MECHANICAL, DURABLE AND ACOUSTIC PROPERTIES EVALUATION OF CONCRETE CONTAINING GRANULATED BLAST FURNACE SLAG AND WASTE TYRES AGGREGATE

AKRAM MOHAMED MHAYA

UNIVERSITI TEKNOLOGI MALAYSIA

BAHAGIAN A - Pengesahan Kerjasama*

Adalah disahkan bahawa projek penyelidikan tesis ini telah dilaksanakan melalui kerjasama antara _________________________dengan _________________________

Disahkan oleh:

Tandatangan : Tarikh :

Nama :

Jawatan :

(Cop rasmi)

** Jika penyediaan tesis atau projek melibatkan kerjasama.*

BAHAGIAN B - Untuk Kegunaan Pejabat Sekolah Pengajian Siswazah

Tesis ini telah diperiksa dan diakui oleh:

Nama dan Alamat Pemeriksa Luar : **Prof. Madya Dr. Roszilah Hamid**
No. 38 Jln 3/51
Taman Tasik Bangi 3
Bandar Baru Bangi

Nama dan Alamat Pemeriksa Dalam : **Prof. Madya Dr. Zaiton Bt Haron**
Sekolah Kejuruteraan Awam
Fakulti Kejuruteraan
Universiti Teknologi Malaysia
Johor Bahru

Nama Penyelia Lain (jika ada) :

Disahkan oleh Naib Pengerusi (Akademik & Pembangunan Pelajar) :

Tandatangan : Tarikh : 28APRIL 2021

Nama :

MECHANICAL, DURABLE AND ACOUSTIC PROPERTIES EVALUATION OF CONCRETE CONTAINING GRANULATED BLAST FURNACE SLAG AND WASTE TYRES AGGREGATE

AKRAM MOHAMED MHAYA

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy

School of Civil Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

APRIL 2021

To the soul of my father who encouraged me to be the best I can be, to my beloved Mother, for her sacrifice and prayers for me. To my brothers and sisters, for care and support all the times.

ACKNOWLEDGEMENT

First of all, I deeply thank to Allah SWA for giving me opportunity, determination and strength to do my research blessing.

I thank and acknowledge my supervisor, Dr. Ahmad Razin Zainal Abidin, for his valuable advice and support, motivation, and patience throughout the past years.

I would like to express my sincere appreciation and gratitude to my co- supervisor Prof. Dr. Mohammad Bin Ismail for his support, guidance, encouragement and patient throughout this research period. Without his unwavering guidance, support, and valuable advice during the research and writing, this thesis would have been completed. His dedication and technical expertise proved to be the key elements to my doctoral research.

I am also indebted to Universiti Teknologi Malaysia (UTM) for providing the facilities for my research, and also the technicians and staff at the Civil Engineering Material and Structure Lab for their assistance in this study.

My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed.

ABSTRACT

The disposal of rubbers from the waste tyres remains the main environmental concern worldwide unless recycled in an eco-friendly way. The incorporation of these wastes into the concretes as replacement agent for some of the natural aggregates is strategized as one of the possible solutions. Based on these factors, this study evaluates the effects of the tire rubber crumb wastes (TRCWs) at various contents (5, 10, 20 and 30% of volume) and granulated blast furnace slag (GBFS) as the fine and coarse aggregates replacement on the properties of newly designed concretes. Twelve batches of such concretes are prepared by blending the industrial wastes including the GBFS and TRCWs with ordinary Portland cement (OPC). The mechanical, durability and acoustic performance of these modified concretes are analyzed using slump, compacting factor, water absorption, compressive, tensile, flexural strength, and modulus of elasticity test. Added to that the resistance to carbonation, acid, sulphate attack and elevated temperatures, as well as the microstructure tests such as scanning electron microscope (SEM), x-ray diffraction (XRD), energy dispersive x-ray (EDX), and impedance tube test. The concrete modified with 20% of GBFS as OPC replacement shows enhanced mechanical traits wherein the compressive strength after the curing age of 28 days is higher (42.8 MPa) than the OPC control mix (33.8 MPa). Moreover, the mix designed with 5% of TRCWs as fine or/and coarse aggregates replacement is nearly 14.8% compared to the OPC specimens. The results show that the TRCWs substitution up to a limit of 10% of the river sand and gravel into the concrete can be effective without any strength loss. The modified concretes' performance in aggressive environments are analyzed using residual compressive strength, weight loss, surface textures and microstructure tests. The concrete modified with 20% of GBFS as OPC replacement shows enhanced durability properties wherein the residual compressive strength after exposed to sulfuric attack of one year is higher (10.7%) than the OPC control mix (2.9%). Moreover, the mix designed with 5% of TRCWs as fine or/and coarse aggregates replacement is nearly 7% compared to the OPC specimens. Modified concretes with 30% of TRCWs aggregates exhibit an enhancement on noise reduction coefficient (NRC) by 137.7% and lower sound transmission coefficient (STC) by 37.3% compared to the control specimen. Since the compressive strength is in an acceptable range (27MPa), modified concrete contains 30% of fine TRCWs has good potential to be utilised as an acoustic absorber as the capability of absorbing sound energy at 500 Hz to 2000 Hz has improved. Therefore, modified concrete contains 30% of fine TRCWs can be applied as a sound-absorping material for application in railway concrete slabs, precast concrete walls and concrete pavement blocks. It is established that the use of TRCWs into concrete will be an environmental remedy and renewable resource for developing construction materials, leading to sustainability (minimization of the depletion of natural resources including river sand and gravel).

ABSTRAK

Pembuangan getah dari tayar terpakai sentiasa menjadi kerisauan utama berkaitan alam sekitar di seluruh dunia melainkan ianya dikitar semula dengan cara yang mesra alam. Penggunaan sisa ini ke dalam konkrit sebagai agen pengganti agregat semulajadi distrategikan sebagai satu kemungkinan penyelesaiannya. Berdasarkan faktor ini, kajian ini menilai kesan sisa tayar getah (TRCW) pada kandungan yang pelbagai (5, 10, 20 dan 30% isipadu) dan sanga relau bagas berbutir (GBFS) sebagai penggantian agregat halus dan kasar pada sifat konkrit baru yang direkabentuk. Dua belas kumpulan konkrit tersebut disediakan dengan mengadunkan sisa industri termasuk GBFS dan TRCW dengan simen Portland biasa (OPC). Prestasi mekanikal, ketahanan dan akustik bagi konkrit yang diubah ini dianalisis menggunakan ujian turun, faktor pemadatan, penyerapan air, mampatan, tegangan, kekuatan lenturan dan modulus keanjalan. Ini ditambah pula dengan ujian rintangan terhadap karbonasi, asid, serangan sulfat dan suhu tinggi, serta struktur mikro seperti ujian kemikroskopan elektron imbasan (SEM), belauan sinar-X (XRD), sinar-X sebaran tenaga (EDX), dan tiub galangan. Konkrit yang diubah dengan 20% GBFS sebagai pengganti OPC menunjukkan sifat mekanikal tertingkat di mana kekuatan mampatan selepas usia 28 hari adalah lebih tinggi (42.8 MPa) berbanding campuran OPC kawalan (33.8 MPa). Di samping itu, campuran yang dirancang dengan 5% TRCW sebagai pengganti agregat halus atau/dan kasar adalah hampir 14.8% berbanding dengan spesimen OPC. Keputusan menunjukkan bahawa penggantian TRCW sehingga 10% daripada pasir sungai dan kerikil ke dalam konkrit adalah efektif tanpa mengurangkan kekuatannya. Prestasi konkrit yang diubah, dalam persekitaran yang agresif, dianalisis menggunakan ujian kekuatan mampatan baki, kehilangan berat, tekstur permukaan dan struktur mikro. Konkrit yang diubah dengan 20% GBFS sebagai pengganti OPC menunjukkan sifat ketahanan tertingkat di mana kekuatan mampatan baki selepas didedahkan kepada serangan sulfurik selama setahun adalah lebih tinggi (10.7%) daripada campuran OPC kawalan (2.9%). Di samping itu, campuran yang dirancang dengan 5% TRCW sebagai pengganti agregat halus atau/dan kasar adalah hampir 7% berbanding dengan spesimen OPC. Konkrit yang diubah dengan 30% agregat TRCW menunjukkan peningkatan pada pekali penyerapan bunyi (NRC) sebanyak 137.7% dan pekali kehilangan hantaran bunyi (STC) yang rendah sebanyak 37.3% berbanding dengan spesimen kawalan. Oleh kerana kekuatan mampatan berada dalam julat yang dapat diterima (27MPa), konkrit yang diubah dengan 30% agregat TRCW halus adalah berpotensi untuk digunakan sebagai medium penyerap akustik kerana kemampuannya menyerap tenaga bunyi pada kadar 500 Hz hingga 2000 Hz telah ditambah baik. Oleh itu, konkrit yang diubah dengan 30% agregat TRCW halus ini dapat digunakan sebagai bahan penyerap bunyi untuk kegunaan lantai konkrit keretapi, dinding konkrit pratuang dan blok turapan konkrit. Ini menunjukkan bahawa penggunaan TRCW ke dalam konkrit akan menjadi penawar kepada alam sekitar dan sebagai sumber yang diperbaharui untuk pembangunan bahan binaan, yang mengarah kepada kelestarian (meminimumkan penipisan sumber semulajadi termasuk pasir sungai dan kerikil).

TABLE OF CONTENTS

CHAPTER 2 LITERATURE REVIEW 13

CHAPTER 4 MATERIAL CHARACTERISTICS, CONCRETE MIX DESIGN, AND WORKABILITY OF MODIFIED RUBBERISED CONCRETE 109

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACI - American Concrete Institute
ASHTTO - American Association of State Highway and Transportation
ASTM - American Society for Testing and Materials
BET - Blaine Fineness
BS - British Standard
BS-EN - British Standard European Norm
CaO - Calcium Oxide
CRC - Crumb Rubber Concrete
DOSM - The Department of Statistics Malaysia
DTA - Differential Thermal Analysis
E - Modulus of Elasticity
EDX - Energy Dispersive X-ray
ETRMA - The European Tyre & Rubber Manufacturers Association
FA - Fly Ash
FTIR - Fourier Transformed Intrared
GBFS - Ground Granulated Blast Furnace Slag
G_S - Specific Gravity
HCP - Hardened Cement Paste
HPCs - Resistance of High Performance Concretes
ITZ - Interfacial Transition Zone
MK - Metakaolin
MOE - Modulus of Elasticity
NRC - Noise Reduction Coefficient
OPC - Ordinary Portland Cement
POFA - Palm Oil Fuel Ash
PRC - Plain Rubberized Concrete
RC - Coarse Aggregates Rubber Replacement
RCPT - Rapid Chloride Penetration Test

RF	-	Fine Aggregates Rubber Replacement
RFC	-	Fine and Coarse Aggregates Rubber Replacement
RHA	-	Rise Husk Ash
RMA	-	Rubber Manufacturers Association
SBR	-	Styrene Butadiene Rubber
SEM	-	Scanning Electron Micrograph
SF	-	Silica Fume
SSD	-	Saturated Surface Dry
STC	-	Sound Transmission Loss Coefficient
STL	-	Sound Transmission Loss
TGA	-	Thermogravimetry Analysis
TL	-	Transmission Loss Function
TRCWs	-	Tyre Rubber Crumb Wastes
UPV	-	Ultrasonic Pulse Velocity
w/c	-	Cement-Water Ratio
XRD	-	X-Ray Diffraction
XRF	-	X-Ray Fluorescenc

LIST OF SYMBOLS

Al - Alumina

Al_2O_3 - Aluminium oxide

Ca - Calcium

$Ca(OH)_2$ - Calcium hydroxide

CaO - Calcium oxide

$CaO:SiO_2$ - Calcium to silicate ratio

CO_2 - Carbon dioxide

C-S-H - Calcium silicate hydrate

Fb - Bond strength

Fc - Compressive strength

Fe - Iron

Fs - Flexural strength

Ft - Tensile strength

H_2SO_4 - Sulphuric acid

KOH - Potassium hydroxide

$MgSO_4$ - Magnesium sulphate

MPa - Mega pascal

NaOH - Sodium hydroxide

Na_2O - Sodium oxide

Na_2SO_3 - Sodium silicate

NH:NS - Sodium hydroxide to sodium silicate ratio

P - Porosity

PSA - Particles size analysis

S:B - Solution to binder ratio

Si - Silicon

SiO_2 - Silicate oxide

$SiO_2:Al_2O_3$ - Silicate to aluminium ratio

Θ - Theta

Al_2O_3 - Aluminium Oxide

dB - Decibels

ITZ - Interfacial Transition Zone

α - Sound Absorption Coefficient

α_{band} - Sound Absorption Coefficient

σ - Compressive Strength

f - Frequency

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Concrete containing rubber aggregates known as rubberised concrete is a composite material of portland cement, water, natural and rubber aggregates. It different from conventional concrete is that it contains rubber aggregates as a partial replacement in the concrete mixture. Rubber particles significantly increase the strain capacity and improve the impact resistance of concrete. Moreover, rubber aggregate enhances toughness and ductility of the composite, and with a higher degree of air entrainment that can be easily pumped at higher flow rates, and also improves the efficiency of sound absorption and thermal insulation, although the mechanical strength of concrete is reduced. Rubberised concrete also has a lower unit weight, higher porosity, and lower splitting tensile strength.

Utilise tyre rubber crumb wastes (TRCWs) in construction and other applications can reduce environmental problems by preventing the accumulation of tyres that end their life service without been burned, and also save energy, cost, and risk of stockpiling. In fact, tyres demand a huge space to stockpile and long duration to decompose. Meanwhile rubberised concrete is lighter by weight than conventional concrete with an economic impact on the total cost of the building, as it reduces the weight of Dead Load, also using waste rubber reduces the demand for natural raw materials, and saves landfill space. Rubberised concrete with all the desirable enhancement on concrete properties. Still it does not fully fulfil the construction work requirements, due to the low compression strength caused by the major weakness of using rubber in concrete.

The compressive strength of the concretes made from TRCWs showed a remarkable reduction and strongly depended on the rubber contents. When fine aggregates were entirely replaced by crumb rubbers, a decrease in the compressive strength was observed to reach 65%. The elastic modulus of the proposed concrete specimens were decreased with the increase in the substitution levels. Further parametric analysis demonstrated that rubber particles can only compose up to 20% of the material’s total composition before a large drop in the strength of the concrete occurs. However, the way in which rubber performs in concrete is directly influenced by the type of rubber used and its associated properties. The rigidity of the rubber and the size of its particles, gradations as well as its surface properties all had an effect on its performance within concrete.

Wise management of waste materials can be quite intensive in terms of environmental friendliness and human safety. Hence, proper recycling of industrial wastes in concrete industry can lead to immense practical benefits, and waste materials as supplementary cementitious materials (SCMs) can improve the performance of concrete and mortar in many ways such as microstructure, durability, and mechanical properties compared to conventional concrete.

Characteristically, today the SCMs are widely used in concrete either in blended cements or added separately in the concrete mixer. The use of SCMs such as ground granulated blast furnace slag (GBFS), a by-product from iron production, or fly ash (FA) from coal combustion represent a viable solution to partially substitute OPC. The use of GBFS as SCMs strongly recommended by several researchers to enhance the mechanical and durable properties.

Over the years, numerous studies have been made to determine the performance of the concrete that contains GBFS. Multiple studies reported an improvement in the freshness, strength, and durability of concrete which incorporated GBFS. When GBFS is incorporated as a SCMs, the porosity of OPC concrete is reduced due to the precipitation of additional calcium-silicate-hydrate (C-S-H) gel and the carbon footprint of the concrete is reduced due to the drop in OPC usage.

1.2 Problem Background

Automobile industry worldwide is growing and the number of tyres generated and accumulated growing as well. Recently, most of countries in the world avoid or forbid burn, stockpiling or landfill of used tyres, and provide incentive for exploring recycling strategies of used tyres.

In US, about 1 billion tyres stockpiled without effective solution for disposing of waste tyres. Consequently, the interest of using wastes tyres increased over the last two decades to help prevent environmental problems and carried out how to re-use TRCWs in construction industry (RMA, 2015).

In last decade, the worldwide tyre production reached 1.1 billion units, only in Europe, and about 3.2 million tons of used tyres were discarded, 96% were recovered, and 38% were recycled according to The European Tyre & Rubber Manufacturers Association (ETRMA, 2009). The Department of Statistics Malaysia estimated that 12.88 millions of Tyres (pneumatic) were generated in Malaysia in 2014, and 4% were exported (DOSM, 2015).

In 2013, Rubber Manufacturers Association (RMA) estimates that 233.3 millions of tyres were used in the US. The recovery ratio was 95.88%, of which 8.2% were Land-disposed, 6.2% were exported, 4.3% were for Civil Engineering industry, and the rest were recycled or used for energy production. Stockpiles of existing waste tyres have been reduced by 92% since 1990 (RMA, 2013).

Annually around billions tyres have been used and end their service life, and more than 50% are discarded to landfills or garbage without any treatment, continue to pose environmental challenges. By the year 2030, there would be 5000 million tyres to be discarded on a regular basis. (Blessen and Ramesh, 2016; Jorge and René, 2019).

Therefore, the research on use of tyre scraps should be more emphasised as an obtainable resource and find their benefits. Furthermore, discarded without any treatment can led to environment and health problems.

Using of waste rubber as a partial or full replacement of natural aggregate in construction activities not only reduces the demand for extraction of natural raw materials, but also saves landfill space and solve the environmental problems.

It is well known, the tyres scrap demands a huge space to stockpile than other waste due to their volume and shape, 75% of a tyre's volume is void, and it is non-decomposed material for short term. Furthermore, used tyres may accumulate water and create a suitable environment for breeding bacteria, molds, insects or mice. In the case of burning, tyres generate toxic gases such as dioxin, and cause a serious pollution problem, and the emissions compounds are very dangerous to humans, animals and plants.

The current environmental and economical states of the world have led the researchers towards experiencing new methods and to rubber recycling industry. Rubber tyre can be used in a variety of civil and non-civil engineering applications.

In USA, according to RMA use of wastes tyres in civil engineering dropped from 639.99 thousands of tons in 2005 to 172 thousands of tons in 2013, with a ratio of reduction 73.12%, which means the demand of using it on constructional applications decrease (RMA, 2014). The main reason restricted using TRCWs in a wide range in concrete industry because of low compressive strength performance compared to traditional concrete. It is well known the strength performance depended on bond between the aggregates surface and the paste (cement), and also compressive strength as an indirect index on durability indicates a reduction in durability performance caused by the inclusion of rubber particles in concrete, and due to the weak bond and the porosity increment. Therefore, several methods used to enhance the bond strength between paste and aggregates. It concluded that the bond improvement takes two ways; one focus in enhance the paste properties and the second focusing in aggregates side. In aggregates side, there are many studies reported the ability to improve the rubberized concrete performance by using different size of aggregate or improve the surface of aggregates using different methods for treatment. However, mostly methods used for this purpose such as treatment with sodium hydroxide still very expensive and not solve the problem. Likewise, several studies reported that the improve paste properties will help to improve the bond strength with rubber aggregates.

GBFS Slag has been widely used as SCM and extensive research has also been conducted on it. Using GBFS may reduce the problem of land fill, cost, and enhance the performance of the proposed concrete. About 1180 million tons of hot metal (2017) about 380 million tons of blast furnace slag are produced yearly worldwide. Most of it (about 280 million tons) is quenched forming the glassy granulated blast furnace slag (GBS).

1.3 Problem Statement

Commercial materials such as epoxy resin, polymers or silica fume used for this purpose and given a good performance but still not suitable for work in construction sector as these materials very expensive and effect negatively on life cycle of produced concrete. Yet, GBFS waste materials introduce a high performance SCMs improved the strength and durability of modified concrete. Several researchers recommended GBFS as OPC to enhance the sustainability performance of cement concrete. However, there are ability to use GBFS wastes as partial replacement to cement to enhance the bond strength performance. In rubberized concrete industry, replacing cement by GBFS will lead to produce new modified binder can contribute to enhance the bond zone with rubber aggregates and allow to recycle high amount of rubbers in concrete industry.

The compressive strength of GBFS modified concrete increases as the GBFS replacement ratio increases, up until a 40-60 replacement level, beyond this level, the strength of the GBFS concrete begins to decrease. Previous studies undertook the evaluation of the durability, strength, and porosity of GBFS concrete within different environments, under varying conditions and curing regimes. These studies proved that GBFS concrete was suitable to a broad range of construction applications.

In-depth researches on the GBFS included concretes has suggested that it has a lower heat evolution, less permeability, greater strength over time, fewer chlorine ions penetration, and high resistance against the sulphate attack, alkaline silicate reaction and elevated temperature. Despite various studies that displayed the practicality of the GBFS-based concretes most of them so far used the OPC as the binder. On top, the effects of the GBFS inclusion on the durability properties of the rubberized concretes with TRCWs as the replacement agent to the fine and/or coarse aggregates remained unexplored. In this perception, this work tried to enhance the durability traits of the GBFS and TRCWs included OPC-based concretes by exposing them against the aggressive environments (for example elevated temperatures and acid, sulphate as well as carbonation attacks).

Producing a concrete containing tyre rubber aggregate, which increase sound absorption through the concrete can increase the use of tyres rubber in civil engineering construction. By using the tyres rubbers aggregate in this mixture concrete can be constructed in areas where noise prohibits exceeding the permissible level increase interest toward using of tyres rubber in civil engineering. Noise negatively may effect human health and well-being. Problems related to noise include hearing loss, stress, high blood pressure, increase heart rate, sleep loss, distraction, lost productivity, and a general reduction of the quality of life and opportunities for tranquility. Although rubberised concrete has good sound absorption attributes, the sound transmission loss coefficient (STC) inside the concrete decrease as a percentage of rubber content replacement increase. The ability to isolate the sound from travelling through the concrete affected by the porosity of concrete. Therefore, using SCMs such as GBFS may have the potential to partially restore the transmission loss value through the rubberised concrete.

Rubberised concrete with many advantages such as enhance the concrete ductility, toughness, impact resistance and strain capacity, reduce the noise and improve the building sustainability. Therefore, researches in develop strength perfomance and an environmental-friendly process for the exploitation of wastes tyres rubber are needed, instead of become a pollutant sources on environment. With such development and immense benefit of waste tyre rubbers incorporated concretes, this study attempted to achieve high performance, durable and eco-friendly rubberized concretes wherein amount of OPC was replaced by GBFS. The influence of GBFS inclusion in rubberized concretes (containing TRCWs as fine and coarse aggregates) matrix as OPC replacement was examined in terms of concrete workability, strength and microstructure performance. Durability of modified rubberized concretes as a function of varied TRCWs content was also determined. The sound transmission of prepared concretes were evaluated. Results were discussed in terms of strength, durability, environmental benefits and sustainability of such purposed concretes.

1.4 Aims and Objectives

This research aims to evaluate the use of waste tyre aggregates, and GBFS as partial substitution of OPC. The specific objectives of the research are:

i. To optimize the GBFS replacement level, as well as determine the effect of GBFS and different amounts and sizes of TRCWs on the workability of fresh rubberised concrete.

ii. To determine the effect of GBFS and different amounts and sizes of TRCWs on the short and long-term performance of mechanical properties of rubberised concrete.

iii. To evaluate the durability and physical performance of GBFS modified rubberised concrete exposed to chemical attack and elevated temperature.

iv. To identify the influence of GBFS combined with different amounts and sizes of TRCWs on acoustic properties.

1.5 Scope of the Study

This research focus on workability and long-term performance of durability and mechanical properties as well as fire safety performance and acoustic properties of GBFS modified rubberised concrete. Concrete mixes produced with and without rubber crumb. Fourteen batches made by blending tyre rubber crumb wastes (TRCWs at various contents 5, 10, 20 and 30% of volume) as the fine and coarse aggregates replacement with 20% GBFS and ordinary Portland cement. The main properties studied include slump, compacting factor, compressive strength, flexural strength, indirect tensile strength, modulus of elasticity, water absorption, ultrasonic pulse velocity, fire endurance test, resistance to carbonation, sulfate, and acid attack, as well as the microstructure tests such as scanning electron microscope (SEM), x-ray diffraction (XRD), energy dispersive x-ray (EDX), thermogravimetric analyzer (TGA), differential thermal analysis (DTA) and impedance tube test.

1.6 Significance of the Research

In general, using TRCWs in concrete decrease the demand of natural raw materials, and saves landfill space, and it applications is potentially an effective way of limiting the environmental dangers described, also prevent the toxic gases due to burning tyres scrap. Several efforts have been made to use the TRCWs in various types of concretes to examine their impacts on the mechanical behavior of concretes, and earlier reports revealed a substantial drop in the compressive strength. Since the major problem of rubberised concrete is the reduction of the compressive straight, using pozzolanic material such as GBFS can led to improve the performance of rubberised concrete in term of durability and mechanical properties. In this spirit, supplementary cementitious materials may help to increase the incorporation of TRCWs and identify a balance, which may led to improve the rubberised concrete characteristic such as sound proof. Besides, rubberised concrete containing GBFS can reduce CO_2 emissions that generated by manufacturing of Portland cement.

It is established that the use of TRCWs into concrete can be reduce the environment problems, developing renewable resource for construction materials and enhance the ductility performance. The outcome of this research can prepare supportive information for utilising GBFS as a binder replacement and TRCWs as aggregates. Furthermore, this research work aim to provide a sound absorbing concrete with the use of TRCWs with proper compressive strength, which is accepted as a property of structural concrete that may be deemed as strength of this research.

1.7 Novelty or the originality of the research

Utilizing by-product as GBFS with TRCWs, constituting a novel strategy with immeasurable environmental, technological and economic benefits. This study took an attempt to determine the role played by TRCWs when incorporated in concrete as partial replacement with GBFS. Concrete specimens with varied predefined ratios of TRCWs and GBFS were designed.

Performances of the prepared concrete specimens (fresh and hardened) were evaluated and compared with the control mix (OPC). As prepared concrete specimens were characterized using several tests to properties determine such as workability, durability, microstructure, and mechanical properties.

Furthermore, to provide a sound absorbing concrete with proper compressive strength, this study determines sound absorption and sound transmission loss of rubberised concrete containing GBFS with various proportions and sizes of TRCWs.

1.8 Project or Thesis Organisation

The Outline of the study as follows:

Chapter 1: Chapter one is an introduction of the study, which included overview, aims and objectives of the research, problem background, problem statement, scope of the study, significance of the research, as well as the novelty and the originality of the research. Moreover, a brief description layout of the thesis with a schematic summary of thesis organisation as shown in Figure 1.1.

Chapter 2: In chapter two, previous studies provided as supportive information to explain the concept and contribution of utilising of TRCWs, GBFS, and other related materials on the concrete properties. Literature Review on recent researches of Concrete, in terms of Acoustic durability mechanical Properties, as well as other Properties related to this filed.

Chapter 3: The discussion of research methodology and experimental program to examine the materials, mix design, and rubberised concrete properties are described in this chapter.

Chapter 4: Chapter four analysis the result of the experimental on raw materials, and also produce mix design with utilizing a different proportions and sizes of TRCWs with optimized GBFS as partial replacement of OPC, and also study the workability performance of fresh rubberized concrete by using slump and Compacting factor test.

Chapter 5: The main properties studied in this chapter are microstructure and mechanical properties. This chapter reveals the effect of TRCWs incorporated with GBFS on the modulus of elasticity, compressive, indirect tensile, and flexural strengths, as well as microstructure tests.

Chapter 6: This chapter discuss and analysis durability and physical properties. Long term study and several of parameters conducted including water absorption, total porosity, resistance to carbonation, sulfate, and acid attack, Fire endurance, and then microstructure tests such as scanning electron microscope (SEM), X-ray Diffraction (XRD), Energy Dispersive X-ray (EDX), Thermogravimetric analyzer (TGA), and differential thermal analysis (DTA).

Chapter 7: This chapter will focus on acoustic properties of rubberised concrete containing GBFS with various proportions of TRCWs, study the sound absorption and sound transmission loss of high and low-frequency of sound wave by using impedance tube test.

Chapter 8: Chapter eight as the closure chapter, summarize the findings, achievements, and contribution of the research. And bring acknowledgement for further research related to this filed.

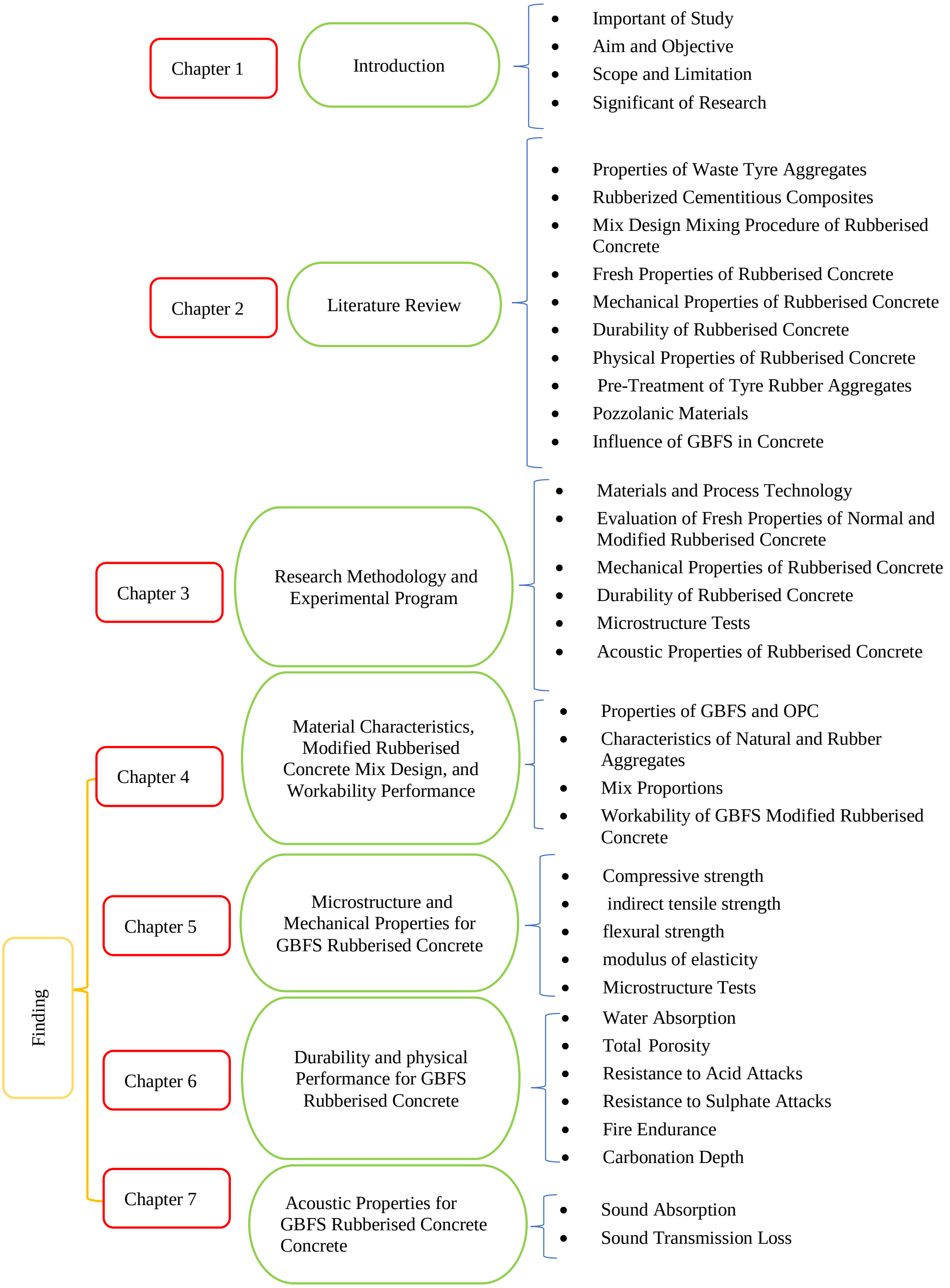

Figure 1.1 Schematic summary of the thesis

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Nowadays, the sustainable development and environmental safety became the main concern of the researchers worldwide, especially in the developed nations. For sustainable development of the buildings, the use of the construction materials is of highest importance. These materials can considerably affect the energy consumption, carbon dioxide emission, landfill and conservation of natural resources (Gregori et al., 2019; Huseien et al., 2019).

The concretes remain the most commonly utilized construction material for many years now, with its worldwide production surpassing approximately 1 ton of the concrete per person on the earth. A single cubic meter (m^3) of the concrete includes nearly 0.6 to 0.7 m^3 of aggregate. It is often, the fine and coarse natural aggregates are the preferred choice due to its widespread availability and low cost. The traditional concrete shows substandard performance against the presence of sulfate and sulfuric acid. The presence of the calcium compounds in the OPC makes it non-resistant towards the acid attack. The easy dissolution of the calcium compounds in the acidic environment results in the increased porosity and rapid deterioration (Huseien et al., 2019).

Likewise, the production of the concretes requires the consumption of the aggregate, thereby the rapid depletion of the natural aggregates as the resources. Thus, the quest of finding some new aggregates alternative to the natural one is never-ending. In order to completely or partially replace the concrete constituents, the possibility of using the processed waste materials is explored in the recent decades. The recycled construction

REFERENCE

Abd Aziz, F., N., Bida, S., M., Mohd Nasir, N., A., Jaafar, M., S. 2014. Mechanical properties of lightweight mortar modified with oil palm fruit fibre and tire crumb, *Constr. Build. Mater*. 73, 544–550.

Abdel Kader, M., M., Abdel-wehab, S., M., Helal, M., A., Hassan, H., H. 2012. Evaluation of thermal insulation and mechanical properties of waste rubber/natural rubber composite. *HBRC J*. 8, 69–74.

Abdurrahman, H., Qoryati, M., Muklisin, Olivia M. 2019. Properties of concrete using crumb rubber and rice husk ash as additive for rigid pavement material in peat environment. *MATEC Web of Conferences.* 276, 01020.

Ahmaruzzaman, M. 2010. A review on the utilization of fly ash. *Progress in Energy and Combustion Science*, 36 (3), 327-363.

Ahmed, B., Hussin, M.,W., Muthusamy, K., Ismail, M., E. 2010. Performance of high strength POFA concrete in acidic environment. *Concrete research letters*. 1(1), p.14-18.

Aiello, M., A., Leuzzi, F. 2010. Waste tyre rubberized concrete: properties at fresh and hardened state. *Waste management*, 30(8-9), 1696–704.

Akinyele, J., O., Salim, R., W., Kupolati, W., K. 2016. The impact of rubber crumb on the mechanical and chemical properties of concrete. *Engineering Structures and Technologies*. 7(4), p. 197-204.

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.

Al-Tayeb, M., M., Abu Bakar, B., H., Akil, H., M., Ismail, H. 2013. Performance of rubberized and hybrid rubberized concrete structures under static and impact load conditions. *Exp. Mech*. 53, 377–384.

Angelin, A., F., Miranda, Jr., Dos Santos, J., M., Lintz, R., Gachet- Barbosa, A. 2019. Rubberized mortar: the influence of aggregate granulometry in mechanical resistances and acoustic behavior. *Constr. Build. Mater*. 200, 248–254.

Antil, Yogender, Verma, Vivek, Singh, Bhupinder. 2014. Rubberized concrete with crumb rubber. *Int. J. Sci. Res*. 3 (5), 1481–1483.

Anu Bala, Vinay, K., S., Babita, S. 2014. Effect of Fly ash and Waste Rubber on Properties of Concrete composite. *Journal of Concrete Research Letters*. 5(3).

Ariffin, M., Bhuttab, M., A., R., Tahir, M., Nor Aziah. 2013. Sulfuric acid resistance of blended ash geopolymer concrete. *Construction and building materials.* 43, p. 80-86.

Aslani, F. 2015. Mechanical properties of waste tire rubber concrete. *Journal of Materials in Civil Engineering*. 28(3), p. 04015152.

Aslani, F. 2016. Mechanical properties of waste tire rubber concrete. *J. Mater. Civ. Eng*. 28, 04015152.

Aslani, F., and Khan, M. 2019. Properties of high-performance self-compacting rubberized concrete exposed to high temperatures. *Journal of Materials in Civil Engineering*. 31(5), p. 04019040.

Aslani, F., Khan, M. 2019. Properties of high-performance self-compacting rubberized concrete exposed to high temperatures. *J. Mater. Civ. Eng*. 31, 04019040.

Aslani, F., Ma, G., YimWan, D., L., Tran Le, V., X. 2018. Experimental investigation into rubber granules and their effects on the fresh and hardened properties of self-compacting concrete. *J. Clean. Prod*. 172, 1835–1847.

ASTM C 989-93. 1993. *Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars*. Philadelphia: American Society for Testing and Materials.

ASTM C1012 / C1012M – 10. 2010. *Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution*. Philadelphia: American Society for Testing and Materials.

ASTM C136 / C136M. 2006. *Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates*. Philadelphia: American Society for Testing and Materials.

ASTM C1365 – 18 .2018. *Standard Test Method for Determination of the Proportion of Phases in Portland Cement and Portland-Cement Clinker Using X-Ray Powder Diffraction Analysis.* 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 C150/C150M. 2007. *Standard specification for Portland cement*. Philadelphia: American Society for Testing and Materials.

ASTM C1723 – 10. 2010. *Standard Guide for Examination of Hardened Concrete Using Scanning Electron Microscopy*. Philadelphia: American Society for Testing and Materials.

ASTM C192 / C192M - 16a. 2016. *Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory*. Philadelphia: American Society for Testing and Materials.

ASTM C267 – 01. 2012. *Standard Test Methods for Chemical Resistance of Mortars, Grouts, and Monolithic Surfacings and Polymer Concretes*. 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 – 01. 1999. *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*. 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 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 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 C642 – 06. 2006. *Standard Test Method for Density, Absorption, and Voids in Hardened Concrete*. Philadelphia: American Society for Testing and Materials.

ASTM C989 – 99. 1999. *Standard Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars*. Philadelphia: American Society for Testing and Materials.

ASTM D6270-08. 2008. *Standard Practice for Use of Scrap Tires in Civil Engineering Applications.* Philadelphia: American Society for Testing and Materials.

ASTM E1050 - 10. 2010. *Standard Test Method for Impedance and Absorption of Acoustical Materials Using A Tube, Two Microphones and A Digital Frequency Analysis System*. Philadelphia: American Society for Testing and Materials.

ASTM E1131 – 03. 2003. *Standard Test Method for Compositional Analysis by Thermogravimetry*. Philadelphia: American Society for Testing and Materials.

ASTM E119 – 07. 2007. *Standard Test Methods for Fire Tests of Building Construction and Materials*. Philadelphia: American Society for Testing and Materials.

ASTM E413 – 16. 2016. *Classification for Rating Sound Insulation.* Philadelphia: American Society for Testing and Materials.

Asutkar, P., Shinde, S., B., Patel, R. 2017. Study on the behaviour of rubber aggregates concrete beams using analytical approach, *Eng. Sci. Technol. an Int. J*. 20, 151–159.

Atahan, A., O., Yücel, A., Ö. 2012. Crumb rubber in concrete: Static and dynamic evaluation, *Constr. Build. Mater*. 36, 617–622.

Atis, C., D., Bilim, C. 2007. Wet and dry cured compressive strength of concrete containing ground granulated blast-furnace slag. *Building and Environment*. 42(8): p. 3060-3065.

Awal, A., A., Shehu, I. 2015. Performance evaluation of concrete containing high volume palm oil fuel ash exposed to elevated temperature. *Construction and Building Materials*. 76, p. 214-220.

Ayesha, S., Al Mamun, A., Md., Rayed, A., Amran, Y., H., M., Aslani, F., Alabduljabbar, H. 2019. Properties and utilizations of waste tire rubber in concrete: A review. *Construction and Building Materials*. 224. 711–731.

Azevedo, F., Pacheco-Torgal, F., Jesus, C., de Aguiar Barroso, J.-L., Canôes, A.F., 2012. Properties and durability of HPC with tyre rubber wastes. *Constr. Build. Mater*. 34, 186–191.

Balaha, M., M., Badawy, A., A., M., Hashish, M. 2007. Effect of using ground tire rubber as fine aggregate on the behaviour of concrete mixes. *Indian J. Eng. Mater. Sci*. 14, 427–435.

Bamaga, S., O., Ismail, M., A., Ismail, M., Zaiton, A., M., Hussin, M., W. 2013. Evaluation of sulfate resistance of mortar containing palm oil fuel ash from different sources. *Arabian Journal for Science and Engineering*. 38(9): p. 2293-2301.

Baoshan Huang. Guoqiang Li. Su-Seng Pang. John Eggers. Investigation into waste tire rubber filled concrete. *J. Mater. Civ. Eng*.16 (3). 187–194.

Basheer, P., Russell, D., P., Rankin, G., I., B. 1999. 40 designs of concrete to resist carbonation. Vol 1, pp 423-435. NRC Research Press Ottawa, Canada.

Baricevic, A., Pezer, M., Jelcic Rukavina, M., Serdar, M., Stirmer, N. 2018. Effect of polymer fibers recycled from waste tires on properties of wet-sprayed concrete, *Constr. Build. Mater.* 176 (2018) 135–144.

Batayneh, M., K., Marie, I., Asi, I. 2008. Promoting the use of crumb rubber concrete in developing countries. *Waste Management*. 28(11), 2171–2176.

Bellmann, F., Matschei,. T., Stark, J. 2005. Hydration behaviour of sulphate-activated slag cements. Advances in Cement Research. 17(4): p. 167-178.

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.

Bhutta, M., A., R., Hussin, M., Mohd Azreen, Tahir, M., M. 2014. Sulphate resistance of geopolymer concrete prepared from blended waste fuel ash. *Journal of Materials in Civil Engineering*. 26(11): p. 04014080.

Bies, D., A., Hansen, C., H., 2009. Engineering Noise Control: Theory and Practice, Fourth Edition. CRC Press.

Bilim, C., Atis, C., D., Harun, T., Okan, K. 2009. Predicting the compressive strength of ground granulated blast furnace slag concrete using artificial neural network. *Advances in Engineering Software*. 40(5): p. 334-340.

Blessen, S.,T., Ramesh, C., G. 2016. A comprehensive review on the applications of waste tire rubber in cement concrete. *Renewable and Sustainable Energy Reviews*. Vol 54 Pages 1323–1333.

Boukendakdji O., Kadri, E., Kenai, S. 2012. Effects of granulated blast furnace slag and superplasticizer type on the fresh properties and compressive strength of self-compacting concrete. *Cement Concr. Compos*. 34 (4), 583–590.

Bravo, M. 2009. Concrete with Incorporation of Aggregates from Grinded Used Rubber Tyres. Durability Related Performance (In Portuguese). Master dissertation in Civil Engineering, IST, Technical University of Lisbon, Lisbon, Portugal, 132 pp.

Bravo, M., de Brito, J. 2012. Concrete made with used tyre aggregate: durability related performance. *Journal of Cleaner Production*. 2012. 25. 42–50.

BS 1881: Part 103. 1983. *Method for Determination of Compacting Factor*. British Standard Institution.

BS 1881: Part 116. 1983. *Testing concrete. Method for determination of compressive strength of concrete cubes.* British Standard Institution.

BS 1881: Part 118. 1983. *Method for determination of flexural strength*. British Standard Institution.

BS 1881-210. 2013. *Testing hardened concrete. Determination of the potential carbonation resistance of concrete. Accelerated carbonation method*. British Standard Institution.

BS 5328-2. 1997. *Concrete. Methods for SpeciFying Concrete mixes*. British Standards Institution.

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.

Cairns, R., Kew, H.,Y., Kenny, M., J. 2004. The use of recycled rubber tyres in concrete construction. The University of Strathclyde, Glasgow.

Chee Ban Cheah, Mahyuddin Ramli. 2011. The implementation of wood waste ash as a partial cement replacement material in the production of structural grade concrete and mortar: *An overview. Resources Conservation and Recycling.* 55(7), 669-685.

Chidiac, S., Panesar, D. 2008. Evolution of mechanical properties of concrete containing ground granulated blast furnace slag and effects on the scaling resistance test at 28 days. *Cement and Concrete Composites*. 30(2): p. 63-71.

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., Donnini, J. 2019. Waste rubber aggregates, in: New Trends Eco-Efficient Recycl. Concr., Elsevie. pp. 87–119.

Corinaldesi, V., Mazzoli, A., Moriconi, G. 2011. Mechanical behaviour and thermal conductivity of mortars containing waste rubber particles. *Materials & Design*. 32(3), p. 1646-1650.

Corredor-Bedoya, A., C., Zoppi, R., A., Serpa, A., L. 2017. Composites of scrap tire rubber particles and adhesive mortar – Noise insulation potential. *Cem. Concr. Compos*. 82, 45–66.

Crouch, L., Smith, N., Walker, A., Dunn, T., Sparkman, A. 2006. Pervious PCC Compressive Strength in the Laboratory and the Field: The Effects of Aggregate Properties and Compactive Effort. Proceedings of the 2006 NRMCA Concrete Technology Forum – Focus on Pervious Concrete, Nashville, TN.

Czajczyńska, D., Krzyżyńska, R., Jouhara, H., Spencer, N. 2017. Use of pyrolytic gas from waste tire as a fuel: A review. *Energy*. 134, pp. 1121–1131.

De Brito, J., Saikia, N. 2012. Recycled aggregate in concrete: use of industrial, *construction and demolition waste*. Springer Science & Business Media.

Department of Statistics, Malaysia. 2015. Block C6, Complex C, Federal Government Administrative Centre, 62514, Putrajaya, Malaysia.

Donatello, S., Fernández-Jimenez, A., Palomo, A. 2013. Very high volume fly ash cements. Early age hydration study using Na_2SO_4 as an activator. *Journal of the American Ceramic Society*. 96(3), p. 900-906.

Dong, M., Elchalakani, M., Karrech, A., Fawzia, S., Sadakkathulla, M., Ali, M., Yang, B., Xu, S. 2019. Circular steel tubes filled with rubberised concrete under combined loading. *Journal of Constructional Steel Research*. 162, p. 105613.

Duan, P., Shuia, Z., Chena, W. 2013. Enhancing microstructure and durability of concrete from ground granulated blast furnace slag and metakaolin as replacement materials. *Journal of Materials Research and Technology*. vol.2, pp.52-59.

Duarte, A., Silva, B., A., Silvestre, N., de Brito, J., Júlio, E., Castroc, J., M.2016. Tests and design of short steel tubes filled with rubberised concrete. *Engineering Structures*. 112, p. 274-286.

El-Alfi, E., A., Gado, R., A. 2016. Preparation of calciumsulfoaluminate-belite cement from marble sludge waste. *Constr. Build. Mater*. 113, 764–772.

Elchalakani, M. 2015. High strength rubberized concrete containing silica fume for the construction of sustainable road side barriers. In Structures. Elsevier.

Eldin, N., N., Senouci, A., B. 1993. Rubber-tire particles as concrete aggregate. *Journal of Materials in Civil Engineering*. 5 (4). 478–496.

Eldin, N., N., Senouci, A. B. 1994. Measurement and perdiction of the strength of rubberized concrete, *Cement and concrete composites*, 16. 287-298.

Emiroglu, M., Kelestemur, M., H., Yildiz, S. 2007. An invatigation on ITZ microstructure of the concrte contain waste vihcles tire. In: Proceeding of the Eighth International Fracture Conference Istanbul. Turkey. 2007

ETRMA – European Tyre & Rubber Manufacturers' Association. 2009. Statistics edition 2014. Brussels, Belgium.

ETRMA – European Tyre & Rubber Manufacturers' Association. 2019. Statistics on scrap tire collection and recycling in Europe. Brussels, Belgium.

Farnoosh Jokar, Mohammad Khorram, Gholamreza Karimi, Nader Hataf. 2019. Experimental investigation of mechanical properties of crumbed rubber concrete containing natural zeolite. Construction and Building Materials 208, 651–658.

Fattuhi, N., I., Clark, L. 1996. Cement-based materials containing shredded scrap truck tyre rubber. *Construction and Building Materials*, 10(4), 229– 236.

FM 5-559. 2011. *Testing of Ground Tire Rubber*. Florida Departement of Transportation.

Fraile-Garcia, E., Ferreiro-Cabello, J., Defez, B., Peris-Fajanes, G. 2016. Acoustic Behavior of HollowBlocks and Bricks Made of Concrete Doped withWaste-Tire Rubber. *Materials*. 9,12, 962.

Francesco, A., D'Alessandro, F., Schiavoni, S. 2008. Sound absorbing properties of materials made of rubber crumbs. *Acoust. Soc. Am*. 123, 3037.

Fu, C., Ye, H., Wang., K. Zhu, K., He, C. 2019. Evolution of mechanical properties of steel fiber-reinforced rubberized concrete (FR-RC). *Composites Part B: Engineering*. vol. 160, pp. 158–166.

Ganesan, N., Raj, J., B., Shashikala, A. 2012. Strength and durability of self compacting rubberized concrete. *Indian Concr. J*., 15–24.

Ganjian, E., Khorami, M., Maghsoudi, A., A. 2009. Crap-tyre-rubber replacement for aggregate and filler in concrete, *Construction and Building Materials*. 23 (5). 1828-1836.

Gesoğlu, M., Güneyisi, E, Hansu, O., İpek, S., Asaad, D., S. 2015. Influence of waste rubber utilization on the fracture and steel–concrete bond strength properties of concrete. *Construction and Building Materials*. 2015. 101, p. 1113-1121.

Gesoğlu, M., 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., Güneyisi, E. 2011. Permeability properties of self-compacting rubberized concretes. *Construction and Building Materials*. 25(8). 3319–3326.

Gesoglu, M., Güneyisi, E., Hansu, O., Ipek, S., Asaad, D., S. 2015. Influence of waste rubber utilization on the fracture and steel–concrete bond strength properties of concrete, *Constr. Build. Mater*. 101,1113–1121.

Gesoğlu, M., Güneyisi, E., Özturan, Turan. 2004. Properties of rubberized concretes containing silica fume. *Cem. Concr*. Res. 34, 2309–2317.

Gheni, A., ElGawady, M., Myers, J. 2017. Mechanical characterization of concrete masonry units manufactured with crumb rubber aggregate, *ACI Mater*. J. 114, 65–76.

Gholampour, A., Ozbakkaloglu, T. 2017. Performance of sustainable concretes containing very high volume Class-F fly ash and ground granulated blast furnace slag. *Journal of Cleaner Production*. 162, p. 1407-1417.

Giacobbe, S. 2008. Study of the physical-mechanical performance of Portland cement concrete with incorporation of tyres rubber (in Portuguese). Master dissertation in Civil and Urban Constructions Engineering, Polytechnic School of the São Paulo University, São Paulo, Brazil, 105 pp.

Gideon M., S. 2012. Properties of concrete with tire derived aggregate and crumb rubber as a ligthweight substitute for mineral aggregates in the concrete mix. University of Texas.

Gintautas, S., Audrius, G., Eugenijus, J. 2010. Porosity and Durability of Rubberized Concrete. *Second International Conference on Sustainable Construction Materials and Technologies*. ISBN 978-1-4507-1490-7.

Gonen, T. 2018. Freezing-thawing and impact resistance of concretes containing waste crumb rubbers. *Constr. Build. Mater*. 177, 436–442.

Gong, K., White, C., E. 2016. Impact of chemical variability of ground granulated blast-furnace slag on the phase formation in alkali-activated slag pastes. *Cement and Concrete Research*. 89: p. 310-319.

Grdić Zoran, Topličić-Ćurčić Godana, Ristić Nenad, Grdić Dusan, Mitković Petar. 2014. Hydro-abrasive resistance and mechanical properties of rubberized concrete. *GRAĐEINAR*. 66 (1), 11–20.

Gregori, A., Castoro, C., Carlo Marano, G., Greco, R. 2019. Strength Reduction Factor of Concrete with Recycled Rubber Aggregates from Tires. *Journal of Materials in Civil Engineering*, 2019. 31(8): p. 04019146.

Grinys, A., Sivilevicius, H., Daukšys, M. 2012. Tyre rubber additive effect on concrete mixture strength. *J. Civ. Eng. Manag*. 18, 393–401.

Gudmundsson, G., 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., Ozturan, T. 2004. Properties of rubberized concretes containing silica fume. *Cement and Concrete Research* 34 (12), 2309-2317.

Guo, S., Dai, Q., Si, R., Sun, X., Lu, C. 2017. Evaluation of properties and performance of rubber-modified concrete for recycling of waste scrap tire. *J. Cleaner Prod*. 148, 681–689.

Gupta T., Tiwari, A., Siddique, S., Sharma, R., K., Chaudhary, S. 2017. Response assessment under dynamic loading and microstructural investigations of rubberized concrete. *J. Mater. Civ. Eng.* 29, 04017062.

Gupta, P., K., Khaudhair, Z., A., Ahuja, A., K. 2016. A new method for proportioning recycled concrete. *Structural Concrete*. 17(4): p. 677-687.

Gupta, T., Chaudhary, S., Sharma, R., K. 2014. Assessment of mechanical and durability properties of concrete containing waste rubber tire as fine aggregate. *Construction and building Materials.* 73, p. 562-574.

Heitzman, M. 1992. Design and construction of asphalt paving materials with crumb rubber modifier, *Transp. Res. Rec*. 1339.

Hernández-Olivares, F., Barluenga, G. 2004. Fire performance of recycled rubberfilled high-strength concrete. *Cem. Concr*. Res. 34, 109–117.

Hernández-Olivares, F., Barluenga, G. 2004. Fire performance of recycled rubber-filled high-strength concrete. *Cement and concrete research*. 34(1): p. 109-117.

Hesami, S., Hikouei, I., S., Emadi, S., A., A. 2016. Mechanical behavior of self-compacting concrete pavements incorporating recycled tire rubber crumb and reinforced with polypropylene fiber. *Journal of cleaner production*. 133: p. 228-234.

Her-Yung Wang, Bo-Tsun Chen, Yu-Wu Wu. 2013. A study of the fresh properties of controlled low-strength rubber lightweight aggregate concrete (CLSRLC). *Constr. Build. Mater*. 41, 526–531.

Higgins, D. 2007. Briefing: GGBS and sustainability. *Proc. Inst. Civil Eng. Constr. Mater*.160: 99-101.

Hilal, A., A. 2011. Effect of crumb tyres rubber on some properties of foamed concrete. *Anbar J. Eng. Sci*. AJES 4, 21–17.

Hoda, S., S. 2009. Factors Influencing Acoustic Performance of Sound Absorptive Materials. *Aust. J. Basic Appl. Sci*. 3, 4610–4617.

Holmes, N., Dunne, K., O’Donnell, J. 2014. Longitudinal shear resistance of composite slabs containing crumb rubber in concrete toppings. *Constr. Build. Mater*. 55, 365–378.

Holmes, Niall, Dunne, Kevin, O’Donnell, John, 2014. Longitudinal shear resistance of composite slabs containing crumb rubber in concrete toppings. *Constr. Build. Mater*. 55, 365–378.

Hooton, R., D. 2000. Canadian Use of Ground Granulated Blast furnace Slag as a Supplementary Cementing Material for Enhanced Performance of Concrete. *Can. J. Civil Eng*., 27: 754-760.

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.

Huseien, Abdul Rahman Mohd Sam, Mirza, J., Tahir, M., Mohammad Ali Asaad, Ismail, M., Kwok Wei Shah. 2018. Waste ceramic powder incorporated alkali activated mortars exposed to elevated Temperatures: Performance evaluation. *Construction and Building Materials.* 187: p. 307-317.

Huseien, G., F., Al-Fasih, M., Y., Hamzah, H. 2015. Performance of self-compacting concrete with different sizes of recycled ceramic aggregates. *International Journal of Innovative Research and Creative Technology*. 1(3) p. 264-269.

Huseien, G., F., Ismail, M., Md Tahir, M., M., Mirza, J., Hussein, A., A., Nur Hafizah Abd Khalid, Noor Nabilah Sarbini. 2018. Effect of binder to fine aggregate content on performance of sustainable alkali activated mortars incorporating solid waste materials. *Chem. Eng*. 63: p. 667-672.

Huseien, G., F., Shah, K., W. 2020. Durability and life cycle evaluation of self-compacting concrete containing fly ash as GBFS replacement with alkali activation. *Construction and Building Materials*. 235, p. 117458.

Huseien, G., F., Shah, K., W., Sam, A., R., M. 2019. Sustainability of nanomaterials based self-healing concrete: An all-inclusive insight. *Journal of Building Engineering*. 23, p. 155-171

Huseien, G., F., Abdul Rahman Mohd Sam, Kwok Wei Shah, Mirza, J. 2020. Effects of ceramic tile powder waste on properties of self-compacted alkali-activated concrete. *Construction and Building Materials*. 236: p. 117574.

Huseien, Mirza, J., Ismail, M., Mohd Warid Hussin. 2016. Influence of different curing temperatures and alkali activators on properties of GBFS geopolymer mortars containing fly ash and palm-oil fuel ash. *Construction and Building Materials*. 125: p. 1229-1240.

Hussain F., M., Zahid, Shahjal, Md., Kamrul, Islam, Mohammad, Tiznobaika, Shahria, M., Alama. 2019. Mechanical properties of recycled aggregate concrete containing crumb rubber and polypropylene fiber. *Construction and Building Materials*. 225: p. 983-996.

Hwang, C., L., Wu, D., S. 1989. Properties of cement paste containing rice husk ash. ACI, SP-114, Editor: Malhotra, V.M., 733-765.

ISO 834-12. 2012. *Fire resistance tests — Elements of building construction — Part 12: Specific requirements for separating elements evaluated on less than full scale furnaces*. International Organization for Standardization.

Jang, J., G., Lee, H., -K. 2016. Effect of fly ash characteristics on delayed high-strength development of geopolymers. *Construction and Building Materials*. 102: p. 260-269.

Jaturapitakkul, C., Kraiwood Kiattikomol, Weerachart Tangchirapat, Tirasit Saeting. 2007. Evaluation of the sulfate resistance of concrete containing palm oil fuel ash. *Construction and Building Materials*. 21(7): p. 1399-1405.

Jedidi, M., Gargouri, A., Daoud, A. 2014. Effect of Rubber Aggregates on the Thermophysical Properties of Self-Consolidating Concrete. *Int. J. Therm. Environ. Eng*. 2014, 8, 1–7.

Jiang, Y., Tung-Chai Ling, Caijun Shi, Shu-Yuan Pan. 2018. Characteristics of steel slags and their use in cement and concrete—A review. Resources, *Conservation and Recycling*. 136, p. 187-197.

Johari, M., M., Brooks, J., Kabir, S., Rivard, P. 2011. Influence of supplementary cementitious materials on engineering properties of high strength concrete. *Constr. Build. Mater*. 25(5), 2639–2648.

Jorge, O., René, A. 2019. Reverse logistics network design for large off-the-road scrap tires from mining sites with a single shredding resource scheduling application. *Waste Management*. 100, 219–229.

Kaewunruen, S., Li, D., Chen, Y., Xiang, Z. 2018. Enhancement of dynamic damping in eco-friendly railway concrete sleepers using waste-tyre crumb rubber, *Materials (Basel)*. 11, 1169.

Kanema, M., Noumowe, A., Gallias, J., L., Cabrillac, R. 2005. Influence of the mix parameters and microstructure on the behaviour of concrete at high temperature. Proceedings of 18th international conference on structural mechanics in reactor technology.

Kang, J., Yan, C. 2011. Correlation of strength, rubber content, and water - cement ratio in roller compacted rubberized concrete. *Advanced Materials Research*. Vol 243-249, pp 1179-1185.

Karri, S., K., Rao, G., R., Raju, P., M. 2015. Strength and durability Studies on GGBS Concrete. *SSRG International Journal of Civil Engineering*. 2(10), p. 34-41.

Kashani, A., Ngo, T., D., Hemachandra, P., Hajimohammadi, A. 2018. Effects of surface treatments of recycled tyre crumb on cement-rubber bonding in concrete composite foam. *Constr. Build. Mater*. 171, 467–473.

Khairol Azhar Nordin, Adamu M., Forouzani P., Ismail, M. 2013. Performance of waste tyre and palm oil fuel ash concrete. *Malaysian Journal of Civil Engineering* 25(2), 177-189.

Khaloo, A., R., Dehestani, M., Rahmatabadi, P. 2008. Mechanical properties of concrete containing a high volume of tire-rubber particles. *Waste Manage* 28(12), 2472–82.

Khatib, Z., K., Bayomy, F., M. 1999. Rubberized Portland Cement Concrete. *ASCE J Mater Civil Eng*. 11(3), pp. 206-13.

Khusru, S., Fawzia, Sabrina,. Thambiratnam, D., P., Elchalakani, M. 2020. A parametric study: High performance double skin tubular column using rubberised concrete. *Composite Structures*. 235: p. 111741.

Kosmatka, S., H., Kerkhoff, B., William, C. 2003. Design and Control of Concrete Mixtures. 14th Edn., Portland Cement Association, USA.

Krishna, C., B. 2003. Akron rubber development laboratory, astm standards & testing of recycle rubber, in: Rubber Div. Meet. Am. Chem. Soc., San Francisco, California.

Leitao, C., Qiuxia, F., Yang, S., Bin, D., Jianyong Y. 2018. Porous materials for sound absorption. *Composites Communications*. 10, 25-35.

Lesovik, V., S., Pershina, I., L. 2018. Acoustic Factor in the Formation of Architectural Space. In Proceedings of the IOP Conference Series: Materials Science and Engineering. 26–29.

Li Guoqiang, Garrick, G., Eggers, J., Abadie, C., Stubblefield, M.A., Pang, S.-S. 2004-a. Waste tire fiber modified concrete. Composites Part B: Engineering 35 (4), 305-312.

Li Guoqiang, 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 Guoqiang, 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, D., Zhuge, Y., Gravina, R., Mills, J., E. 2018. Compressive stress strain behavior of crumb rubber concrete (CRC) and application in reinforced CRC slab. *Constr. Build. Mater*. 166, 745–759.

Li, G., S., Pang, S., Ibekwe, S., I. 2011. FRP tube encased rubberized concrete cylinders, *Mater. Struct*. 44, 233–243.

Li, Guoxin, Ai Zhang, Song Zhanping, Shengjun Liu, Jiangbo Zhang. 2018. Ground granulated blast furnace slag effect on the durability of ternary cementitious system exposed to combined attack of chloride and sulfate. *Construction and Building Materials*. 158: p. 640-648.

Li, L., Ruan, S., Zeng, L. 2014. Mechanical properties and constitutive equations of concrete containing a low volume of tire rubber particles, *Constr. Build. Mater*. 70, 291–308.

Li, Y., Chen, Y. 2006. Influence of ground mineral admixtures on pore structure of hardened cement paste and strength of cement mortar. *JOURNAL-CHINESE CERAMIC SOCIETY*. 34(5), p. 575.

Liew, K., A. Sojobi, and L. Zhang, Green concrete: Prospects and challenges. Construction and building materials, 2017. 156: p. 1063-1095.

Liu Chunlin, Zha Kunpeng, Depeng Chen. 2011. Possibility of concrete prepared with steel slag as fine and coarse aggregates: a preliminary study. *Proc. Eng*. 24, 412–416.

Liu, F., Wanhu Zheng, Lijuan Li, Wenxian Feng, Guofang Ning. 2013. Mechanical and fatigue performance of rubber concrete. *Construction and Building Materials*. 47: p. 711-719.

Liu, H., Wang, X., Jiao, Y., Sha, T. 2016. Experimental investigation of the mechanical and durability properties of crumb rubber concrete. *Materials*. 9,172.

Lothenbach, B., Scrivener, K., Hooton, R. 2011. Supplementary cementitious materials. *Cement and concrete research*. 41(12): p. 1244-1256.

Mahir M., H., Farah Nora, A., A., Aznieta, Gatea, S., J. 2017. Evaluation of rubberized fibre mortar exposed to elevated temperature using destructive and non-destructive testing. *KSCE J. Civ. Eng*. 21, 1347–1358.

Marques, A., C., Akasaki, J., Trigo, A., M., Marques, M. 2008. Influence of the surface treatment of tire rubber residues added in mortars. Revista IBRACON de Estruturas e Mater. 1 (2),113–120.

Marques, A., Correia, J., De Brito, J. 2013. Post-fire residual mechanical properties of concrete made with recycled rubber aggregate. *Fire Safety Journal*. 58, p. 49-57.

Marques, A., M., Correia, J., R., de Brito, J. 2013. Post-fire residual mechanical properties of concrete made with recycled rubber aggregate. *Fire Saf. J.* 58, 49–57.

McLellan, Benjamin, C., Ross, P., Williams, Janine, Lay, Arie, van Riessen, Cordera, Glen, D. 2011. Costs and carbon emissions for geopolymer pastes in comparison to ordinary portland cement. *Journal of cleaner production*. 19(9-10): p. 1080-1090.

Medina, N., F., Flores-Medina, D., Hernández-Olivares, F. 2016. Influence of fibers partially coated with rubber from tire recycling as aggregate on the acoustical properties of rubberized concrete, *Constr. Build. Mater*. 129, 25–36.

Memon, S., A., Lo, T., Y., Barbhuiya, S., Xu, W. 2013. Development of form-stable composite phase change material by incorporation of dodecyl alcohol into ground granulated blast furnace slag. *Energy Build*. 62, 360–367.

Mo, Kim, Hung, Tung-Chai, Ling, U., Johnson, Alengaram, Mohd, Zamin, Jumaat. 2017. Material and structural properties of waste-oil palm shell concrete incorporating ground granulated blast-furnace slag reinforced with low-volume steel fibres. *Journal of Cleaner Production*. 133: p. 414-426.

Mo, Kim, Hung, Tung-Chai, Ling, U., Johnson, Alengaram, Soon, Poh, Yap, Choon, Wah, Yuena. 2017. Overview of supplementary cementitious materials usage in lightweight aggregate concrete. *Construction and Building Materials.* 139: p. 403-418.

Mohammadhosseini, H. Tahir, M., M., Abdul Rahman Mohd Sam, Nor Hasanah Abdul Shukor Lim, Samadi, M. 2018. Enhanced performance for aggressive environments of green concrete composites reinforced with waste carpet fibers and palm oil fuel ash. *Journal of Cleaner Production*. 2018. 185, p. 252-265.

Mohammadhosseini, H., Jamaludin Mohamad Yatim, Abdul Rahman Mohd Sam, A. S. M. Abdul Awal. 2017. Durability performance of green concrete composites containing waste carpet fibers and palm oil fuel ash. *Journal of Cleaner Production*. 144: p. 448-458.

Mohammadhosseini, H., Nor Hasanah Abdul Shukor Lim, Tahir, M., M., Rayed Alyousef, Hisham Alabduljabbar, Samadi, M. 2019. Enhanced performance of green mortar comprising high volume of ceramic waste in aggressive environments. *Construction and Building Materials*. 2019. 212, p. 607-617.

Mohammadi, I., Khabbaz, H. 2015. Shrinkage performance of Crumb Rubber Concrete (CRC) prepared by water-soaking treatment method for rigid pavements, *Cem. Concr. Compos*. 62 (2015) 106–116.

Mohammadi, I., Khabbaz, H., Vessalas, K. 2014. In-depth assessment of Crumb Rubber Concrete (CRC) prepared by water-soaking treatment method for rigid pavements. *Constr. Build. Mater.* 71, 456–471.

Mohammed, B., S., Hossain, K., M., A., Swee, E., Wong, Grace W., Abdullahi M. 2012. Properties of crumb rubber hollow concrete block. *J. Clean. Prod.* 23, 57–67.

Mohammed. B., S., Adamu, M., Shafiq, N. 2017. Establishing relationship between modulus of elasticity and strength of nano silica modified roller compacted rubbercrete, Int. J. Geomate. 13 (2017) 103–110.

Mohammed. B., S., Liew, M., S., Alaloul, W., S., Al-Fakih, A., Ibrahim, W., Adamu, M. 2018. Development of rubberized geopolymer interlocking bricks, *Case Stud. Constr. Mater*. 8 401–408.

Moustafa, A., ElGawady, M. 2017. Dynamic properties of high strength rubberized concrete, *ACI Spec*. Publ. 1–22.

Mucsi, G., Szenczi, Á., Nagy, S. 2018. Fiber reinforced geopolymer from synergetic utilization of fly ash and waste tire, *J. Clean. Prod*. 178 (2018) 429–440.

Mukherjee, A., Pathak, S., R., Pal, S., C. 2003. Investigation of hydraulic activity of ground granulated blast furnace slag in concrete. *Cem. Concr. Res.* 33 (2003) 1481– 1486.

Muñoz-Sánchez Belén, M., J., Arévalo-Caballero, M., C., Pacheco-Menor. 2017. Influence of acetic acid and calcium hydroxide treatments of rubber waste on the properties of rubberized mortars. *Mater. Struct*. 50, 75.

Najim, K., B., 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, 2043–2051.

Najim, K., B., Hall, M., R. 2012. Mechanical and dynamic properties of self-compacting crumb rubber modified concrete. *Constr. Build. Mater*. 27, 521–530.

Najim, K., B., Hall, M., R. 2013. Crumb rubber aggregate coatings/pre-treatments and their effects on interfacial bonding, air entrapment and fracture toughness in self-compacting rubberised concrete (SCRC). *Mater. Struct.* 46, 2029–2043.

Neville, A., M. 1996. Properties of Concrete, fourth ed., John Wiley and Sons, Inc., New York.

Neville, A., M. 2011. Properties of concrete - 5th edition. Pearson Education Limited.

Neville, A., M. 2012. Properties of concrete. 5th edion. Longman, London.

Neville. A., M. 1995. Properties of concrete. 4th edion. Longman, London.

Noaman, A., T., Abu Bakar, B., H., Akil, H., M. 2016. Experimental investigation on compression toughness of rubberized steel fibre concrete, *Constr. Build. Mater*. 115, 163–170.

Noruzman, A., Ismail, M., Aamer Bhutta, Taliat Ola Yusuf, Shehu Ibrahim Abu Bakar, Ibrahim Ogiri Hassan. 2013. Strength and durability characteristicompressive strength of polymer modified concrete incorporating Vinyl acetate effluent. *In Advanced Materials Research*. 2013. Trans Tech Publ.

Noumowe, A., Clastres, P., Debicki, G., Bolvin, M. 1994. High temperature effect on high performance concrete (70-600 C) strength and porosity. *Special Publication*. 145: p. 157-172.

Omid Rezaifar, Mohsen Hasanzadeh, Majid Gholhaki. 2016. Concrete made with hybrid blends of crumb rubber and metakaolin: Optimization using Response Surface Method. *Construction and Building Materials*. 123, 59–68.

Onuaguluchi, O. 2015. Effects of surface pre-coating and silica fume on crumb rubber-cement matrix interface and cement mortar properties, *J. Clean. Prod*. 104, 339–345.

Oscar. López-Zaldívar, Lozano-Díez, R., Herrero del Cura, S., Mayor-Lobo, P., Hernández-Olivares, F. 2017. Effects of water absorption on the microstructure of plaster with end-of-life tire rubber mortars, *Constr. Build. Mater*. 150, 558–567.

Özbay, E., Erdemir, M., Durmuş, H., İ. 2016. Utilization and efficiency of ground granulated blast furnace slag on concrete properties–A review. *Construction and Building Materials*. 105: p. 423-434.

Özkan, Ö., Yüksel, I., Muratoğlu, Ö. 2007. Strength properties of concrete incorporating coal bottom ash and granulated blast furnace slag. *Waste management*. 27(2): p. 161-167.

Pacheco-Torres, R., Cerro-Prada, E., Escolano, F., Varela, F. 2018. Fatigue performance of waste rubber concrete for rigid road pavements, *Constr. Build. Mater*. 176, 539–548.

Pal, S., Mukherjee, A., Pathak, S. 2003. Investigation of hydraulic activity of ground granulated blast furnace slag in concrete. *Cement and Concrete Research*. 33(9): p. 1481-1486.

Park, Y., Abolmaali, A., Mohammadagha, M., Lee, S.-H. 2014. Flexural characteristic of rubberized hybrid concrete reinforced with steel and synthetic fibers, *Adv. Civ. Eng. Mater*. 3, 20140011.

Pastor, J., M., Garcia, L., D., Quintana, S., Pena, J. 2014. Glass reinforced concrete panels containing recycled tyres: evaluation of the acoustic properties of for their use as sound barriers, *Construct. Build. Mater*. 54, 541–549.

Pham, T., M., Zhang, X., Elchalakani, M., Karrech, A., Hao, H., Ryan, A., Dynamic response of rubberized concrete columns with and without FRP confinement subjected to lateral impact, *Constr. Build. Mater*. 186, 207–218.

Qiang, W., Mengxiao, S., and Jun, Y. 2016. Influence of classified steel slag with particle sizes smaller than 20 μm on the properties of cement and concrete. *Construction and Building Materials*. 123: p. 601-610.

Raffoul S., Garcia R., Pilakoutas K., Guadagnini M., Medina N.F. 2016. Optimisation of rubberised concrete with high rubber content: An experimental investigation. *Constr. Build. Mater*. 124, 391–404.

Raffoul, S., Garcia, R., Escolano-Margarit, D., Guadagnini, M., Hajirasouliha, I., Pilakoutas, K. 2017. Behaviour of unconfined and FRP confined rubberised concrete in axial compression, *Constr. Build. Mater.* 147, 388–397.

Raj, B., Ganesan, N., Shashikala, A.P., 2011. Engineering properties of self-compacting rubberized concrete. *J. Reinf. Plast. Compos*. 30 (23), 1923–1930.

Rajeev, R., Rebecca, J., Gravina, Yan Zhuge, Xing Ma, Osama Youssf, Julie E., M. 2020. A comprehensive review on the mechanical properties of waste tire rubber concrete. *Construction and Building Materials*. 237, 117651.

Rashad, A., M. 2016. A comprehensive overview about recycling rubber as fine aggregate replacement in traditional cementitious materials. *International Journal of Sustainable Built Environment*. 5, 46–82.

Rashad, A., M., Sadek, D., M., and Hassan, H., A. 2016. An investigation on blast-furnace stag as fine aggregate in alkali-activated slag mortars subjected to elevated temperatures. *Journal of Cleaner Production*. 2016. 112: p. 1086-1096.

Rashid, K., Yazdanbakhsh, A., and Rehman, M., U. 2019. Sustainable selection of the concrete incorporating recycled tire aggregate to be used as medium to low strength material. *Journal of Cleaner Production*. 224, p. 396-410.

Rivas-Vázquez, L., Suárez-Orduña, R., Hernández-Torres, J., Aquino Bolaños, E. 2015. Effect of the surface treatment of recycled rubber on the mechanical strength of composite concrete/rubber, *Mater. Struct*. 48(9), 2809–2814.

RMA – Rubber Manufacturers Association (USA). 2013. U.S. Scrap Tire Management Summary. Washington (DC).

RMA – Rubber Manufacturers Association (USA). 2015. *Scrap Tire Management Summary*, RMA, Washington (DC).

Roman, F., Mugahed, A., Nikolai, V., Yuriy, V., Valery, L., Togay, O. 2021. Acoustic Properties of Innovative Concretes: A Review. Materials. 14, 398.

Rosa, D., Moreno, A., Martins, T. 2007. Evaluation of the influence of size grading in the incorporation of waste tyres in concrete composites (in Portuguese). Brazilian Journal of Vacuum Applications. 26 (2), 103-110.

Ruben Snellings, Gilles Mertens, Jan Elsen. 2012. Supplementary Cementitious Materials.Reviews in Mineralogy and Geochemistry. vol. 74 pp. 211-278.

Sahani, A., K., Samanta, A., K., Roy, D., K., S. 2019. Influence of mineral by-products on compressive strength and microstructure of concrete at high temperature. *Advances in concrete construction*. 7(4), p. 263-275.

Samadi, M., Kwok Wei Shah, Huseien G., F., Nor Hasanah Abdul Shukor Lim. 2020. Influence of Glass Silica Waste Nano Powder on the Mechanical and Microstructure Properties of Alkali-Activated Mortars. *Nanomaterials*. 10(2), p. 324.

Samiha Ramdani, Abdelhamid Guettala, ML Benmalek, José B. Aguiar. Physical and mechanical performance of concrete made with waste rubber aggregate, glass powder and silica sand powder. *Journal of Building Engineering*. 21, 302–311.

Sancak, E., Sari, Y., D., Simsek, O. 2008. Effects of elevated temperature on compressive strength and weight loss of the light-weight concrete with silica fume and superplasticizer. *Cement and Concrete Composites*. 30(8), p. 715-721.

Senin, M., S., Shahidan, S., Abdullah, S., R., Guntor, N., A., Leman, A., S. 2017. A review on the suitability of rubberized concrete for concrete bridge decks. *IOP Conf. Ser. Mater. Sci. Eng*. 271.

Shafiqul Islam, Gajanan Bhat. 2019. Environmentally-friendly thermal and acoustic insulation materials from recycled textiles. *Journal of Environmental Management.* 251, 109536.

Shakya, P., R., Pratima Shrestha, Chirika S. Tamrakar, Pradeep K. Bhattarai. 2008. Studies on potential emission of hazardous gases due to uncontrolled open-air burning of waste vehicle tyres and their possible impacts on the environment. *Atmospheric Environment*. 42(26): p. 6555-6559.

Shetty, M. 2005. Concrete technology. S. chand & company LTD. p. 420-453.

Shi, C., Qian, J. 2000. High performance cementing materials from industrial slags: A review. *Resour. Conserv. Recycl.*, 29: 195-207.

Si, R., Wang, J., Guo, S., Dai, Q., Han, S. 2018. Evaluation of laboratory performance of self-consolidating concrete with recycled tire rubber, *J. Clean. Prod*. 180, 823–831.

Siddique, R., Kaur., D. 2012. Properties of concrete containing ground granulated blast furnace slag (GGBFS) at elevated temperatures. *J. Adv. Res*. 3(1), 45-51.

Siddique, R., Naik, T., R. 2004. Properties of concrete containing scrap-tire rubber: an overview. *Waste Management*. 24 (6), 563-569.

Sienkiewicz, M., Justyna Kucinska-Lipka, Helena Janik, Adolf Balas. 2012. Progress in used tyres management in the European Union: A review. Waste Management. Elsevier Ltd, 32(10), pp. 1742–1751.

Si-Huy Ngo, Trong-Phuoc Huynh, Phuong-Trinh Bui. 2020. Engineering Properties and Microstructure of Reactive Powder Concrete using High-Volume Fly Ash and Natural-Fine River Sand. *International Journal of Recent Technology and Engineering*. 8(5), 2277-3878.

Snellings, R. 2016. Assessing, understanding and unlocking supplementary cementitious materials. *RILEM Technical Letters*. 1: p. 50-55.

Sofi, A. 2017. Effect of waste tyre rubber on mechanical and durability properties of concrete – A review, *Ain Shams Eng. J*. 1–10.

Song, Ha-Won, Saraswathy, V. 2006. Studies on the corrosion resistance of reinforced steel in concrete with ground granulated blast-furnace slag—An overview. *Journal of hazardous materials*. 138(2): p. 226-233.

Su, H., Jian Yang, Tung-Chai Ling, Gurmel S. Ghataora, Samir Dirar. 2015. Properties of concrete prepared with waste tyre rubber particles of uniform and varying sizes. *Journal of Cleaner Production*. 2015. 91: p. 288-296.

Su, H., Yang, J., Ling, T., C., Ghataora, G., S., Dirar, S. 2015. Properties of concrete prepared with waste tyre rubber particles of uniform and varying sizes, *J. Clean. Prod.* 91, 288–296.

Sukontasukkul, P. 2009. Use of crumb rubber to improve thermal and sound properties of pre-cast concrete panel. *Constr Build Mater*. 23(2):1084–92.

Sukontasukkul, P., Chaikaew, C., 2006. Properties of concrete pedestrian block mixed with crumb rubber. *Constr. Build. Mater*. 20, 450–457.

Sun, J., Study of effects of ground steel slag on mechanical performance and soundness of concrete. *Coal Ash China*, 2003. 15(5): p. 7-9.

Swapna, V., P., Stephen, R. 2016. Recycling of rubber, in: Recycl. Polym., Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, Germany. pp. 141–161.

Taha, M., M., El-Dieb, A., S., AbdEl-Wahab, M., A., Abdel-Hameed, M., E. 2008. Mechanical, fracture, and microstructural investigations of rubber concrete. *J. Mater. Civ. Eng. ASCE*, 640–649.

Tang, P., Yu, R., Spiesz, P., Brouwers, H. 2014. A study of multiple effects of nano-silica and hybrid fibres on the properties of Ultra-High Performance Fibre Reinforced Concrete (UHPFRC) incorporating waste bottom ash (WBA). *Constr. Build. Mater*. 60, 98–110.

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.

Thomas, B., S., and Gupta, R., C. 2016. Properties of high strength concrete containing scrap tire rubber. *Journal of Cleaner Production*. 113, p. 86-92.

Thomas, B., S., and Gupta, R., C., Kalla, P., Cseteneyi, L. 2014. Strength, abrasion and permeation characteristics of cement concrete containing discarded rubber fine aggregates. *Constr. Build. Mater*. 59, 205–212.

Thomas, B., S., and Gupta, R., C., Panicker, V., J. 2016. Recycling of waste tire rubber as aggregate in concrete: durability-related performance. *Journal of Cleaner Production*. 112, p. 504-513.

Thomas, B., S., Gupta, R., C., Mehra, P., Kumar, S. 2015. Performance of high strength rubberized concrete in aggressive environment, *Constr. Build. Mater*. 83, 320–326.

Topcu, B. 1995. The Properties of Rubberized Concrete. *Cement and Concrete Research*. 25(2), pp. 304-10.

Topçu, I., B., Unverdi, A. 2018. Scrap tires/crumb rubber, In: Waste Suppl. Cem. Mater. Concr., *Elsevier*. pp. 51–77.

Turatsinze, A., Bonnet S., Granju, J., L. 2007. Potential of rubber aggregates to modify properties of cement based-mortars: improvement in cracking shrinkage resistance. *Construction and Building Materials*. 2007. 21(1), p.176-181.

Turatsinze, A., 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.

Turgut, P., Yesilata, B. 2008. Physico-mechanical and thermal performances of newly developed rubber-added bricks. *Energy Build*. 40(5),679–88.

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.

Turki, M., Inès Zarrad, Estelle Bretagne, Michèle Quéneudec.2012. Influence of filler addition on mechanical behavior of cementitious mortar-rubber aggregates: experimental study and Modeling. *Journal of Materials in Civil Engineering*. 24(11), p. 1350-1358.

Tzer Sheng Tie, Kim Hung Mo, Azma Putra, Siaw Chuing Loo, U. Johnson Alengara, Tung-Chai Ling. 2020. Sound absorption performance of modified concrete: A review. *Journal of Building Engineering.* 30, 101219.

Uygunoğlu Tayfun, Topęu Ilker Bekir, 2010. The role of scrap rubber particles on the drying shrinkage and mechanical properties of selfconsolidating mortars. *Constr. Build. Mater.* 24, 1141–1150.

Vadivel, T., Senthil, Thenmozhi, R., Dodurani, M. 2014. Experimental behavior of waste tyre rubber aggregate concrete under impact loading. *IJST, Trans. Civ. Eng*. 38, 251–259.

Valadares, F. 2009. Mechanical Performance of Structural Concrete with Rubber Granulates from Used Tyres (In Portuguese). Master dissertation in Civil Engineering, IST, Technical University of Lisbon, Lisbon, Portugal. 139 pp.

Walid, D., Oudjit, M., N., Bouzid, A., Belagraa, L. (2015), "Effect of incorporating blast furnace slag and natural pozzolana on compressive strength and capillary water absorption of concrete", *Proc. Eng.*, 108, 254-261.

Wang, X.,Y., Lee, H., S. 2010. Modeling the hydration of concrete incorporating fly ash or slag, *Cem. Concr. Res*. 40, 984–996.

Wee, T., H., Suryavanshi, A., K., Wong, S., F., Rahman, A. 2000. Sulfate resistance of concrete containing mineral admixtures, *ACI Mater. J.* 97(5), 536–549.

Yang, J., Jiang, G. 2003. Experimental Study Properties of Pervious. Concrete Pavement Materials. *Cement and Concrete Research*. 33, p. 381-386.

Yazıcı, H., Mert Y. Yardımcı, Hüseyin Yiğiter, Serdar Aydın, Selçuk Türkel. 2010. Mechanical properties of reactive powder concrete containing high volumes of ground granulated blast furnace slag. *Cement and Concrete Composites*. 32(8), p. 639-648.

Yilmaz, A., Degirmenci, N. 2009. Possibility of using waste tire rubber and fly ash with Portland cement as construction materials. *Waste management*. 29 (5). 1541–6.

Youssf, O., E., Hassanli R., Mills, J., Skinner, W., Ma, X., Zhuge, Y., Roychand, R., Gravina, R. 2019. Influence of mixing procedures, rubber treatment, and fibre additives on rubcrete performance, *J. Compos. Sci*. 3(2), 41.

Youssf, O., Hassanli, R., Mills, J., E. 2017. Mechanical performance of FRP-confined and unconfined crumb rubber concrete containing high rubber content. *Journal of Building Engineering*. 11: p. 115-126.

Youssf, O., Mills, J., E., Hassanli R. 2016. Assessment of the mechanical performance of crumb rubber concrete, Constr. Build. Mater. 125, 175–183.

Yusuf, O. 2015. Performance of slag blended alkaline activated palm oil fuel ash mortar in sulfate environments. *Construction and Building Materials*. 98, p. 417-424.

Zhang Binyu, Poon Chi Sun. 2018. Sound insulation properties of rubberized lightweight aggregate concrete. *Journal of Cleaner Production*. Vol 172, Pages 3176-3185.

Zhanga, Y., Lia, H., Ahmed, A., Jie, Y. 2020. Effect of different factors on sound absorption property of porous concrete. *Transportation Research*. Part D, 87, 102532.

Zhang, Z., Ma, H., Qian, S. 2015. Investigation on properties of ECC incorporating crumb rubber of different sizes, *J. Adv. Concr. Technol*. 13 (2015) 241–251.

Zhao, J., Wang, X., M., Chang, J., M., Yao, Y., Cui, Q. 2010. Sound insulation property of wood–waste tire rubber composite. *Composites Science and Technology*. 70, 2033–2038.

Zheng L., Huo, X., S., Yuan, Y. 2008. Strength, modulus of elasticity, and brittleness index of rubberized concrete. *J. Mater. Civ. Eng*. 20, 692–699.