28
2.8	Ductility and Deformability of Rubberised Concrete	29
2.8.1	Modulus of Elasticity	29
2.8.2	Toughness and Impact Resistance of Rubberised Concrete	31
2.9	Acoustic Properties of Rubberised Concrete	35
2.10	Thermal Movement of Rubberised Concrete	36
2.11	Processing for Quality Improvement of Rubber Aggregates	37
2.12	Influence of the Rubber Aggregate on Durability Parameters of Rubberised Concrete	38
2.12.1	Water Absorption	39
2.12.2	Chloride Permeability in Rubberised Concrete	40
2.12.3	Rubberised Concrete and Fire Exposure	40
2.12.4	Shrinkage of Rubberised Concrete	41
2.13	Pozzolanic Materials	43
2.14	Types of Pozzolanic Materials	44
2.14.1	Pulverised Fuel Ash (Fly Ash)	44
2.14.2	Ground Granulated Blast-Furnace Slag (GGBS)	44



2.14.3	Rice Husk Ash (RHA)	45
2.14.4	Silica Fume	46
2.14.5	Palm Oil Fuel Ash (POFA)	46
2.15	Physical and Chemical Properties of POFA	47
2.16	Pozzolanic Reaction of POFA	48
2.17	Influence of POFA in Concrete	50
2.17.1	Setting Time	50
2.17.2	Workability	52
2.17.3	Compressive Strength	52
2.17.4	Flexural Strength	54
2.17.5	Tensile Strength	55
2.18	Durability of POFA Concrete	55
2.18.1	Sulfate Resistance	56
2.18.2	Water Permeability	56
2.19	Carbonation	57
2.19.1	Mechanisms of carbonation	58
2.19.2	POFA Concrete in Carbonation	59
2.20	Summary of research Gap	59
<b>3</b>	<b>METHODOLOGY</b>	<b>62</b>
3.1	Introduction	62
3.2	Materials and Process Technology Standardisation	66
3.2.1	Cement	67
3.2.2	Palm Oil Fuel Ash (POFA)	67
3.2.2.1	Preparation of POFA	67
3.2.3	Aggregates	70
3.2.3.1	Natural Fine Aggregate	70
3.2.3.2	Natural Coarse Aggregate	70
3.2.3.3	Tyre Rubber Aggregate (TRA)	71
3.2.3.4	Fine Fibre Tyre Rubber Aggregate – Type R <sub>1</sub>	72
3.2.3.5	Fine Granular Tyre Rubber Aggregate – Type R <sub>2</sub>	72
3.2.3.6	Coarse Granular Tyre Rubber Aggregate – Type R <sub>3</sub>	73

3.2.4	Mixing Water	74
3.2.5	Admixture	74
3.3	Cement and POFA Analysis	74
3.3.1	Particle Size Analysis	75
3.3.2	Pozzolanic Activity Index	76
3.4	Mix Design Concrete	76
3.5	Fresh Properties of Normal, POFA, and Modified Rubberised Concrete	77
3.5.1	Workability Measurement	77
3.5.1.1	Slump	77
3.5.1.2	Compacting Factor Test	78
3.5.2	Fresh Density (Unit Weight)	79
3.5.3	Air Content Test	80
3.6	Hardened Properties of Conventional and Modified Rubberised Concrete	81
3.6.1	Compressive Strength	81
3.6.2	Indirect Tensile Strength	82
3.6.3	Flexural Strength	83
3.6.4	Ultrasonic Pulse Velocity (UPV) Test	85
3.6.5	Modulus of Elasticity	87
3.7	Durability of Modified Rubberised Concrete	89
3.7.1	Fire Endurance	90
3.7.2	Rapid Test on Resistance to Chloride Penetration	91
3.7.3	Density, Water Absorption and Voids	93
3.8	Microstructure	94
3.8.1	Scanning Electron Microscopy	95
3.8.2	X-ray Diffraction	95
3.9	Acoustic Properties	95
3.9.1	Acoustic Determination of Sound Absorption Coefficient and Impedance in Impedance Tube	96
<b>4</b>	<b>MIX DESIGN FOR POFA RUBBERISED CONCRETE</b>	<b>100</b>

4.1	Introduction	100
4.2	Investigation on Properties of POFA	100
4.2.1	Physical Characteristics of POFA	101
4.2.1.1	Effect of Grinding Time on POFA Particle Size	101
4.2.1.2	Particle Size Analysis and Physical Characteristics of POFA	102
4.2.2	Correlation of POFA Particle Size and Pozzolanic Activity Index	103
4.2.3	Chemical Composition of POFA	105
4.2.4	Morphology and Microstructure of POFA	106
4.3	Characteristics of Natural Aggregates	108
4.3.1	Natural Coarse Aggregate	108
4.3.2	Natural Fine Aggregate	109
4.4	Characteristics of Rubber Aggregates	111
4.4.1	Fiber Tyre Rubber Aggregate – Type R <sub>1</sub>	111
4.4.2	Granular Tyre Rubber Fine Aggregate – Type R <sub>2</sub>	112
4.4.3	Coarse Granular Tyre Rubber Aggregate – Type R <sub>3</sub>	113
4.5	Trial Mix Proportion	114
4.5.1	Trial Concrete Mix Design for Optimised Level of POFA Replacement	115
4.6	Optimisation of Super Plasticiser in Concrete Mixtures	120
4.6.1	Concrete Mix Design for Rubberised Concrete	122
<b>5</b>	<b>EXPERIMENTAL RESULTS AND DISCUSSION ON THE MECHANICAL PROPERTIES OF POFA RUBBERISED MODIFIED CONCRETE</b>	<b>126</b>
5.1	General	126
5.2	Results and Discussion of Fresh Properties of POFA Rubberised Concrete	126
5.2.1	Workability of POFA Rubberised Concrete	127
5.2.1.1	Slump Measurement of Fine Fibre Rubberised POFA Concrete	127

5.2.1.2 Slump Measurement of Fine Granular Rubberised POFA Concrete	129
5.2.1.3 Slump Measurement of Coarse Granular Rubberised POFA Concrete	131
5.2.1.4 Summary of Workability in Terms of Slump Results	133
5.2.2 Air Content Measurement of Rubberised Concrete	134
5.2.2.1 Air Content of Concrete Incorporating Fine Fibre Rubber Aggregates	135
5.2.2.2 Air Content of Concrete Incorporating Fine Granular Rubber Aggregates	136
5.2.2.3 Air Content of Concrete Incorporating Coarse Granular Rubber Aggregates	137
5.2.2.4 Summary of Air Content Measurement in Rubberised Concrete	138
5.2.3 Compacting Factor Measurement of Rubberised POFA Concrete	140
5.2.4 Fresh Density of Rubberised Concrete	142
5.3 Results and Discussion of Mechanical Properties of POFA Rubberised Concrete	145
5.3.1 Compressive Strength of Type R1 Modified Rubberised Concrete	145
5.3.2 Compressive Strength of Type R2 Modified Rubberised Concrete	148
5.3.3 Compressive Strength of POFA Concrete Containing Coarse Granular Rubber Particles	150
5.3.4 Comparative Analysis of Compressive Strength of Rubberised POFA Concrete in terms of Size, Type, and Rubber Particle Content	152
5.3.5 Splitting Tensile Strength of Modified Rubberised Concrete Incorporating type R1 Rubber Particles	156
5.3.6 Splitting Tensile Strength of Modified Rubberised Concrete Containing Fine Granular Rubber Particles – Type (R <sub>2</sub> )	158

5.3.7	Splitting Tensile Strength of Modified Rubberised Concrete Containing Coarse Granular Rubber Particles – Type (R <sub>3</sub> )	159
5.3.8	Comparative Analysis of Indirect Tensile Strength of Rubberised POFA Concrete in terms of Size, Type, and Rubber Particle Content	160
5.3.9	Flexural Strength of Modified Rubberised Concrete Containing Type R1 Rubber Aggregates	165
5.3.10	Flexural Strength of Concrete Containing Fine Granular Rubber Aggregates	166
5.3.11	Flexural Strength of Concrete Containing Type R <sub>3</sub> Rubber Aggregates	167
5.3.12	Comparative Analysis of Flexural Strength of Rubberised POFA Concrete in terms of Size, Type, and Rubber Particle Content	168
5.3.13	Modulus of Elasticity	172
<b>6</b>	<b>DURABILITY OF MODIFIED RUBBERISED CONCRETE</b>	<b>180</b>
6.1	General	180
6.2	Fire Endurance	180
6.2.1	Elevated temperature gradient	181
6.2.2	Effect of Temperature on the Physical Properties of Concrete Containing Type R1 Rubber Aggregates	182
6.2.3	Impact of Temperature and Cooling Regime on the Weight loss of Type R <sub>1</sub> Rubberised Concrete	185
6.2.4	Residual Compressive Strength of Type R <sub>1</sub> Rubberised Concrete at Elevated Temperatures under Different Cooling Regimes	189
6.2.5	Ultrasonic Pulse Velocity (UPV) of R1 Rubberised Concrete in Air and Water Cooling Regime	192
6.2.6	Relationship between UPV Values and Residual Compressive Strength of Type R <sub>1</sub> Rubberised Concrete under Different Cooling Regimes	196

6.2.7 Impact of Elevated Temperatures on the Physical Characteristics of Concrete Containing Fine Granular Rubber Aggregates	199
6.2.8 Impact of Temperature and Cooling Regime on the Weight loss of Concrete Containing Fine Granular Rubber Aggregates	203
6.2.9 Residual Compressive Strength of Type R2 Rubberised Concrete at Elevated Temperature under Different Cooling Regimes	205
6.2.10 Ultrasonic Pulse Velocity (UPV) of R <sub>2</sub> Rubberised Concrete in the Air and Water Cooling Regimes	208
6.2.11 Relationship between UPV Values and Residual Compressive Strength of Type R <sub>2</sub> Rubberised Concrete under Different Cooling Regimes	211
6.2.12 Impact of Elevated Temperatures on the Physical Characteristics of Concrete Containing Coarse Granular Rubber Aggregates	214
6.2.13 Impact of Temperature and Cooling Regime on the Weight loss of Concrete Containing Coarse Granular Rubber Aggregates	219
6.2.14 Residual Compressive Strength of Type R3 Rubberised Concrete at Elevated Temperature under Different Cooling Regimes	222
6.2.15 Ultrasonic Pulse Velocity (UPV) of Type R3 Rubberised Concrete in the Air and Water Cooling Regimes	225
6.2.16 Relationship between UPV Values and Residual Compressive Strength of Type R <sub>3</sub> Rubberised Concrete under Different Cooling Regimes	228
6.2.17 Discussion on fire performance of Rubberised Concrete	232

6.3	Permeability attributed to the Water Absorption of Rubberised Concrete	234
6.4	Rapid Chloride Ion Permeability	237
<b>7</b>	<b>ACOUSTIC PROPERTIES OF MODIFIED RUBBERISED CONCRETE</b>	<b>239</b>
7.1	General	239
7.2	Sound Absorption Properties of Rubberised Concrete	239
7.2.1	Sound Absorption of Type R <sub>1</sub> Modified Rubberised Concrete	240
7.2.2	Sound Absorption of Type R <sub>2</sub> Modified Rubberised Concrete	242
7.2.3	Sound Absorption of Type R <sub>3</sub> Modify Rubberised Concrete	244
7.3	Sound Transmission Loss in Type R <sub>1</sub> Rubberised Concrete	246
7.3.1	Sound Transmission Loss in Type R <sub>1</sub> Rubberised Concrete	246
7.3.2	Sound Transmission Loss in Type R <sub>2</sub> Rubberised Concrete	249
7.3.3	Sound Transmission Loss in Type R <sub>3</sub> Rubberised Concrete	252
<b>8</b>	<b>CONCLUSIONS AND RECOMMENDATIONS</b>	<b>255</b>
8.1	General	255
8.2	Conclusion	255
8.2.1	Characterisation of Waste Binder Materials (POFA)	255
8.2.2	Concrete Mix Proportion	256
8.2.3	Fresh Properties of Modified Rubberised Concrete	256
8.2.4	Hardened Properties of Modified Rubberised Concrete	257
8.2.5	Durability Characterisation	258
8.2.6	Acoustical Properties	259

8.3 Contribution of the Research	260
8.4 Recommendations	261
<b>REFERENCES</b>	<b>263</b>
Appendix A	286



## LIST OF TABLES

<b>TABLE NO.</b>	<b>TITLE</b>	<b>PAGE</b>
	Table 1.1: Number of scrap tyres generated in Malaysia (National Solid Waste Management Department, 2011)	2
<b>Table 2.1:</b>	Typical composition of manufactured tyres by weight (RMA, 2000)	13
<b>Table 2.2:</b>	Typical materials used in manufacturing tire (RMA, 2000)	14
<b>Table 2.3:</b>	Range of chemical composition of ASTM Type F, C, and POFA	48
<b>Table 3.1:</b>	Physical properties of rubber particles	71
<b>Table 3.2:</b>	Chemical properties of rubber particles	71
<b>Table 3.3:</b>	Specific of used super plasticiser	74
<b>Table 3.4:</b>	Classification of the quality of concrete on the basis of Pulse velocity.	87
<b>Table 3.5:</b>	Chloride Permeability Based on Charge Passed (ASTM C1202)	92
<b>Table 4.1:</b>	Physical properties of OPC and POFA	103
<b>Table 4.2:</b>	Major chemical compositions of OPC and POFA	106
<b>Table 4.3:</b>	properties of natural coarse aggregate	108
<b>Table 4.4:</b>	Physical properties of natural fine aggregate	110
<b>Table 4.5:</b>	Concrete mix design with 0.50 w/b ratio and different level of POFA replacement	116
<b>Table 4.6:</b>	Concrete mix design with 0.43 w/b ratio and different level of POFA replacement	116
<b>Table 4.7:</b>	Concrete mix design with 0.38 w/b ratio and different level of POFA replacement	117
<b>Table 4.8:</b>	Concrete mix design with 0.35 w/b ratio and different level of POFA replacement	117

<b>Table 4.9:</b> Rubberised concrete mix design incorporating fine fibre rubber aggregate	124
<b>Table 4.10:</b> Rubberised concrete mix design incorporating fine granular rubber aggregate	124
<b>Table 4.11:</b> Rubberised concrete mix design incorporating coarse granular rubber aggregate	125
<b>Table 6.1:</b> Changing UPV values of modified rubberised concrete containing fine fibre rubber aggregates underwent exposed to elevated temperature in different cooling regime	195
<b>Table 6.2:</b> Changing UPV values of modified rubberised concrete containing fine granular rubber aggregates underwent exposed to elevated temperature in different cooling regime	210
<b>Table 6.3:</b> Changing UPV values of modified rubberised concrete containing coarse granular rubber aggregates underwent exposed to elevated temperature in different cooling regime	227

## LIST OF FIGURES

<b>FIGURE NO.</b>	<b>TITLE</b>	<b>PAGE</b>
<b>Figure 1.1:</b>	Schematic summary of thesis organisation	10
Figure 2.1:	Workability of rubberised concrete (Mohammed et al., 2011)	19
Figure 2.2:	Density of concrete with different rubber aggregate contents (Pierce and Blackwell, 2003)	23
Figure 2.3:	Result of compressive strength after 28 days (Ganjian et al., 2009)	26
Figure 2.4:	Results of tensile strength test (Ganjian et al., 2009)	27
<b>Figure 2.5:</b>	Deflection of rubberised concrete in different rubber proportions (Taha et al., 2009)	31
<b>Figure 2.6:</b>	Toughness index of several rubberised concrete types (Khaloo et al., 2008)	32
<b>Figure 2.7:</b>	Stress-Strain curve for different rubberised concrete types (Batayneh et al., 2008)	34
<b>Figure 2.8:</b>	Ungrounded POFA (a) and grounded POFA (b) (Tangchirapat et al., 2009)	47
<b>Figure 2.9:</b>	Relationship between the compressive strength of concretes and POFA replacement (Sata et al., 2007)	54
<b>Figure 3.1:</b>	Diagram of representation of empirical program	63
<b>Figure 3.2:</b>	POFA preparation process for use in concrete	68
<b>Figure 3.3:</b>	Agro-industrial waste from palm oil	69
<b>Figure 3.4:</b>	Fine fibre rubber aggregate – Type R <sub>1</sub>	72
<b>Figure 3.5:</b>	Fine granular rubber aggregate – Type R <sub>2</sub>	73
<b>Figure 3.6:</b>	Coarse granular rubber aggregate – Type R <sub>3</sub>	73
Figure 3.7:	Bruker S4 Pioneer XRF spectrometer with automatic sample changing system	75
Figure 3.8:	CILAS 1180 particle size analyser	76

Figure 3.9: Slump Test	78
Figure 3.10: Compacting factor test	79
<b>Figure 3.11:</b> Apparatus used for the fresh density and air content test	81
<b>Figure 3.12:</b> Testing for compressive strength	82
<b>Figure 3.13:</b> Operational procedure for splitting tensile strength testing	83
<b>Figure 3.14:</b> Operational procedure for flexural strength test	84
Figure 3.15: An operational process of Ultrasonic pulse velocity (UPV) test	85
<b>Figure 3.16:</b> Modulus of elasticity test	89
<b>Figure 3.17:</b> The operational procedure for water cooling regime	90
Figure 3.18: Electrically controlled furnace – Carbolite Furnace 1100	91
Figure 3.19: Experimental temperature–time curve of electrically controlled furnace	91
<b>Figure 3.20:</b> Operational process for the rapid chloride penetration test (RCPT)	93
Figure 3.21: Impedance tube instrument	97
Figure 3.22: Impedance tube; Small size and Large size tube	97
Figure 3.23: Preparing samples for sound absorption test	98
Figure 3.24: Specimens for impedance tube test; small size disc $27 \times 25$ mm for high frequency impedance tube test and big size disc $99 \times 25$ mm for low frequency	98
<b>Figure 4.1:</b> Relationship between grinding time and POFA particle size	102
<b>Figure 4.2:</b> Particle size analysis of POFA and OPC	103
<b>Figure 4.3:</b> Correlation of strength activity index and POFA grinding time	104
<b>Figure 4.4:</b> Scanning electron micrograph of POFA	107
<b>Figure 4.5:</b> X-ray diffraction pattern of ground POFA	107
<b>Figure 4.6:</b> Grading Curve of natural coarse aggregates in relation to ASTM C33 limits	109
<b>Figure 4.7:</b> Sieve analysis of natural fine aggregate in relation to ASTM C33 limits	110
<b>Figure 4.8:</b> Sieve analysis of type R <sub>1</sub> TRA in relation to fine natural aggregate	111
<b>Figure 4.9:</b> Substitution area of R <sub>1</sub> TRA in relation to its grading	112

<b>Figure 4.10:</b> Sieve analysis of type R <sub>2</sub> TRA in relation to fine natural aggregate	112
<b>Figure 4.11:</b> Substitution area of R <sub>2</sub> TRA in relation to its grading	113
<b>Figure 4.12:</b> Sieve analysis of type R <sub>3</sub> TRA in relation to natural coarse aggregate and substitution area of R <sub>3</sub> in basis on its grading	114
<b>Figure 4.13:</b> Compressive strength of concrete with different percentage of POFA at 0.50 w/b ratio	119
<b>Figure 4.14:</b> Compressive strength of concrete with different percentage of POFA at 0.43 w/b ratio	119
<b>Figure 4.15:</b> Compressive strength of concrete with different percentage of POFA at 0.38 w/b ratio	119
<b>Figure 4.16:</b> Compressive strength of concrete with different percentage of POFA at 0.35 w/b ratio	120
<b>Figure 4.17:</b> Relationship between the addition of super plasticiser to the slump of concrete at 0.38 w/b ratio and different percentages of POFA	121
<b>Figure 5.1:</b> Effect of fibre rubber aggregates on the slump of rubberised concrete	128
<b>Figure 5.2:</b> Effect of fine granular rubber aggregates on the slump of rubberised concrete	130
<b>Figure 5.3:</b> Effect of coarse granular rubber aggregates on the slump of rubberised concrete	133
<b>Figure 5.4:</b> Effect of types and concentrations of rubber aggregates on slump values	134
<b>Figure 5.5:</b> Air content of concrete containing 5% to 30% fine fibre rubber aggregate	136
<b>Figure 5.6:</b> Air content of concrete containing 5% to 30% fine granular rubber aggregate	137
<b>Figure 5.7:</b> Air content of concrete containing 5% to 30% coarse granular rubber aggregate	138
<b>Figure 5.8:</b> Air content of rubberised concrete relative to different sizes and amounts of rubber particles	139
<b>Figure 5.9:</b> Effect of higher air content of rubberised concrete can appear as small holes on the surface of specimens	139

<b>Figure 5.10:</b> Compacting factor of concrete containing 5% to 30% fine fibre rubber aggregate	141
Figure 5.11: Compacting factor of concrete containing 5% to 30% fine granular rubber aggregate	142
<b>Figure 5.12:</b> Compacting factor of concrete containing 5% to 30% coarse granular rubber aggregate	142
Figure 5.13: Fresh density of rubberised POFA concrete	145
<b>Figure 5.14:</b> Compressive strength of rubberised POFA concrete containing fibre rubber aggregates; (a) normal concrete; (b) 20% POFA concrete; (c) 5% R <sub>1</sub> rubberised POFA concrete; (d) 10% R <sub>1</sub> rubberised POFA concrete; (e) R <sub>1</sub> 20% rubberised POFA concrete; (f) R <sub>1</sub> 30% rubberised POFA concrete	147
<b>Figure 5.15:</b> Compressive strength of rubberised POFA concrete containing fine granular rubber aggregates; (a) normal concrete; (b) 20% POFA concrete; (c) 5% R <sub>2</sub> rubberised POFA concrete; (d) 10% R <sub>2</sub> rubberised POFA concrete; (e) R <sub>2</sub> 20% rubberised POFA concrete; (f) R <sub>2</sub> 30% rubberised POFA concrete	149
<b>Figure 5.16:</b> Compressive strength of rubberised POFA concrete containing coarse granular rubber aggregates; (a) normal concrete; (b) 20% POFA concrete; (c) 5% R <sub>3</sub> rubberised POFA concrete; (d) 10% R <sub>3</sub> rubberised POFA concrete; (e) 20% R <sub>3</sub> rubberised POFA concrete; (f) 30% R <sub>3</sub> rubberised POFA concrete	151
<b>Figure 5.17:</b> Compressive strength of rubberised POFA concrete containing 5% fine fibre, fine granular and coarse granular rubber aggregates	152
<b>Figure 5.18:</b> Compressive strength of rubberised POFA concrete containing 10% fine fibre, fine granular and coarse granular rubber aggregates	153
Figure 5.19: Compressive strength of rubberised POFA concrete containing 20% fine fibre, fine granular and coarse granular rubber aggregates	153
Figure 5.20: Compressive strength of rubberised POFA concrete containing 30% fine fibre, fine granular and coarse granular rubber aggregates	154

Figure 5.21: Splitting tensile strength of rubberised POFA concrete containing fine fiber rubber aggregates	157
Figure 5.22: Splitting tensile strength of rubberised POFA concrete containing fine granular rubber aggregates	159
<b>Figure 5.23:</b> Splitting tensile strength of rubberised POFA concrete containing coarse granular rubber aggregates	160
Figure 5.24: Splitting tensile strength of rubberised POFA concrete containing 5% R <sub>1</sub> , R <sub>2</sub> and R <sub>3</sub> rubber aggregates	161
Figure 5.25: Splitting tensile strength of rubberised POFA concrete containing 10% R <sub>1</sub> , R <sub>2</sub> and R <sub>3</sub> rubber aggregates	161
Figure 5.26: Splitting tensile strength of rubberised POFA concrete containing 20% R <sub>1</sub> , R <sub>2</sub> and R <sub>3</sub> rubber aggregates	162
Figure 5.27: Splitting tensile strength of rubberised POFA concrete containing 30% R <sub>1</sub> , R <sub>2</sub> and R <sub>3</sub> rubber aggregates	163
<b>Figure 5.28:</b> Rubberised concrete sample showing large deformation without disintegration by increasing the level of rubber particles in mixture	164
Figure 5.29: Flexural of rubberised POFA concrete containing fine fibre rubber aggregates (R <sub>1</sub> )	165
<b>Figure 5.30:</b> Flexural of rubberised POFA concrete containing fine granular rubber aggregates (R <sub>2</sub> )	167
Figure 5.31: Flexural of rubberised POFA concrete containing coarse granular rubber aggregates	168
Figure 5.32: Flexural strength of rubberised POFA concrete containing 5% R <sub>1</sub> , R <sub>2</sub> and R <sub>3</sub> rubber aggregates	170
Figure 5.33: Flexural strength of rubberised POFA concrete containing 10% R <sub>1</sub> , R <sub>2</sub> and R <sub>3</sub> rubber aggregates	170
Figure 5.34: Flexural strength of rubberised POFA concrete containing 20% R <sub>1</sub> , R <sub>2</sub> and R <sub>3</sub> rubber aggregates	171
Figure 5.35: Flexural strength of rubberised POFA concrete containing 30% R <sub>1</sub> , R <sub>2</sub> and R <sub>3</sub> rubber aggregates	171
Figure 5.36: Failure mode of concrete under flexural test of rubberised POFA concrete containing high (20% and 30%) and low (5% and 10%) volume rubber aggregates	172

Figure 5.37: Modulus of elasticity of concrete containing various concentration “R <sub>1</sub> ” rubber aggregates	173
Figure 5.38: Modulus of elasticity of concrete containing various concentration “R <sub>2</sub> ” rubber aggregates	174
Figure 5.39: Modulus of elasticity of concrete containing various concentration “R <sub>3</sub> ” rubber aggregates	174
<b>Figure 5.40:</b> Stress-Strain behaviour of concrete containing 10%, 20% and 30% type R <sub>1</sub> aggregates	177
<b>Figure 5.41:</b> Failure mode of various concrete containing type R <sub>1</sub> rubber particles and the control concrete during Stress-Strain test	177
<b>Figure 5.42:</b> Stress-Strain behaviour of concrete containing 10%, 20% and 30% type R <sub>2</sub> aggregates	178
<b>Figure 5.43:</b> Failure mode of various concrete containing type R <sub>2</sub> rubber particles and the control concrete during Stress-Strain test	178
<b>Figure 5.44:</b> Stress-Strain behaviour of concrete containing 10%, 20% and 30% type R <sub>3</sub> aggregates	179
<b>Figure 5.45:</b> Failure mode of various concrete containing type R <sub>3</sub> rubber particles and the control concrete during Stress-Strain test	179
<b>Figure 6.1:</b> Actual time – temperature curves for various thermal exposure and the standard curve of ISO 834	181
Figure 6.2: Type R <sub>1</sub> rubberised concrete specimens after exposure to 150 °C	183
Figure 6.3: Type R <sub>1</sub> rubberised concrete specimens after exposure to 300 °C	184
<b>Figure 6.4:</b> R <sub>1</sub> rubberised concrete specimens after exposure to 500 °C.	184
<b>Figure 6.5:</b> Ignition of rubberised concrete containing fine fibre rubber aggregates after exposure to 500 °C	184
<b>Figure 6.6:</b> Retaining ash of rubber particles on surface, cracks and wide voids on the surface of specimens after exposure to 800 °C	185
<b>Figure 6.7:</b> Rate of mass loss for R <sub>1</sub> 5CP20 in various elevated temperature regarding to different cooling regime	187



<b>Figure 6.8:</b> Rate of mass loss for R <sub>1</sub> 10CP20 in various elevated temperature regarding to different cooling regime	187
<b>Figure 6.9:</b> Rate of mass loss for R <sub>1</sub> 20CP20 in various elevated temperature regarding to different cooling regime	188
<b>Figure 6.10:</b> Rate of mass loss for R <sub>1</sub> 30CP20 in various elevated temperature regarding to different cooling regime	188
<b>Figure 6.11:</b> Residual compressive strength of normal and 20% POFA in various elevated temperature regarding to different cooling regime	191
<b>Figure 6.12:</b> Residual compressive strength of R <sub>1</sub> rubberised concrete 150 °C under different cooling regime	191
<b>Figure 6.13:</b> Residual compressive strength of R <sub>1</sub> rubberised concrete 300 °C under different cooling regime	191
<b>Figure 6.14:</b> Residual compressive strength of R <sub>1</sub> rubberised concrete 500 °C under different cooling regime	192
<b>Figure 6.15:</b> Residual compressive strength of R <sub>1</sub> rubberised concrete 800 °C under different cooling regime	192
<b>Figure 6.16:</b> Correlation between UPV values and residual compressive strength of type R <sub>1</sub> rubberised concrete under air cooling regime	198
<b>Figure 6.17:</b> Correlation between UPV values and residual compressive strength of type R <sub>1</sub> rubberised concrete under water cooling regime	199
<b>Figure 6.18:</b> Hairy cracks on the surface due to water cooling after sample exposed to 150 °C	201
<b>Figure 6.19:</b> Craze cracks on the surface after exposed to 300 °C	201
<b>Figure 6.20:</b> Physical characteristics of type R2 rubberised concrete after exposed to 500 °C, leakage of melted rubber highlighted with red circles	201
<b>Figure 6.21:</b> Ignition of concrete containing fine granular rubber aggregates and leakage of melted rubber aggregates after exposure to 500 °C	202
<b>Figure 6.22:</b> Physical characteristics of type R2 rubberised concrete after exposed to 800 °C; cracks indicates with red eclipse	202

<b>Figure 6.23:</b> Rate of weight loss for R <sub>2</sub> 5CP20 in various elevated temperature regarding to different cooling regime	204
<b>Figure 6.24:</b> Rate of weight loss for R <sub>2</sub> 10CP20 in various elevated temperature regarding to different cooling regime	204
<b>Figure 6.25:</b> Rate of weight loss for R <sub>2</sub> 20CP20 in various elevated temperature regarding to different cooling regime	204
<b>Figure 6.26:</b> Rate of weight loss for R <sub>2</sub> 30CP20 in various elevated temperature regarding to different cooling regime	205
<b>Figure 6.27:</b> Residual compressive strength of R <sub>2</sub> rubberised concrete at 150 °C under different cooling regime	206
<b>Figure 6.28:</b> Residual compressive strength of R <sub>2</sub> rubberised concrete at 300 °C under different cooling regime	207
<b>Figure 6.29:</b> Residual compressive strength of R <sub>2</sub> rubberised concrete at 500 °C under different cooling regime	207
<b>Figure 6.30:</b> Residual compressive strength of R <sub>2</sub> rubberised concrete at 800 °C under different cooling regime	207
<b>Figure 6.31:</b> Correlation between UPV values and residual compressive strength of type R <sub>2</sub> rubberised concrete under air cooling regime	213
<b>Figure 6.32:</b> Correlation between UPV values and residual compressive strength of type R <sub>2</sub> rubberised concrete under water cooling regime	214
<b>Figure 6.33:</b> Hair line cracks on the surface after exposed to 300 °C; popouts occurred in the environs of rubber aggregates	217
<b>Figure 6.34:</b> Physical characteristics of type R <sub>2</sub> rubberised concrete after exposed to 500 °C, leakage of melted rubber highlighted with red circles	218
<b>Figure 6.35:</b> Physical characteristics of type R <sub>2</sub> rubberised concrete after exposed to 800 °C; popouts and cracks indicate with red eclipse	218
<b>Figure 6.36:</b> Rate of weight loss for R <sub>3</sub> 5CP20 in various elevated temperature regarding to different cooling regime	220
<b>Figure 6.37:</b> Rate of weight loss for R <sub>3</sub> 10CP20 in various elevated temperature regarding to different cooling regime	220

<b>Figure 6.38:</b> Rate of weight loss for R <sub>3</sub> 20CP20 in various elevated temperature regarding to different cooling regime	221
<b>Figure 6.39:</b> Rate of weight loss for R <sub>3</sub> 30CP20 in various elevated temperature regarding to different cooling regime	221
<b>Figure 6.40:</b> Residual compressive strength of R <sub>2</sub> rubberised concrete at 150 °C under different cooling regime	223
<b>Figure 6.41:</b> Residual compressive strength of R <sub>3</sub> rubberised concrete at 300 °C under different cooling regime	224
<b>Figure 6.42:</b> Residual compressive strength of R <sub>3</sub> rubberised concrete at 500 °C under different cooling regime	224
<b>Figure 6.43:</b> Residual compressive strength of R <sub>3</sub> rubberised concrete at 800 °C under different cooling regime	224
<b>Figure 6.44:</b> Correlation between UPV values and residual compressive strength of type R <sub>3</sub> rubberised concrete under air cooling regime	230
<b>Figure 6.45:</b> Correlation between UPV values and residual compressive strength of type R <sub>3</sub> rubberised concrete under water cooling regime	231
<b>Figure 6.46:</b> Water absorption of various R <sub>1</sub> rubberised concrete at 28 and 90 days	236
<b>Figure 6.47:</b> Water absorption of various R <sub>2</sub> rubberised concrete at 28 and 90 days	236
<b>Figure 6.48:</b> Water absorption of various R <sub>3</sub> rubberised concrete at 28 and 90 days	236
<b>Figure 6.49:</b> Effect of TRA replacement on modified rubberised concrete resistance to chloride-ion penetration at 28 and 90 days	238
<b>Figure 7.1:</b> Sound absorption coefficient of type R <sub>1</sub> rubberised concrete; (a) Sound absorption of concrete with 5% type R <sub>1</sub> particles; (b) Sound absorption of concrete with 10% type R <sub>1</sub> particles; (c) Sound absorption of concrete with 20% type R <sub>1</sub> particles; (d) Sound absorption of concrete with 30% type R <sub>1</sub> particles	241
<b>Figure 7.2:</b> Noise reduction coefficient (NRC) versus type R <sub>1</sub> rubber particles	242
<b>Figure 7.3:</b> Sound absorption coefficient of type R <sub>2</sub> rubberised concrete; (a) Sound absorption of concrete with 5% type R <sub>2</sub> particles; (b) Sound	

absorption of concrete with 10% type R <sub>2</sub> particles; (c) Sound absorption of concrete with 20% type R <sub>2</sub> particles; (d) Sound absorption of concrete with 30% type R <sub>2</sub> particles	243
<b>Figure 7.4:</b> Noise reduction coefficient (NRC) versus type R <sub>2</sub> rubber particles	244
<b>Figure 7.5:</b> Sound absorption coefficient of type R <sub>3</sub> rubberised concrete; (a) Sound absorption of concrete with 5% type R <sub>3</sub> particles; (b) Sound absorption of concrete with 10% type R <sub>3</sub> particles; (c) Sound absorption of concrete with 20% type R <sub>3</sub> particles; (d) Sound absorption of concrete with 30% type R <sub>3</sub> particles	245
<b>Figure 7.6:</b> Noise reduction coefficient (NRC) versus type R <sub>3</sub> rubber particles	246
<b>Figure 7.7:</b> Sound transmission loss versus frequency for type R <sub>1</sub> rubberised concrete; (a) Sound transmission loss for concrete with 5% type R <sub>1</sub> particles; (b) Sound transmission loss for concrete with 10% type R <sub>1</sub> particles; (c) Sound transmission loss for concrete with 20% type R <sub>1</sub> particles; (d) Sound transmission loss for concrete with 30% type R <sub>1</sub> particles	248
<b>Figure 7.8:</b> Sound transmission coefficient (STC) versus type R <sub>1</sub> rubber particles	249
<b>Figure 7.9:</b> Sound transmission loss versus frequency for type R <sub>2</sub> rubberised concrete; (a) Sound transmission loss for concrete with 5% type R <sub>2</sub> particles; (b) Sound transmission loss for concrete with 10% type R <sub>2</sub> particles; (c) Sound transmission loss for concrete with 20% type R <sub>2</sub> particles; (d) Sound transmission loss for concrete with 30% type R <sub>2</sub> particles	251
<b>Figure 7.10:</b> Sound transmission coefficient (STC) versus type R <sub>2</sub> rubber particles	251
<b>Figure 7.11:</b> Sound transmission loss versus frequency for type R <sub>3</sub> rubberised concrete; (a) Sound transmission loss for concrete with 5% type R <sub>3</sub> particles; (b) Sound transmission loss for concrete with 10% type R <sub>3</sub> particles; (c) Sound transmission loss for concrete with 20% type R <sub>3</sub> particles; (d) Sound transmission loss for concrete with 30% type R <sub>3</sub> particles	253

**Figure 7.12:** Sound transmission coefficient (STC) versus type R<sub>3</sub> rubber particle

**LIST OF ABBREVIATIONS**

ACI	-	American Concrete Institute
AEA	-	Air Entraining Admixture
ASCE	-	American Society Civil Engineers
ASHTTO	-	American Association of State Highway and Transportation Officials
ASR	-	Alkali Silica Reaction
ASTM	-	American Society for Testing and Materials
EDX	-	Energy Dispersive X-ray
FESEM	-	Field Emission Scanning Electron Micrograph
GGBS	-	Ground Granulated Blast Furnace Slag
LOI	-	Loss on Ignition
LVDT	-	Linear Variable Displacement Transducer
MOE	-	Modulus of Elasticity
NRC	-	Noise Reduction Coefficient
OPC	-	Ordinary Portland Cement
POFA	-	Palm Oil Fuel Ash
PRC	-	Plain Rubberized Concrete
RCPT	-	Rapid Chloride Penetration Test
RHA	-	Rise Husk Ash
RILEM	-	International Union of Testing and Research Laboratory for Materials and structures
SBR	-	Styrene Butadiene Rubber

SEM	-	Scanning Electron Micrograph
SP	-	Supper Plasticiser
SSD	-	Saturated Surface Dry
STC	-	Sound Transmission Loss
TRA	-	Tire Rubber Aggregate
UPV	-	Ultrasonic Pulse Velocity
VDC	-	Volts of Direct Current
XRD	-	X-ray Diffraction

## LIST OF SYMBOLS

$A_c$	-	The cross section of specimen
$A_c$	-	Design air content
$A_s$	-	Air content of the sample tested
$GS_R$	-	Specific gravity of rubber aggregate
$L_r$	-	Distance between the lower roller
$M_c$	-	Mass of container filled with concrete
$M_m$	-	Mass of container
$V_{N.F}$	-	Solid volume of fine aggregate
$V_m$	-	Volume of container
$W_R$	-	Weight of rubber aggregates in concrete mixture
$f_c$	-	The compressive strength in mega Pascal
$f'_c$	-	Compressive Strength
$f_{ct}$	-	Flexural strength in mega Pascal
$g_1$	-	Bulk density, dry
$g_2$	-	Apparent density
$\gamma_w$	-	Density of water
Al	-	Almina
Al <sub>2</sub> O <sub>3</sub>	-	Aluminium oxide
c	-	Mass of surface
C	-	Carbon
C <sub>2</sub> S	-	Calcium silicate
C <sub>3</sub> Al	-	Tricalcium aluminate
Ca(OH) <sub>2</sub>	-	Calcium hydroxide
CaO	-	Calcium oxide
C-A-S-H	-	Calcium silicate hydrate
Cl	-	Chloride
CO <sub>2</sub>	-	Carbon dioxide



C-S-H	-	Calcium silicate hydrate
$E$	-	Dynamic modulus of elasticity
$E_s$	-	Modulus of Elasticity
Fe	-	Iron
$Fe_2O_3$	-	Iron oxide
$f_r$	-	Flexural Strength
$K_2O$	-	Potassium oxide
MgO	-	Magnesium oxide or magnesia
$P_2O_5$	-	Phosphorus oxide
R	-	Percentage of rubber aggregate replacement
$SG_c$	-	Specific gravity of cement
$SG_{ca}$	-	Specific gravity of coarse aggregate on saturated surface dry basis
$SiO_2$	-	Silicon oxide
$SO_3$	-	Sulphur trioxide
$TiO_2$	-	Titanium oxide
W/B	-	Water to binder ratio (by weight)
$D$	-	Density of concrete
$E$	-	Modulus of elasticity
$G$	-	Aggregate correction factor
$L$	-	Distance between transducers (m)
$T$	-	Effective transit time
$V$	-	Pulse velocity
$\varepsilon$	-	Longitudinal strain
$\mu$	-	Dynamic poisson's ratio
$\rho$	-	density of water

**LIST OF APPENDICES**

<b>APPENDIX.</b>	<b>TITLE</b>	<b>PAGE</b>
A	List of Publications	286

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Overview**

Concrete has been the most commonly used manufactured material in the world since its invention. Concrete is a composite material comprising three major fractions, namely aggregate, cement, or binder (supplementary cement materials), and water, in suitable proportions, thus allowing the resulting mixture to set and harden over time. It is common knowledge that aggregates are the inert materials in concrete; however, being the major constituent, the proper selection of aggregates is very important to accomplish innovation in concrete production (de Brito and Saikia, 2013). In fact, the proper selection of aggregates and the manipulation of their size distribution are very important steps in the development of almost all types of special concrete. The aggregate fraction in concrete is about 60% to 80% of its total volume (Neville, 2011). Moreover, the preparation of some types of concrete, such as light and heavyweight concrete, as well as concrete resistant to sound or vibration, can only be achieved through the proper selection of aggregates.

Recently, the worldwide growth of the automobile industry and the increase in car use has tremendously boosted tyre production. For example, in the United States alone, around 233.3 million scrap tyres were generated in 2013; this is approximately equal to 3,824.3 thousand tonnes (U.S. Environmental Protection Agency, 2013). The European Union countries discarded 3.2 million tonnes of scrap tyres in 2009 (Bravo and de Brito, 2012). In Malaysia, the estimated number of waste tyres is 8.2 million annually (Thiruvangodan, 2006). Furthermore, the quantity of scrap tyres generated in Malaysia for various years is presented in Table 1.1. Therefore, large quantities of waste materials and by-products are generated

from manufacturing processes, service industries, and municipal solid wastes. As a result, solid waste management has become one of the major environmental concerns in the world. The increase in public awareness about the environment, the scarcity of landfill space, and the ever-increasing cost of goods, the utilisation of waste materials and by-products has become an attractive alternative to disposal. The high consumption of natural sources, extreme quantities of industrial wastes produced, and environmental pollution require the delineation of new solutions for sustainable development.

**Table 1.1:** Number of scrap tyres generated in Malaysia (National Solid Waste Management Department, 2011)

Year	Quantity of Scrap Tyres (Tonne/Year)
2007	208.911
2008	211.209
2009	232.325
2010	245.087

Another important recent development in the field of concrete science is the utilisation of waste materials and by-products in the construction industry, as well as the use of these materials as aggregates in the production of various types of concrete. The utilisation of waste materials and by-products is a partial solution to environmental and ecological problems. The use of these materials helps not only in having them utilised in cement, concrete, and other construction materials but also in reducing the cost of cement and concrete manufacturing. It also has numerous indirect benefits, such as reduction in landfill costs, energy savings, and environmental protection from possible pollution effects. Furthermore, the utilisation of these materials may improve the microstructure, durability, and mechanical properties of mortar and concrete, which may be difficult to achieve using only ordinary Portland cement.

Meanwhile, palm oil fuel ash is known as an agricultural by-product, and such waste material is simply disposed in landfills without any commercial returns. However, this may have a mal-effect role in the environment and landfills areas. In fact, Malaysia is the second largest producer of palm oil in the world. According to a report on the Malaysian palm oil industry (2009), palm oil production reached 17.7 million tonnes. There are more than 200 palm oil mills operating in the country. On average, 43 tonnes or more of empty fruit bunches, husks, and shells are generated per 100 tonnes of fresh fruit bunches processed. The total solid waste generated by this industry has been estimated to amount to more than 8.1 million tonnes a year. These wastes are mostly used in boilers as fuel to generate power for the mill. After this process, the waste becomes ash. This ash is known as palm oil fuel ash (POFA) (Shafiq et al., 2014; Foo and Hameed, 2009)

Significant research on the use of by-products in cement-based materials has been on-going, and the results show that POFA has the great potential to serve as a partial replacement binder material in concrete mixtures.

## **1.2 Importance of the Study**

The disposal of rubber tyre waste has become a serious problem because of the generation of huge amounts of tyres, which are non-biodegradable by nature. Over the past decades, millions of scrap tyres have been disposed into open land fields. These stockpiles seriously threaten both the environment and public health because of their potential to serve as suitable breeding fields for mosquitoes, particularly because scrap tyres oftentimes retain water, which provides enough humidity and a warm place for mosquito breeding. Mosquitoes are one of the major public health threats that increase the likelihood of spreading disease. Moreover, these stockpiles create a fire danger because tyre components contain flammable content. Some researchers reported that tyre fires had continued for several months. Moreover, under the high temperatures of tyre fires, the tyres melt and release hydrocarbons and other pollutants to the ground and, in some cases, even to the ground water. In addition, tyre fires have produced black smoke, which causes serious air pollution (Guneyisi et al., 2004; Eldin and Senouci 1994; Hernandez–

Oliveras et al., 2002; Li et al., 2004-b; Topcu 1995; Khaloo et al., 2008; Siddique and Naik, 2004; Khatib and Bayomy 1999; Ghaly and Cahill, 2005).

Although concrete is the most commonly used construction material, it does not always fulfil some requirements, especially in service. Portland cement concrete (PCC) is a composite material that is well-known for its mechanical properties, with including adequate compressive strength, acceptable tensile strength, and low toughness, which resulted in brittleness and low deformability (Guneyisi et al., 2004; Khaloo et al., 2008). An ideal PCC is expected to have such properties as high tensile strength and light weight. Moreover, the prompted demand for the modification of the brittle property of concrete resulted in the utilisation and application of alternative materials with deformable property, such rubber tyres, as coarse or fine aggregates or as a filler materials for the preparation of various types of concrete (Kumaran et al. 2012; Siddique and Naik 2004; Fattuhi and Clark, 1996; Chiu, 2008; Khaloo et al., 2008; Li et al., 2004-a). Elastic and deformable of tyre-rubber particles could improve concrete properties, especially in terms of brittleness and sound insulation properties. Therefore, the addition of proper materials to concrete is one of the most popular fields in the concrete modification research area, and a large number of studies have been conducted to identify and introduce new materials as additives or replacements to improve or modify concrete properties (Hall et al., 2012; Khaloo et. al 2008; Pelisser et al., 2011; Sunthonpagasit and Duffey, 2004).

### **1.3 Problem statement**

At present, the rapid growth of the automobile industry increased not only automobile production, but also the amount of industrial waste materials, such as scrap tyres. Industrial waste materials, such as waste tyres, should be handled properly to reduce the mal-effect on the environment and the rate of wastage. Moreover, the economic situation in developing countries demands for cost reduction in construction projects. Therefore, cutting costs related to concrete has a major role in this goal, given that concrete is the most commonly used material in construction projects.

The utilisation of pozzolanic materials, polymers, fibres, and waste materials in concrete has been studied many years ago because shortcomings in the performance of concrete, either in the fresh or hardened state, motivated engineers to seek improvements. The inclusion of all these materials is a typical approach. Over the past decades, numerous research works have been conducted on the use of agro-waste ashes as supplementary cementing material in concrete construction. Among others, palm oil fuel ash (POFA) played a tremendous role in this regard.

In addition, in the application of concrete, desirable concrete properties include lighter weight, higher toughness, better sound absorption, and higher impact resistance. Although concrete is the most commonly used construction material, it does not always fulfil these requirements. New applications for recycling waste materials have recently been realised to improve the properties of concrete. One of these applications is the utilisation of scrap tyres to replace aggregates partially. The major weakness of using rubber in concrete is the low compression strength of rubberised concrete. It remains a problem in the use of rubberised concrete as a structural component. Thus, it is recommended for use as a non-loading member in construction. Utilising tyre-rubber aggregates in concrete has great potential to produce acoustic material. However, the low strength of rubberised concrete prevents engineers from fully benefiting from this attribute.

Therefore, this research endeavours to find a way to utilise rubberised POFA concrete in structural application, especially in the floor component for low-cost buildings, as concrete with high potential in terms of acoustic and soundproofing properties.

#### **1.4 Aim and Research Objective**

The aim of this research is to investigate the effect of incorporating palm oil fuel ash (POFA) for the partial substitution of cementitious material, with tyre-rubber aggregate replacement utilised as the aggregate in concrete to achieve green and sustainable concrete production.

- i. The main objectives of this research are as follows:
  - i. To determine the optimum mix design for rubberised concrete with different types, sizes, and amounts of tyre-rubber particles incorporating POFA for application to structural concrete.
  - ii. To identify the engineering properties of concrete with different types, shapes, and sizes of tyre-rubber aggregate in terms of physical and mechanical qualities.
  - iii. To evaluate the durability of POFA-rubberised concrete, this study was based on such parameters as fire endurance, water absorption, chloride penetration, and carbonation of modified-rubberised concrete.
  - iv. To determine the property-improvement of POFA-rubberised concrete in terms of acoustic properties. The properties to be evaluated include: sound absorption and sound transmission properties of POFA-rubberised concrete in the corporation and different types, shapes, amounts, and sizes of tyre-rubber aggregates.

## **1.5 Scope and Limitation of the Research**

In general, this research focused on the impact of tyre-rubber aggregate on the engineering properties of concrete. However, this research work was concerned with the development of the utilization palm oil fuel ash (POFA) concrete. Primarily, POFA replaced cement partially at a range from 15% to 30%. Then, the amount of replacement was optimised based on the compressive strength. Tyre-rubber aggregates were categorised in three groups, namely fine fibre crumb rubber (0.8 to 3.3 mm), fine granular crumb rubber (1 to 4 mm), and coarse granular crumb rubber (5 to 8 mm). The range of replacement level of natural aggregate with the tyre-rubber aggregate was from 5% to 30%.



The experimental study focused on the engineering properties of modified rubberised concrete, particularly, compressive strength, as well as the acoustic properties, durability, and fire safety performance of rubberised POFA concrete.

## **1.6 Significance of the Research**

The disposal of rubber tyre waste has become a serious problem because of the generation of huge amounts of tyres, which are non-biodegradable by nature. The extensive references, including excellent reviews, are available on the use of tyre-rubber as coarse or fine aggregates or as a filler material for the preparation of various types of concrete (Kumaran et al. 2012; Kumaran et al. 2011; Siddique and Naik 2004). Meanwhile, studies are on-going to identify a balance between reutilising scrap tyres and the mechanical properties of rubberised concrete, especially in terms of compressive strength.

Furthermore, previous research found that POFA exhibited a satisfactory performance when introduced to the concrete as a pozzolanic material. Therefore, reusing of by-products from the agro-industry, such as POFA, may help decrease the threats of disposal hazard materials and save nature by reducing the CO<sub>2</sub> emissions associated with reduction in the demand manufacturing of Portland cement.

The outcome of this research can prepare supportive information for utilising POFA as a binder replacement and tyre-rubber particles as aggregates. Furthermore, this research work aim to provide a soundproof concrete with the used of the tyre aggregates with proper compressive strength, which is accepted as a property of structural concrete that may be deemed as strength of this research.

## **1.7 Thesis Organisation**

The thesis is organised and presented in several chapters as follows:

Chapter One: This chapter presents a general appraisal and overview of the study. It includes the introduction, importance of the study, problem statement, aim of the study, objectives of the research, as well as the scope and significance of research in this field. Furthermore, the layout of the thesis is briefly described in this chapter.

Chapter Two: This chapter provides a comprehensive description of the properties of rubberised concrete and explains the recent research works on the use of POFA as pozzolanic material. An in-depth review of the effects of the application of POFA as pozzolanic material on the properties of concrete is discussed. The contribution of rubber aggregate utilisation to the concrete properties, specifically both fresh and hardened properties, is described.

Chapter Three: The use of the proper materials and the methodology for the use of the appropriate standard and modification are necessary when conducting the tests described in this chapter.

Chapter Four: The procedures for the modification of the mixture proportion of concrete in terms of POFA utilisation in concrete as pozzolanic material to enhance concrete strength and rubber aggregate to serve as a partial replacement for natural aggregates. This chapter reveals the results of POFA and its effect on concrete properties. It also presents the methods of substitution for rubber aggregates and why this method was chosen.

Chapter Five: This chapter reveals the properties of rubberised POFA concrete in the fresh and hardened states in long-term studies. The parameters studied in this chapter include workability in terms of the slump of concrete, fresh density, and air content. In addition, the relationship between some data is developed in order to establish a correlation. For the investigation on hardened properties, tests falling in this category include compressive, flexural, and tensile strength. It also presents the results obtained and discussion made on the evaluation of mechanical properties. The deformability and conductivity of modified rubberised concrete is discussed in this chapter. Tests conducted in this category include modulus of elasticity and ultrasonic wave transmit of concrete containing different amounts and sizes of rubber aggregates.

Chapter Six: The aspects of durability performance considered in this chapter are permeability (water absorption and total porosity), chloride content (rapid chloride penetration test), carbonation, and fire endurance.

Chapter Seven: The acoustic properties of rubberised concrete in the high- and low-frequency sound wave study are outlined in this chapter. Furthermore, the soundproofing properties of rubberised concrete with different types and amounts of rubber aggregates are discussed.

Chapter Eight: This chapter concludes this dissertation by stating the findings and achievements of the study and the contribution of the research to the existing knowledge. Recommendations are presented for further research in related areas as well.

## REFERENCES

- Abdullah, K., Nasly, M. A. Hussin, M. W., Nordin, N., Zakaria, Z. (2010). Properties of Aerated Concrete Containing Various Amount of Palm Oil Fuel Ash, Water Content and Binder Sand Ratio. *2nd International Conference on Chemical, Biological and Environmental Engineering (ICBEE 2010)*. 391–395.
- ACI Committee 211 (approve 2002) *Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete*, ACI 211.1-91, American Concrete Institute, Farmington Hills, Michigan, 1991, 38
- Adhikari, B., De, D., Maiti, S., (2000). Reclamation and recycling of waste rubber. *Progress in Polymer Science*, 25 (7), 908-948.
- Advancing Sustainable Materials Management, (2013). *Assessing Trends in Material Generation, Recycling and Disposal in the United States* United States Environmental Protection Agency Solid Waste and Emergency Response (5306P) Washington, DC 20460
- Ahmad, M. H., Omar, R. C., Malek, M. A., Noor, N. M., Thiruselvam, S. Compressive Strength of Palm Oil Fuel Ash Concrete. ICCBT 2008 – A (27), 297–306
- Ahmaruzzaman M. (2010). A review on the utilization of fly ash. *Progress in Energy and Combustion Science*, 36 (3), 327-363
- Aiello M.A., Leuzzi F., Centonze G., Maffezzoli A. (2009), Use of steel fibres recovered from waste tyres as reinforcement in concrete: Pull-out behaviour, compressive and flexural strength. *Waste Management*, 29, 1960–1970
- Aiello, M. A and Leuzzi, F. (2010). Waste tyre rubberized concrete: properties at fresh and hardened state. *Waste management*, 30(8-9), 1696–704.
- Al-Akhras Nabil M., Smadi Mohammed M. (2004), Properties of tire rubber ash mortar. *Cement & Concrete Composites* 26, 821–826

- Aldahdooh, M. a a, Muhamad Bunnori, N. and Megat Johari, M. a. (2014). Influence of palm oil fuel ash on ultimate flexural and uniaxial tensile strength of green ultra-high performance fiber reinforced cementitious composites. *Materials and Design*, 54, 694–701
- Aldahdooh, M. A. A., Bunnori, M. N., MegatJohari M. A. (2013). Development of green ultra- high performance fiber reinforced concrete containing ultrafine palm oil fuel ash. *Construction and Building Materials*, 48, 379–89.
- Ali, N., Amos, A., Roberts, M., (1993). Use of Ground Rubber Tyres in Portland Cement Concrete. International Conference on Concrete. University of Dundee, United Kingdom. , 379-390.
- Al-mulali, M.Z., Awang, H., Abdul Khalil, H. P .S., Aljoumaily, Z. S. (2015). The incorporation of oil palm ash in concrete as a means of recycling: A review. *Cement and Concrete Composites*. 55, 129–138.
- Al-Mutairi, N., Al-Rukaibi, F. & Bufarsan, A., 2010. Effect of microsilica addition on compressive strength of rubberized concrete at elevated temperatures. *Journal of Material Cycles and Waste Management*, 12.41–49.
- Altwair, N. M., Johari, M. A. M. and Hashim, S. F. S. (2011). Strength Activity Index and Microstructural Characteristics of Treated Palm Oil Fuel Ash. *International Journal of Civil and Environmental Engineering*. 11(5), 6.
- Altwair, N. M., Megat Johori, M. A. and Sayed Hashim, S. F. (2013). Influence of treated palm oil fuel ash on compressive properties and chloride resistance of engineered cementitious composites. *Materials and Structure*, 47(4). 667–682.
- Anon. (2012). Natural Polymers, Biopolymers, Biomaterials, and Their Composites, Blends, and IPNs, CRC Press
- Aprianti, E., Shafigh, P., Bahri, S. and Farahani, J.N. (2015). Supplementary cementitious materials origin from agricultural wastes – A review. *Construction and Building Materials*, 74. 176–187.
- Arioz, O. (2007). Effects of elevated temperatures on properties of concrete. *Fire Safety Journal*. 42(8), 516-522
- Aslani, F. (2015). Mechanical Properties of Waste Tire Rubber Concrete. *Journal of Materials in Civil Engineering*, 1–14.
- ASTM C191 (2005). *Standard test method for time setting of hydraulic cement by Vicat Needle*. Philadelphia: American Society for Testing and Materials.

- ASTM C469 (2010). *Test for static modulus of elasticity and poisson's ratio of concrete in compression*. Philadelphia: American Society for Testing and Materials.
- ASTM D6270-08 (2008). (Reapproved 2012) *Standard Practice for Use of Scrap Tires in Civil Engineering Applications*. Philadelphia: American Society for Testing and Materials.
- ASTM C114-13 (2013). *Standard Test Methods for Chemical Analysis of Hydraulic Cement* . Philadelphia: American Society for Testing and Materials.
- ASTM C1202 (2012). *Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration*. Philadelphia: American Society for Testing and Materials.
- ASTM C1240/C1240M (2012). *Standard Specification for Silica Fume Used in Cementitious Mixtures*. Philadelphia: American Society for Testing and Materials.
- ASTM C127-12 (2009). *Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate* .Philadelphia: American Society for Testing and Materials.
- ASTM C128-12 (2012). *Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate* .Philadelphia: American Society for Testing and Materials.
- ASTM C138/C138M – (2012). *Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete*. Philadelphia: American Society for Testing and Materials.
- ASTM C143/C143M (2012). *Standard Test Method for Slump of Hydraulic-Cement Concrete*. Philadelphia: American Society for Testing and Materials.
- ASTM C231/M231 (2014). *Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method*. Philadelphia: American Society for Testing and Materials.
- ASTM C29/C29M (2012). *Standard Test Method for Bulk Density (Unit Weight) and Voids in Aggregate* . Philadelphia: American Society for Testing and Materials.
- ASTM C311 / C311M – 13 (2013). *Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete* . Philadelphia: American Society for Testing and Materials.

- ASTM C33 / C33M - 13 (2013). *Standard Specification for Concrete Aggregates*. Philadelphia: American Society for Testing and Materials.
- ASTM C39/C39M (2012). *Standard test method for compressive strength of cylindrical concrete specimens*. Philadelphia: American Society for Testing and Materials.
- ASTM C494/C494M (2012). *Standard Specification for Chemical Admixtures for Concrete*. Philadelphia: American Society for Testing and Materials.
- ASTM C496/C496M (2011). *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*. Philadelphia: American Society for Testing and Materials.
- ASTM C597 - 09 (2009). *Standard Test Method for Pulse Velocity Through Concrete*. Philadelphia: American Society for Testing and Materials.
- ASTM C597- 09 (2009). *Standard Test Method for Pulse Velocity Through Concrete*. Philadelphia: American Society for Testing and Materials.
- ASTM C618 - 12A (2012). *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*. Philadelphia: American Society for Testing and Materials.
- ASTM C618 - 12A (2012). *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*. Philadelphia: American Society for Testing and Materials.
- ASTM C618- 05 (2008). *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete* . Philadelphia: American Society for Testing and Materials.
- ASTM D 5644 (2009). *Standard Test Methods for Rubber Compounding Materials—Determination of Particle Size Distribution of Recycled Vulcanizate Particulate Rubber*. Philadelphia: American Society for Testing and Materials.
- ASTM D1509-05 (Reapproved 2012). *Standard Test Methods for Carbon Black—Heating Loss* .Philadelphia: American Society for Testing and Materials.
- ASTM D5603-01 (Reapproved 2008). *Standard Classification for Rubber Compounding Materials—Recycled Vulcanizate Particulate Rubber* Philadelphia: American Society for Testing and Materials.
- ASTM D5644-01 (Reapproved 2013). *Standard Test Methods for Rubber Compounding Materials—Determination of Particle Size Distribution of*

- Recycled Vulcanizate Particulate Rubber*. Philadelphia: American Society for Testing and Materials.
- ASTM E413-10 (2010). *Classification for Rating Sound Insulation*. Philadelphia: American Society for Testing and Materials
- ASTM E413-10 (2010). *Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements*. Philadelphia: American Society for Testing and Materials.
- Atahan, A.O. & Yücel, A.Ö. (2012). Crumb rubber in concrete: Static and dynamic evaluation. *Construction and Building Materials*, 36. 617–622.
- Awal A. S. M. and Hussin, M. W. (1997). The effectiveness of palm oil fuel ash in preventing expansion due to alkali-silica reaction. *Cement and Concrete Composites*, 19 (4). 367-372.
- Awal, A. S. M. A. (1998). *A study of strength and durability performance of concrete containing palm oil fuel ash*. Ph.D. Thesis, Universiti Teknologi Malaysia.
- Awal, A. S. M. A. and Abubakar, S. I. (2011). properties of concrete containing high volume palm oil fuel ash: a short-term investigation. *Malaysian Journal of Civil Engineering*. 23(2). 54–66.
- Awal, A. S. M. A. and Hussin, M. W. (2011). Effect of Palm Oil Fuel Ash in Controlling Heat of Hydration of Concrete. *Procedia Engineering*. 14, 2650-2657.
- Awal, A. S. M. A. and Hussin, M. W. (2011). Effect of Palm Oil Fuel Ash in Controlling Heat of Hydration of Concrete. *Procedia Engineering*. 14(0), 2650-2657.
- Awal, A. S. M. A. and Shehu, I. A., (2013). Evaluation of heat of hydration of concrete containing high volume palm oil fuel ash. *Fuel*, 105. 728–731
- Azmi, N. J., Mohammed, B. S., Al-Matarneh, H. M. A. (2008). Engineering properties of concrete with recycled tire rubber. *International conference on construction and building technology, ICCBT 2008*, Kuala Lumpur, Malaysia, B (34), 141-158
- Bapat, J. D. (2012). *Mineral Admixtures in Cement and Concrete*, CRC Press.
- Batayneh, M.K., Marie, I. & Asi, I., (2008). Promoting the use of crumb rubber concrete in developing countries. *Waste Management*, 28(11), 2171–2176.



- Benazzouk, A., Douzane, O., Langlet, T., Mezreb, K., Roucoult, J.M., Quéneudec, M., (2007). Physico-mechanical properties and water absorption of cement composite containing shredded rubber wastes. *Cement & Concrete Composites*, 29, 732-740.
- Benazzouk, A., Douzane, O., Mezreb, K., Laidoudi, B., Quéneudec, M. (2008). Thermal conductivity of cement composites containing rubber waste particles: Experimental study and modelling. *Construction and Building Materials*, 22(4). 573–579.
- Benazzouk, A., Douzane, O., Mezreb, K., Quéneudec, M. (2006). Physico-mechanical properties of aerated cement composites containing shredded rubber waste. *Cement and Concrete Composites*, 28(7). 650–657.
- Benazzouk, a., Mezreb, K., Doyen, G., Goullieux, a., & Quéneudec, M. (2003). Effect of rubber aggregates on the physico-mechanical behaviour of cement–rubber composites-influence of the alveolar texture of rubber aggregates. *Cement and Concrete Composites*, 25(7). 711–720.
- Bignozzi, M.C., Sandrolini, F., (2006). Tyre rubber waste recycling in self-compacting concrete. *Cement and Concrete Research*, 36 (4). 735-739.
- Borges P. H. R., Costa J. O., Milestone N. B., Lynsdale C. J., Streatfield R. E. (2010) Carbonation of CH and C-S-H in composite cement pastes containing high amounts of BFS. *Cement Concrete. Reserch*. 40, 284-292.
- Borges, P. H. R., Costa, J. O., Milestone, N. B., Lynsdale, C. J. Streatfield R. E. (2010). Carbonation of CH and C-S-H in composite cement pastes containing high amounts of BFS, *Cement and Concrete Research*, 40. 284-292.
- Bravo, M. and de Brito, J. (2012). Concrete made with used tyre aggregate: durability-related performance. *Journal of Cleaner Production*, 25. 42–50.
- Brown, K. M., Cummings, R., Mrozek, J. R., and Terrebonne, P. (2001). Scrap tire disposal: Three principles for policy choice. *Natural Resources Journal*, 41 (1). 9–22.
- BS 1881: Part 103 (1983). *Method for Determination of Compacting Factor*. British Standard Institution.
- BS 1881: Part 118 (1983). *Method for determination of flexural strength*. British Standard Institution.

- BS 5075: Part 1 (1982). *Concrete admixtures. Specification for accelerating admixtures, retarding admixtures and water reducing admixtures*. British Standard Institution.
- BS 5075: Part 3 (1985). *concrete admixtures. specification for superplasticizing admixtures*. British Standard Institution.
- BS1881 Part 3
- Bui, D. D., Hu J., Stroeven, P. (2005). Particle size effect on the strength of rice husk ash blended gap-graded Portland cement concrete, *Cement and Concrete Composites*, 27(3). 357-366.
- Cheerarat R, Jaturapitakkul C. A (2004). Study of disposed fly ash from landfill to replace Portland cement. *Waste Manage* . 24(7), 701–709.
- Chen, J. J., Thomas J. J., Jennings H. M. (2006). Decalcification shrinkage of cement paste, *Cement and Concrete Research*, 36. 801-809.
- Chindaprasirt P, Jaturapitakkul C, Sinsiri T. (2007-b). Effect of fly ash fineness on microstructure of blended cement paste. *Construction and Building Materials*, 21(7). 1534–41.
- Chindaprasirt P., Homwuttiwong S., Jaturapitakkul C. (2007-a), Strength and water permeability of concrete containing palm oil fuel ash and rice husk–bark ash, *Construction and Building Materials*, 21 (7). 1492-1499.
- Chindaprasirt, P., Rukzon, S. & Sirivivatnanon, V. (2008). Resistance to chloride penetration of blended Portland cement mortar containing palm oil fuel ash, rice husk ash and fly ash. *Construction and Building Materials*, 22(5). 932–938.
- Chiu, C. T. (2008). Use of ground tire rubber in asphalt pavements: field trial and evaluation in Taiwan. *Resources, Conservation and Recycling*, 52. 522-532.
- Chou, L. H., Lu, C. K., Chang, J. R., Lee, M. T. (2007). Use of waste rubber as concrete additive. *Waste Management and Research*, 25(1). 68–76.
- Chou, L. H., Yang, C. K., Lee, M. T., Shu, C. C. (2010). Effects of partial oxidation of crumb rubber on properties of rubberized mortar. *Composites Part B: Engineering*, 41(8). 613–616.
- Corinaldesi, V., Mazzoli, A. & Moriconi, G. (2011). Mechanical behaviour and thermal conductivity of mortars containing waste rubber particles. *Materials & Design*, 32(3). 1646–1650

- Cultrone, G., Sebastian, E., Huertas, M. O. (2005). Forced and natural carbonation of lime-based mortars with and without additives: Mineralogical and textural changes, *Cement and Concrete Research*, 35. 2278-2289.
- de Brito, J., Saikia, N. (2013). *Recycled Aggregate in Concrete - Use of Industrial, Use of Industrial, Construction and Demolition Waste*. Springer.
- Demirel, B. and Keleştemur, O. (2010). Effect of elevated temperature on the mechanical properties of concrete produced with finely ground pumice and silica fume. *Fire Safety Journal*. 45(6–8), 385-391
- Eldin, N. N. and Senouci, A. B. (1993). Rubber-tire particles as concrete aggregate. *Journal of Materials in Civil Engineering*, 5 (4). 478–496.
- Eldin, N. N., and Senouci A. B. (1994), Measurement and prediction of the strength of rubberized concrete, *Cement and concrete composites*, 16. 287-298.
- El-Reedy, M. A. (2009). *Advanced materials and techniques for reinforced concrete structures*. CRC Press. Taylor & Francis Group. ISBN 978-1-4200-8891-5
- Emiroglu M, Kelestemur MH, Yildiz S. (2007), An investigation on ITZ microstructure of the concrete containing waste vehicles tire. *In: Proceedings of the eighth international fracture conference, Istanbul/Turkey*;
- Fattuhi, N. I., and Clark, L. a. (1996). Cement-based materials containing shredded scrap truck tyre rubber. *Construction and Building Materials*, 10(4), 229–236.
- FM 5-559 (2011), *Florida method of test for testing of ground tire rubber*.
- Foo, K.Y. and Hameed, B.H., (2009). Value-added utilization of oil palm ash: a superior recycling of the industrial agricultural waste. *Journal of hazardous materials*, 172(2-3), pp.523–31.
- Ganjian, E., Khorami M., Maghsoudi A. A. (2009), Scrap-tyre-rubber replacement for aggregate and filler in concrete, *Construction and Building Materials*, 23 (5). 1828-1836
- Gervais, C., Garrabrants, A. C., Sanchez, F., Barna, R., Oszkowicz, P., Kosson, D. (2004). The effects of carbonation and drying during intermittent leaching on the release of inorganic constituents from a cement-based matrix, *Cement and Concrete Research*, 34. 119-131.
- Gesoğlu, M. and Güneyisi, E. (2007). Strength development and chloride penetration in rubberized concretes with and without silica fume. *Materials and Structures*, 40(9), 953–964.

- Gesoğlu, M. and Güneyisi, E., (2011). Permeability properties of self-compacting rubberized concretes. *Construction and Building Materials*, 25(8). 3319–3326.
- Ghaly, A. M, and Cahill, J. D. (2005). Correlation of strength, rubber content, and water to cement ratio in rubberized concrete. *Canadian Journal of Civil Engineering*, 32. 1075–1081.
- Grinys, A., Sivilevičius, H. & Daukšys, M., (2012). Tyre Rubber Additive Effect on Concrete Mixture Strength. *Journal of Civil Engineering and Management*, 18(3). 393–401.
- Grinys, A., Sivilevičius, H. and Daukšys, M., (2012). Tyre Rubber Additive Effect on Concrete Mixture Strength. *Journal of Civil Engineering and Management*, 18(3), 393–401.
- Groves, G. W., Brough, A., Richardson, I. G., Dobson C. M. (1991). Progressive changes in the structure of hardened C3S cement pastes due to carbonation, *Journal of the American Ceramic Society*, 74(11). 2891-2896.
- Gudmundsson, G. and Olafsson, H. (1999). Alkali-silica reactions and silica fume: 20 years of experience in Iceland , *Cement and Concrete Research*, 29 (8). 1289-1297.
- Guneyisi, E.; Gesoglu, M.; and Ozturan, T., (2004). Properties of Rubberized Concretes Containing Silica Fume, *Cement and Concrete Research*, 34 (12). 2309-2317.
- Guo, Y. C., Zhang, J. H., Chen, G., Chen, G. M., Xie, Z. H. (2014). Fracture behaviors of a new steel fiber reinforced recycled aggregate concrete with crumb rubber. *Construction and Building Materials*, 53. 32–39.
- Hall, M. R., Najim, K. B., Hopfe, C.J. (2012). Transient thermal behaviour of crumb rubber-modified concrete and implications for thermal response and energy efficiency in buildings. *Applied Thermal Engineering*, 33-34. 77–85.
- Handoo, S.K. Agarwal, S. Agarwal, S.K. Physicochemical, mineralogical, an morphological characteristics of concrete exposed to elevated temperatures, *Cement . Concrete. Reserch*. 32 (2002) 1009–1018
- Hassan, I. O., Ismail, M., Noruzman, A. H., Yusuf, T. O., Mehmannaavaz, T., and Usman, J. (2013). Characterization of some key Industrial Waste Products for sustainable Concrete production. *Advance Materials Research*. 690-693, 1091-1094.

- Heitzman, M. (1992). Design and construction of asphalt paving materials with crumb rubber. *Transportation Research Record*. 1339, Transportation Research Board, Washington, D.C., 1–8.
- Hernández-Olivares, F. and Barluenga, G., (2004). Fire performance of recycled rubber-filled high-strength concrete. *Cement and Concrete Research*, 34(1). 109–117.
- Hernández-Olivares, F., Barluenga, G., Bollati, M., Witoszek, B. (2002). Static and dynamic behaviour of recycled tyre rubber-filled concrete, *Cement and Concrete Research*, 32.1 587–1596
- Herrero, S., Mayor, P., Hernández-Olivares, F. (2013). Influence of proportion and particle size gradation of rubber from end-of-life tires on mechanical, thermal and acoustic properties of plaster–rubber mortars. *Materials & Design*, 47. 633–642.
- Hezri, A. A., Hasan, M. N. (2006). Towards sustainable development. The evolution of environmental policy in Malaysia, *Natural Resources*, 30. 37–50 .
- Ho, A. C., Turatsinze, A., Hameed, R., Vu, D. C. (2012). Effects of rubber aggregates from grinded used tyres on the concrete resistance to cracking, *Journal of Cleaner Production*, 23. 209-215.
- Ho, A. C., Turatsinze, A., Vu, D. C. (2008). In: Alexander, M.G., Beushausen, H.D., Dehn, F., Moyo, P. (Eds.), *On the Potential of Rubber Aggregates obtained by Grinding End-of-life Tyres to Improve the Strain Capacity of Concrete*. Taylor & Francis Group, London. 123-129.
- Hobbs, D. W. (1971). The dependence of the bulk modulus, Young's modulus, creep, shrinkage and thermal expansion of concrete upon aggregate volume concentration. *Materials and Structures*, 4, 107–114.
- Huang, B., Li, G., Pang, S., Eggers, J. (2004). Investigation into Waste Tire Rubber-Filled Concrete, *Journal of Materials in Civil Engineering*, 16 (3). 187–194.
- Huang, X., Ranade, R., Ni, W., Li, V. C. (2013). On the use of recycled tire rubber to develop low E-modulus ECC for durable concrete repairs. *Construction and Building Materials*, 46, 134–141.
- Hussin, M. W. and Abdul Awal, A. S. M. (1997). Palm oil fuel ash: A potential pozzolanic material in concrete construction. *Journal of ferrocement*. 27(4), 321-327.

- Hussin, M. W. and Awal A. S. M. A. (1998). Influence of palm oil fuel ash on sulfate resistance of mortar and concrete. In: Proceedings of the sixth CANMET/ACI international conference on fly ash, Silica Fume, Slag, and Natural Pozzolans in Concrete, Bangkok, Thailand. 417-29.
- Isler, J. W. (2012). Assessment of concrete masonry units containing aggregate replacements of waste glass and rubber tire. University of Colorado Denver.
- Ismail, M., El-Gelany I. M., and Muhammad, B. (2011). Influence of elevated temperatures on physical and compressive strength properties of concrete containing palm oil fuel ash. *Construction and Building Materials*, 25(5), 2358–2364.
- Ismail, M., Hassan, I. O., Abdulrahman, A. S., Forozani, P., Noruzman, A. H., and Yusuf, T. O. (2013). Effect of micro-structure and mineralogical composition on the water demand and super plasticiser content of ternary blended self-consolidating paste. *Proceedings of The Thirteenth East Asia-Pacific Conference on Structure Engineering and Construction*. September 11-13, 2013. Sapporo Japan.
- Issa, C. a. and Salem, G.,(2013). Utilization of recycled crumb rubber as fine aggregates in concrete mix design. *Construction and Building Materials*, 42, 48–52.
- Janotka, I. Nurnbergerova, T. (2005). Effect of temperature on structural quality of the cement paste and high-strength concrete with silica fume, *Nucl. Eng. Des.* 235 2019–2032.
- Janssen, G. M. T., Hendriks, C. F. (2002). Sustainable use of recycled materials in building construction, *Advances in Building Technology*, 1399-1406.
- Jaturapitakkul, C., Kiattikomol, K., Tangchirapat, W., Saeting, T. (2007). Evaluation of the sulfate resistance of concrete containing palm oil fuel ash, *Construction and Building Materials*, 21 (7). 1399-1405
- Jaturapitakkul, C., Tangpagasit, J., Songmue, S. and Kiattikomol, K. (2011). Filler effect and pozzolanic reaction of ground palm oil fuel ash. *Construction and Building Materials*, 25(11), pp.4287–4293.
- John, G., Clements-Croome, D., Jeronimidis, G. (2005). Sustainable building solutions: a review of lessons from the natural world, *Building and Environment*, 40 (3). 319-328.

- Kaloush, K. E., Way, G. B., and Zhu, H. (2005). Properties of Crumb Rubberized Concrete. Transportation Research Record, *Journal of the Transportation Research Board*, No. 1914:8–14.
- Kang, J., Han, C., Zhang, Z. (2009). Strength and shrinkage behaviors of roller-compacted concrete with rubber additives. *Materials structures*, 42 (8). 1117-1124
- Kardos, A. J., and Durham, S. A. (2015). Strength, durability, and environmental properties of concrete utilizing recycled tire particles for pavement applications. *Construction and Building Materials*, 98, 832–845.
- Khaliq W, Kodur V. (2011). Thermal and mechanical properties of fiber reinforced high performance self-consolidating concrete at elevated temperatures. *Cement Concrete Reserch* , 41, 1112–1122.
- Khaloo, A. R., Dehestani, M., Rahmatabadi, P. (2008). Mechanical properties of concrete containing a high volume of tire–rubber particles. *Waste Management*, 28. 2472–2482.
- Khatib, Z. K., and Bayomy F. M., (1999). Rubberized Portland cement concrete, *Journal of Materials in Civil Engineering*, 11 (3), August, 1999. 206–0213.
- Kiattikomol K, Jaturapitakkul C, Songpiriyakij S, Chutubtim S. (2001). Study of ground coarse fly ashes with different finenesses from various sources as pozzolanic materials. *Cement Concrete Composite*, 23(4–5),335–343.
- Kim, R.Y. Modeling of Asphalt Concrete, 1st edition. McGraw-Hill Construction, 2009
- Koreňová, Z., Haydary, J., Annus, J., Markoš, J., Jelemenský, L. (2008). Pore structure of pyrolyzed scrap tires. *Chemical Papers*, 62. 86–91.
- Kosmatka, h. S. (2011). *Design and Control of Concrete Mixtures*.Cement Association of Canada Eighth edition.
- Kriker, a., Bali, a., Debicki, G., Bouziane, M., & Chabannet, M. (2008). Durability of date palm fibres and their use as reinforcement in hot dry climates. *Cement and Concrete Composites*, 30(7), 639–648.
- Kroehong, W., Sinsiri, T., Jaturapitakkul, C. and Chindaprasirt, P. (2011). Effect of palm oil fuel ash fineness on the microstructure of blended cement paste. *Construction and Building Materials*, 25 (11). 4095–4104.

- Kumaran, G.S., Lakshmipathy M. and Mushule, N. (2011). Analysis of the transport properties of tyre fiber modified concrete, *American journal of engineering and applied sciences*, 4(3), 400-404.
- Kumaran, G.S., Lakshmipathy M. and Mushule, N. (2012). An investigation on the behaviour of concrete with waste tyre rubber fibres as a partial replacement of coarse aggregate. *Advanced Materials Research*, 367, 49-54,.
- Lamond, J.F. and Pielert, J.H. (2006). Significance of Tests and Properties of Concrete and Concrete-Making Materials, STP 169D.
- Li, G., Stubblefield, M. A., Garrick, G., Eggers, J., Abadie C., Huang, B. (2004-a). Development of waste tire modified concrete, *Cement and Concrete Research*, 34. 2283–2289
- Li, G., Stubblefield, M. A., Garrick, G., Eggers, J., Abadie C., Huang, B. (2004-b), Waste tire fiber modified concrete, Cement and concrete composites: Part B, 35. 305–312
- Li, L. J., Xie, W. F., Liu, F., Guo, Y. C., Deng, J. (2011). Fire performance of high-strength concrete reinforced with recycled rubber particles. *Magazine of Concrete Research*, 63(3). 187–195.
- Lim, S.K., Tan, C.S., Lim, O.Y. and Lee, Y.L. (2013). Fresh and hardened properties of lightweight foamed concrete with palm oil fuel ash as filler. *Construction and Building Materials*, 46. 39–47.
- Ling, T. C. (2011). Prediction of density and compressive strength for rubberized concrete blocks. *Construction and Building Materials*, 25 (11). 4303–4306.
- Ling, T. C. (2012). Effects of compaction method and rubber content on the properties of concrete paving blocks. *Construction and Building Materials*, 28 (1). 164–175.
- Liu, F., Zheng, W., Li, L., Feng, W., Ning, G. (2013). Mechanical and fatigue performance of rubber concrete. *Construction and Building Materials*, 47. 711–719.
- Lomborg, Bjørn. (2001). *The Skeptical Environmentalist: Measuring the Real State of the World*. 138.
- Maas, A. J., Jason, H. I., Maria, Juenger C.G. (2007), Alkali silica reactivity of agglomerated silica fume , *Cement and Concrete Research*, Volume 37, Issue 2, pp 166-174



- Madurwar, M. V., Ralegaonkar, R. V., Mandavgane, S. A. (2013). Application of agro-waste for sustainable construction materials: a – review. *Construction and Building Materials*, 38. 872–878.
- Malaysian Palm Oil Industry Performance. (2009). *Global Oils & Fats Business Magazine*. 6 (1).
- Malhotra, V. M., and Ramezani-pour, A. A. (1994). *Fly Ash in Concrete* (2nd ed.). CANMET
- Malhotra, V. M. (Ed.). (1994). *Advances in Concrete Technology*. (2<sup>nd</sup> ed.). Ottawa, Ontario Canada: CANMET.
- Marques, A. M., Correia, J. R., de Brito, J. (2013). Post-fire residual mechanical properties of concrete made with recycled rubber aggregate. *Fire Safety Journal*, 58. 49–57.
- Marzouki, A., Lecomte, A., Beddey, A., Diliberto, C. and Ben Ouezdou, M. (2013). The effects of grinding on the properties of Portland-limestone cement. *Construction and Building Materials*. 48(0), 1145-1155.
- Mavroulidou, M., and Figueiredo, J. (2010). Discarded tyre rubber as concrete aggregate : a possible outlet for used tyres, *Global NEST Journal*, 12(4). 359–367
- Megat Johari, M. A., Zeyad, A. M., Muhamad Bunnori, N., Ariffin, K. S. (2012). Engineering and transport properties of high-strength green concrete containing high volume of ultrafine palm oil fuel ash. *Construction and Building Materials*, 30. 281–288.
- Mehta, P. K., Monteiro, P. J. M. (2006). *Concrete: microstructure, properties, and materials*. 3rd ed. New York: McGraw – Hill.
- Memari, A., Motlagh, A., Scanlon, A. (2000). Seismic evaluation of an existing reinforced concrete framed tube building based on inelastic dynamic analysis. *Engineering Structures*, 22(6). 621–637.
- Mindess, S., Young, F., and Darwin, D. (2003). *Concrete*. 2nd ed. Prentice Hall.
- Mnahoncakova E, Pavlikova M, Grzeszczyk S, Rovnanikova P, Cerny R. Hydric. (2008). Thermal and mechanical properties of self-compacting concrete containing different fillers. *Construct Build Mater*, 22. 1594–600.
- Mohammed, B. S., Anwar Hossain, K. M., Eng Swee, J. T., Wong, G., & Abdullahi, M. (2012). Properties of crumb rubber hollow concrete block. *Journal of Cleaner Production*, 23(1), 57–67.

- Mohammed, B. S., Azmi, N. J., Abdullahi, M. (2011). Evaluation of rubbercrete based on ultrasonic pulse velocity and rebound hammer tests. *Construction and Building Materials*, 25(3). 1388–1397
- Mohammed, B. S. and Azmi, N.J. (2011). Failure mode and modulus elasticity of concrete containing recycled tire rubber. *Solid Waste Technology and Management*; 37 (1). 16-24.
- Momtazi, A. S. and Zanoosh, R. Z. (2011). The effects of polypropylene fibers and rubber particles on mechanical properties of cement composite containing rice husk ash. *Procedia Engineering*, 10. 3608–3615.
- Munjal, M. L (2014). *Acoustics of ducts and mufflers*. 2<sup>nd</sup> Edition. Wiley. New Yourk
- Muthukumar M., Mohan D. (2004). Studies on polymer concretes based on optimized aggregate mix proportion, *European Polymer Journal*, 40 (9). 2167-2177
- Naik, T. R., Singh, S. S. (1991). Utilization of Discarded Tires as Construction Materials for Transportation Facilities. Report No. CBU-1991-02, UWM Center for By-Products Utilization. University of Wisconsin-Milwaukee, Milwaukee.
- Najim, K. B. and Hall, M. R. (2012). Workability and mechanical properties of crumb-rubber concrete. *Proceedings of the ICE - Construction Materials*, 166. 1–11.
- Najim, K. B., and Hall, M. R. (2010). A review of the fresh / hardened properties and applications for plain- ( PRC ) and self-compacting rubberised concrete (SCRC ). *Construction and Building Materials*, 24 (11). 2043–2051.
- Nas, G. S. Ū., Grinys, A., Ernius, B. Ć. (2007). Deformation Properties of Concrete with Rubber Waste Additives. , 13(3). 219–223.
- Nassar, R.U.D., Soroushian, P. and Ghebrab, T. (2013). Field investigation of highvolume fly ash pavement concrete. *Resources, Conservation and Recycling*. 73, 78-85.
- National Solid Waste Management Department, (2011). Ministry of Housing and Local Government: waste management.
- Nawy, E. G. (2008). Concrete construction engineering handbook, second edition, CRC Press. Taylor & Francis Group.

- Nehdi, M., and Khan, A. (2001), Cementitious Composites Containing Recycled Tire Rubber: An Overview of Engineering Properties and Potential Applications. *Cement, Concrete, and Aggregates*, 23 (1). 3–10
- Neville, A.M. (2011). Properties of concrete - 5th edition. Pearson Education Limited.
- Newman J, Choo BS. (2003). *Advanced concrete technology*. London: Elsevier Ltd.
- Nguyen, T. H., Toumi A., Turatsinze A., Tazi F. (2012). Restrained shrinkage cracking in steel fibre reinforced and rubberised cement-based mortars, *Materials and Structures*, 45 (6). 899-904.
- Oikonomou, N. and Mavridou, S. (2009). Improvement of chloride ion penetration resistance in cement mortars modified with rubber from worn automobile tires. *Cement and Concrete Composites*, 31(6). 403–407.
- Pandey, V. C. and Singh N. (2010), Impact of fly ash incorporation in soil systems, *Agriculture, Ecosystems & Environment*, 136 (1-2). 16-27
- Papadakis, V. G., Vayenas, C. G., Fardis, M. N. (1991). Fundamental modeling and experimental investigation of concrete carbonation, *ACI Materials Journal*, 88. 363-373.
- Park, S. B., Seo, D. S., and Lee, J. (2005). Studies on the sound absorption characteristics of porous concrete based on the content of recycled aggregate and target void ratio. *Cement and Concrete Research*, 35(9), 1846–1854.
- Payá, J., Monzó, J., Borrachero, M. V., Peris, E. and González-López, E. (1997). Mechanical treatments of fly ashes. Part III: Studies on strength development of ground fly ashes (GFA)-Cement mortars. *Cement and Concrete Research*. 27(9), 1365-1377.
- Pelisser, F., Zavarise, N., Longo, T. A., & Bernardin, A. M. (2011). Concrete made with recycled tire rubber: Effect of alkaline activation and silica fume addition. *Journal of Cleaner Production*, 19(6-7), 757–763
- Peng GF, Bian SH, Guo ZQ, Zhao J, Peng XL, Jiang YC. (2008). Effect of thermal shock due to rapid cooling on residual mechanical properties of fiber concrete exposed to high temperatures. *Construction Building Material* ;22(5), 948–55.
- Pierce, C. E. and Blackwell, M. C. (2003). Potential of scrap tire rubber as lightweight aggregate in flowable fill. *Waste management*, 23(3). 197–208.

- Raghvan, D., Huynh, H., Ferraris, C. (1998). Workability, mechanical properties and chemical stability of a recycled tire rubber-filled cementitious composite. *Journal of Materials Science*, 33 (7). 1745-1752.
- Rahal, K., (2007). Mechanical properties of concrete with recycled coarse aggregate. *Building and Environment*, 42(1). 407–415.
- Rahman, M. M., Usman, M., Al-Ghalib, A. A. (2012). Fundamental properties of rubber modified self-compacting concrete (RMSCC). *Construction and Building Materials*, 36. 630–637.
- Report No. FHWASC-96-02. *Department of Civil Engineering, Clemson University in Cooperation with U.S. Department of Transportation*, Clemson, USA.
- Richardson Alan E., Coventry Kathryn A., Ward Gavin. (2012). Freeze/thaw protection of concrete with optimum rubber crumb content. *Journal of Cleaner Production*, 23. 96-103
- Rigo da Silva C. A., Reis R. J. P., Lameiras F. S., Vasconcelos W. L. (2002) Carbonation-related microstructural changes in long-term durability concrete, *Matreial. Reserch*. 5, 287-293.
- Rigo da Silva, C. A., Reis, R. J. P., Lameiras, F. S. Vasconcelos W. L. (2002). Carbonation- related microstructural changes in long-term durability concrete, *Materials Research* , 5. 287-293.
- RILEM – CPC18 (1998). Measurement of hardened concrete carbonation depth. Technical Recommendations for the Testing and Use of Construction Materials. London, E and FN Rivas, H.W. 21. 453-455.
- RMA – Rubber Manufacturers Association (USA). (2009). Scrap Tire Markets in the United States 9th Biennial Report. Washington (DC).
- RMA –Rubber Manufacturers Association (USA). (2000). Scrap tire markets in the UnitedStates, 2000 Edition, RMA, Washington (DC).
- RMA –Rubber Manufacturers Association (USA). (2005). Scrap tire markets in the UnitedStates, 2005 Edition, RMA, Washington (DC).
- Rostami, H.; Lepore, J.; Silverstraim, T.; Zandi, I., (1993). Use of Recycled Rubber Tyres in Concrete. International Conference Concrete 2000 - *Economic and Durable Construction through Excellence*, Dundee, United Kingdom, 391-399.

- Rukzon, S. and Chindaprasirt, P., 2009. An Experimental Investigation of the Carbonation of Blended Portland Cement Palm Oil Fuel Ash Mortar in an Indoor Environment. *Indoor and Built Environment*, 18(4). 313–318.
- Rukzon, S. and Chindaprasirt, P., 2009. An Experimental Investigation of the Carbonation of Blended Portland Cement Palm Oil Fuel Ash Mortar in an Indoor Environment. *Indoor and Built Environment*, 18(4), 313–318.
- Saetta, A. V., Schrefler, B. A., Vitaliani, R. V. (1993). The carbonation of concrete and the mechanism of moisture, heat and carbon dioxide flow through porous materials, *Cement and Concrete Research*, 23. 761-772.
- Salihuddin, R. S. (1993). *Relationships between engineering properties and microstructural characteristics of mortar containing agricultural ash*. Ph.D Thesis. Universiti Teknologi Malaysia.
- Sata V, Jaturapitakkul C, Kiattikomol K. (2007). Influence of pozzolan from various by- product materials on mechanical properties of high-strength concrete. . *Construction and Building Materials*, 21 (7). 1589–98.
- Sata, V., Jaturapitakkul, C. and Kiattikomol, K. (2004). Utilization of Palm Oil Fuel Ash in High-Strength Concrete. *Journal of Materials in Civil Engineering*, 16. 623–628.
- Sata, V., Jaturapitakkul, C. and Rattanashotinunt, C. (2010). Compressive strength and heat evolution of concretes containing palm oil fuel ash. *Journal of Materials in Civil Engineering*. 1033-1038.
- Savva A, Manita P, Sideris KK (2005). Influence of elevated temperatures on the mechanical properties of blended cement concretes prepared with limestone and siliceous aggregates. *Cement Concrete Composite*. 27(2):239–248.
- Segre, N. and Joekes, I., (2000). Use of tire rubber particles as addition to cement paste. *Cement and Concrete Research*, 30 (9). 1421–1425.
- Shafiq P, Mahmud HB, Jumaat MZ, Zargar M. ( 2014). Agricultural wastes as aggregate in concrete mixtures – a review. *Construction and Building Materials*, 53. 110–7.
- Sharma, V. K., Fortuna, F., Mincarini, M., Berillo, M., & Cornacchia, G. (2000). Disposal of waste tyres for energy recovery and safe environment. *Applied Energy*, 65. 381–394.
- Siddique, R. and Naik, T. R. (2004). Properties of concrete containing scrap-tire rubber – an overview. *Waste Management*, 24. 563–569

- Siddique, R., Khatib, J., Kaur, I. (2008). Use of recycled plastic in concrete: a review. *Waste management*, 28 (10). 1835–52.
- Snelson, D.G., Kinuthia, J.M., Davies, P. a and Chang, S.-R., (2009). Sustainable construction: composite use of tyres and ash in concrete. *Waste management* . 29(1),.360–367.
- Snyder, K.A., Ferraris, C.F., Martys, N.S., Garboczi, E.J. (2000). Using Impedance Spectroscopy to Assess the Viability of the Rapid Chloride Test for Determining Concrete Conductivity. *Journal of Research of the National Institute of Standards and Technology*, 105 (4). 497-509
- Stichnothe, H. and Schuchardt, F. (2010). Greenhouse gas reduction potential due to smart palm oil mill residue treatment, *Technology Cooperation And Economic Benefit Of Reduction Of GHG Emission In Indonesia*, Hamburg.
- Sujivorakul, C., Jaturapitakkul, C. A. M., Akkaphol, T. (2011) Utilization of Fly Ash, Rice Husk Ash, and Palm Oil Fuel Ash in Glass Fiber Reinforced Concrete. *Journal of Materials in Civil Engineering. (ASCE)*, 23(9). 1281–1288.
- Sukontasukkul P. (2009). Use of crumb rubber to improve thermal and sound properties of pre-cast concrete panel. *Construction and Building Materials*, 23(2). 1084–1092
- Sukontasukkul, P. and Tiamlom, K. (2012). Expansion under water and drying shrinkage of rubberized concrete mixed with crumb rubber with different size. *Construction and Building Materials*, 29. 520–526.
- Sukontasukkul, P. and Tiamlom, K., 2012. Expansion under water and drying shrinkage of rubberized concrete mixed with crumb rubber with different size. *Construction and Building Materials*, 29, 520–526.
- Sukontasukkul, P., and Chaikaew, C. (2006). Properties of concrete pedestrian block mixed with crumb rubber, *Construction and Building Materials*, 20. 450–457
- Sumadi, S. R. (1993). *Relationships Between Engineering Properties and Microstructural Characteristics of Mortar Containing Agricultural Ash*. Doctor of Philosophy Thesis (Civil Engineering), Universiti Teknologi Malaysia, Skudai.
- Sunthonpagasit, N., Duffey, M.R., (2004). Scrap tires to crumb rubber: feasibility analysis for processing facilities. *Resources, Conservation and Recycling* , 40, 281-299

- Taha Reda, M. M., El-Dieb, A. S., Abd El-Wahab, M. A., and Abdel-Hameed, M. E. (2008). Mechanical, fracture and microstructural investigations of rubber concrete. *Journal of Materials in Civil Engineering*, 20(10), 640–649.
- Taha, M. M. R., El-Dieb A. S., El-Wahab M. A. A., Abdel-Hameed M. E. (2009). Mechanical, Fracture, and Microstructural Investigations of Rubber Concrete, *Journal of Materials in Civil Engineering*, 20 (10). 640–649
- Tangchirapat W., Jaturapitakkul C., Chindaprasirt P. (2009). Use of palm oil fuel ash as a supplementary cementitious material for producing high-strength concrete, *Construction and Building Materials*, 23 (7). 2641-2646
- Tangchirapat, W. and Jaturapitakkul, C. (2010). Strength, drying shrinkage, and water permeability of concrete incorporating ground palm oil fuel ash. *Cement and Concrete Composites*, 32(10). 767–774.
- Tangchirapat, W., Khamklai, S. and Jaturapitakkul, C. (2012). Use of ground palm oil fuel ash to improve strength, sulfate resistance, and water permeability of concrete containing high amount of recycled concrete aggregates. *Materials & Design*, 41. 150–157.
- Tangchirapat, W., Saeting, T., Jaturapitakkul, C., Kiattikomol, K., and Siripanchgorn, A. (2007). Use of waste ash from palm oil industry in concrete. *Waste Management*, 27(1). 81–8.
- Tangchirapat, W., Tangpagasit, J., Waew-kum, S. and Jaturapitakkul, C. (2003). A new pozzolanic material from palm oil fuel ash. , *KMUTT Res. Dev.J.* 26 (4) (2003) 459–473.
- Tasong W.A., Wild S., Tilley R. J. D. (1999). Mechanisms by which ground granulated blastfurnace slag prevents sulphate attack of lime-stabilised kaolinite, *Cement and Concrete Research*, 29 (7). 975-982
- Tay, J. H. (1990). Ash from Oil Palm Waste as a Concrete Material. *Journal of Materials in Civil Engineering*, 2. 96-105.
- Tay, J.-H. and Show, K. Y. (1995). Use of ash derived from oil-palm waste incineration as a cement replacement material. *Resources, Conservation and Recycling*. 13(1). 27-36.
- Thiruvangodan, S.K.A. (2006). *Waste tyer management in malaysia*. Ph.D Thesis Unversiti Putra Malaysia.

- Topcu, I. B and Bilir, T. (2009). Experimental investigation of some fresh and hardened properties of rubberized self-compacting concrete, *Materials and Design*, 30. 3056–3065
- Topçu, İ. B., and Avcular, N. (1997). Analysis of rubberized concrete as a composite material. *Cement and Concrete Research*, 27 (8). 1135–1139.
- Topçu, İ.B. (1995). The properties of rubberized concretes. *Cement and Concrete Research*, 25 (2). 304–310.
- Topçu, İ.B. and Demir, A., (2007). Durability of Rubberized Mortar and Concrete. *Journal of Materials in Civil Engineering*, 19 (2) . 173–178.
- Topçu, İ.B. and Karakurt, C. (2007). A discussion of the paper “Physico-mechanical properties of aerated cement composites containing shredded rubber waste” *Journal of Cement and Concrete Composites*, 29(4). 337–338.
- Topçu, İ.B. and Sarıdemir, M., (2008). Prediction of rubberized concrete properties using artificial neural network and fuzzy logic. *Construction and Building Materials*, 22 (4). 532–540.
- Toutanji, H.A., (1996). The use of rubber tire particles in concrete to replace mineral aggregates. *Cement and Concrete Composites*, 18 (2). 135-139.
- Turatsinze, A. and Garros, M. (2008). On the modulus of elasticity and strain capacity of Self-Compacting Concrete incorporating rubber aggregates. *Resources, Conservation and Recycling*, 52 (10). 1209–1215.
- Turatsinze, A.; Bonnet, S.; Granju, J. (2004). Cracking resistant cement based material. *Fifth International RILEM Conference on Reflective cracking in pavements*, 317-324.
- Turgut, P. and Yesilata, B., (2008). Physico-mechanical and thermal performances of newly developed rubber-added bricks. *Energy and Buildings*, 40. 679–688.
- Turki, M., Bretagne, E., Rouis, M. J., Quéneudec, M. (2009). Microstructure, physical and mechanical properties of mortar-rubber aggregates mixtures. *Construction and Building Materials*, (23). 2715–2722.
- US Environmental Protection Agency. (2013). White House Press Release
- Uygunoglu, T., Topcu, I. B. (2010). The role of scrap rubber particles on the drying shrinkage and mechanical properties of self-consolidating mortars. *Construction and Building Materials*, (24). 1141–1150



- Valadares, F., Bravo, M. and De Brito, J. (2012). Concrete with used tire rubber aggregates: Mechanical performance. *ACI Materials Journal*, (109). 283–292.
- Vieira Raimundo K., Soares Rafael C., Pinheiro Samantha C, Paiva Otavio A., Eleuterio Jose O., Vasconcelos Raimundo P. (2010). Completely random experimental design with mixture and process variables for optimization of rubberized concrete. *Construction and Building Materials*, (24). 1754–1760
- Wang Chao, Zhang Yamei, Ma Aibin. (2010). Investigation into the Fatigue Damage Process of Rubberized Concrete and Plain Concrete by AE analysis, *Journal of Materials in Civil Engineering, Journal of Materials in Civil Engineering*, 23 (7). 953–960.
- Wang, J. C. and Zeng, X. (2006). Influence of Temperature and Pressure on the Dynamic Properties of Rubber-Modified Asphalt Concrete , pp.125–131.
- Wójtowicz, M. a & Serio, M. a, 1996. Pyrolysis of scrap tyres: Can it be profitable? , *Tire Pyrolysis ChemTech*..p. 6
- Xue, J. and Shinozuka, M. (2013). Rubberized concrete: A green structural material with enhanced energy-dissipation capability. *Construction and Building Materials*, 42. 196–204.
- Yang, H., Lin, Y., Hsiao, C. and Liu, J., (2009). Evaluating residual compressive strength of concrete at elevated temperatures using ultrasonic pulse velocity. *Fire Safety Journal*, 44(1). 121–130.
- Yesilata, B., Bulut, H., Turgut, P. (2011). Experimental study on thermal behavior of a building structure using rubberized exterior-walls. *Energy and Buildings* 43. 393–399
- Yesilata, B., Isıker, Y., Turgut, P. (2009). Thermal insulation enhancement in concretes by adding waste PET and rubber pieces. *Construction and Building Materials*, 23 (5). 1878–1882.
- Yilmaz, A. and Degirmenci, N. (2009). Possibility of using waste tire rubber and fly ash with Portland cement as construction materials. *Waste management (New York, N.Y.)*, 29 (5). 1541–6.
- Yung, W. H., Yung, L. C., Hua, L. H. (2013). A study of the durability properties of waste tire rubber applied to self-compacting concrete. *Construction and Building Materials*, 41. 665–672.

- Zachar, J. (2010). Sustainable and Economical Precast and Prestressed Concrete Using Fly Ash as a Cement Replacement, *Journal of Materials in Civil Engineering (ASCE)*, 23 (6). 789–792.
- Zheng, L., Huo, X. S., Yuan, Y. (2008-a). Strength, Modulus of Elasticity, and Brittleness Index of Rubberized Concrete, *Journal of Materials in Civil Engineering*, 20 (11). 692-699
- Zheng, L., Huo, X., Yuan, Y. (2008-b). Experimental investigation on dynamic properties of rubberised concrete. *Construction and Building Materials*, 22 (5). 939-947.