STUDY ON COMPRESSIVE, TENSILE AND BOND PROPERTIES OF USED TIRE RUBBER REINFORCED CONCRETE

By

Theresa Bwalya

A dissertation submitted to the University of Zambia in partial fulfilment of the requirements of the Degree of Master of Engineering in Structural Engineering

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APPROVAL

‘This dissertation of **Theresa Bwalya** has been approved as fulfilling the partial requirements for the award of *Master of Engineering in Structural Engineering* by the University of Zambia.’

Examiner 1 Signature: Date

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Examiner 2 Signature: Date

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ABSTRACT

Concrete is one of the most widely used construction material in the world and the construction industry is looking for ways of making concrete using greener methods so as to reduce ecological effects on the environment that come as a result of large scale exploitation of natural aggregates. The construction industry is also in need of finding cost-effective materials to enhance the properties of concrete. Cement and aggregate, which are the major constituents in concrete production are the vital materials needed in the construction industry. This has inevitably led to a continuous and increasing exploitation of natural materials to produce the constituents for concrete production. The result has been the depletion of virgin raw materials and increased effects of environmental degradation. Parallel to the need for the utilization of the natural resources emerges a growing demand to protect the environment and preserve natural resources such as the aggregates and stone for cement production, by use of alternative materials such as recycled or waste materials. In this research, a study was carried out on the use of recycled rubber tyres as a partial replacement for coarse aggregates in concrete production. Recycled waste tyre rubber is a promising material in the construction industry due to its reduced weight, elasticity, energy absorption, sound and heat insulating properties. However, literature suggests that there is a significant loss in the strength of rubberized concrete with increasing tyre content. Further, workability and bond properties have been reported to reduce as well. Therefore, it is necessary to lower or control this loss of strength and other parameters in concrete in the replacement process of natural aggregates. This research aimed at studying the compressive, tensile and bond properties of used tyre rubber reinforced concrete. The research also aimed at establishing whether the use of rubber reinforced concrete (rubberized concrete) is technically and economically viable in Zambia. Rubber modified concrete was compared to normal concrete produced from natural coarse aggregates and Portland cement. The research involved literature review, laboratory testing on natural raw materials and used rubber as aggregates (to determine their properties and suitability for use in concrete), concrete mix design, concrete trial mixes, and tests on both wet and hardened concrete. Test results from laboratory experiments enabled determination of mechanical, physical and durability properties, as well as establishment of the extent of substitution of normal aggregates with waste rubber as aggregate in concrete production. Three classes of concrete, C15, C20 and C25 were produced by substitution of selected percentages of aggrgates by treated chopped waste tire rubber. The chopped rubber, whose surfaces were first roughened by use a wire brush, was later soaked in clean water and then left to dry completely in the sun. This was done to increase the inter-phase bonding between the rubber particles and cement. The percentage replacement of coarse aggregates was 5, 15 and 25 per cent. The size of the chopped rubber aggregates varied from 20 mm to 19 mm. Slump, permeability and bulk density tests were conducted on fresh concrete mixes for both the normal and treated rubber modified concrete. Similarly, compressive strength, tensile splitting strength, bond test and durability against acid attack tests were conducted on hardened concrete.

The research established that rubber modified concrete compares favourably with standard concrete, with up to 15 per cent replacement of coarse aggregate. At 15 per cent replacement, only 0.1 per cent loss of strength was established. There was observed reduction in properties with 25 per cent replacement. Rubber modified concrete performed better by gradual cracking at elevated temperatures. There is potential for rubber modified concrete products in Zambia which in turn mitigates adverse impacts resulting from over exploitation of natural aggregates and disposal of used rubber tires.

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LIST OF ABBREVIATIONS AND ACRONYMS

CCBs	Coal Combustion By-products
RTSA	Road Transport and Safety Agency
MoHE	Ministry of Higher Education
PCC	Portland cement Concrete
RRC	Rubber Reinforced Concrete
IARC	International Agency for Research of Cancer
WTRAC	Waste Tire Rubber Aggregate Concrete
CTA	Crumb Tire Aggregate
PET (bottles)	Polyethylene Terephthalate
ETRMA	European Tire and Rubber Manufactures Association
SBR (latex)	Styrene Butaliene Rubber
SCRC	Self-Compacting Rubberized Concrete
RPCC	Rubberized Portland cement Concrete

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

Concrete is the most widely used construction material in today's world. It is estimated by World Business Council for Sustainable Development (WBCSD) in 2017 that roughly 25 billion tonnes of concrete are manufactured globally each year. This means over 1.7 billion truck loads each year, or about 6.4 million truck loads a day, or over 3.8 tonnes per person in the world each year. It is very difficult to point out another material of construction as versatile as concrete. It is a material of choice where strength, durability, permanence, impermeability, fire resistance and abrasion resistance are required. It is so closely associated now with every human activity that it touches every human being in day to day living. The basic materials required for producing concrete include cement, fine aggregate (sand), coarse aggregate (broken stone or boulders) and water. Sand and coarse aggregates required for making concrete are obtained from earth's crust, mainly from rock quarries or dredged from river beds.

Large scale exploitation of natural aggregates creates an environmental impact on society. Currently, humanity may be living in an unsustainable manner with respect to its usage of natural resources which may have a direct effect on climate change. Although the supply of natural resources is measurable, the demand for construction activities and demand for raw materials has increased greatly during the years. The growing demand for natural resources may cause the causalities such as technological improvements that have made more products available to society, raising affluence levels in the developing world and the overall increase in the overall global population (Saviour, 2012).

Another concern about the exploitation of natural resources is the potential generation of carbon dioxide emissions and their harmful effect on the globe. These concerns have led to a re-evaluation of how natural resources are used and hence call for the implementation of more sustainable practices that preserve resources and allow them to endure for the future. The extraction of aggregates from rivers may lead to deterioration of river basins, large scale soil erosions, depletion of the water table, and a decrease in sediment supply and may also lead to an increase in pollution and changes in soil pH levels.

Concrete being a crucial building material is utilized all over the world in billions of tones annually and the consumption is increasing at a faster rate with every passing year. The requirement of aggregates is also increasing with an increase in the production of concrete. This large-scale extraction of aggregates will ultimately lead to irreparable damages to the earth's natural resources. As such, we need to search for new construction materials.

In response to these concerns, the engineering community has begun to develop programs and standards that address sustainable construction practices. A number of innovative ideas have been put forward by many researchers suggesting the potential replacements of conventional concrete constituents, particularly coarse and fine aggregates by use of different waste materials which will not only help in reducing the adverse effects on environmental pollution but will also help in producing economical and lightweight concrete.

The use of lightweight concrete has been used since the early 1900s. Concrete is a relatively heavy building material, hence the many experiments throughout the 20th century to decrease its weight without compromising other properties. In the present century, light-weight concrete composite has even become a more popular construction material owing to its low density, reduction of dead load and low handling costs (Kamsiah, 2003). The strength, durability and other characteristics of concrete depend upon the properties of its ingredients, size and proportions of mix, method of compaction and curing. The adoption of lightweight concrete gives an outlet for industrial waste such as scrap rubber tyres, flash, clinkers etc. which otherwise would present problems of disposal as wastes. Scrap tyre rubber and flash are two major industrial wastes which are accumulating in huge volumes every year. Disposal of these organic and inorganic wastes is a serious problem due to severe environmental problems.

With the development of technology, the construction industry has opened a gateway for handling these industrial wastes. Recycling of non-degradable wastes, particularly discarded rubber tyres has become a major issue since these materials are not recommended to form landfills and also incineration of these wastes is not environmental friendly.

The increasing awareness about the environment in Lusaka, Zambia, and worldwide has tremendously contributed to the concerns related to the disposal of the generated wastes. Solid waste management is one of the major environmental concerns worldwide. With the scarcity of space for landfilling and due to its ever-increasing cost, waste use has become an attractive alternative to disposal.

Reuse of bulky wastes is considered the best environmental alternative for solving the problem of waste disposal as cited by Al-Bakari et al., (2016).

One such waste is rubber, which could be used in various applications to produce concrete. Over 2.5 billion tyres are sold globally every as indicated by World Tyres in 2017. Lusaka alone, through the Road transport and safety Agency (RTSA), registers an average of 200 vehicles a day of which 90 per cent of these vehicles are second hand. According to the Road Transport and Safety Agency (RTSA), vehicle registrations increased to an average of 43,000 per year in the last five years. 40, 000 vehicle registrations were recorded in Zambia in 2019; however, a record of 62,000 vehicles entered the country in the same year. With these statistics, a huge volume of tyres is expected to be generated with time and plans on how to discard them will have to be put in place.

Accumulated waste tyres has become a problem of interest because of its non-biodegradable nature (Malladi, 2004). According to the U.S. Tyre Manufacturers Association, the tyres are designed to last about 60,000 miles (96,560.64 kilometres) and can be used well over a decade. Since tyres are made to last this long, the same things that make them durable can also make them difficult to dispose of, thus affecting the environment in the long run. Tyre alone takes thousands of years to decompose it completely. In most of the cases, it ends up being burnt, releasing toxins and pollutants into the air, water and soil. Stockpiling or illegally dumping or landfilling is the traditional method of disposal of waste tyres, but these are short-term solutions. Most of the waste tyre rubbers are used as a fuel in many of the industries such as thermal power plant, cement kilns and brick kilns etc. Researchers at the University of California concluded that this kind of usage is not environmentally friendly and requires high cost.

Research done so far on the reuse of waste tyres has used chipped, crumb and ground rubber in concrete as partial replacement of aggregates. This waste tyre rubber added to concrete is termed as *Rubberized Concrete or Rubcrete,* (Eldin and Seouci, 1993).

This research reports on the investigation conducted on the suitability of rubber tyre aggregates as a construction material in Zambia. It aimed at investigating the optimal use of waste tyre rubber aggregates as coarse aggregates in concrete composite. Based on the literature survey it has been seen that the compressive strength of concrete reduces with the addition of rubber aggregate.

In this study, a number of laboratory tests were carried out on modified concrete specimens using rubber particles obtained from used tyres.

Different percentages of rubber particles were used as a substitute for natural aggregates in the concrete mix and it was established that rubber modified concrete compares favourably with standard concrete, with up to 15 per cent replacement of coarse aggregates.

1.2 Methods of Recycling Waste Tires

There are various techniques and technologies that can be used for processing post-consumer tyres, (Yang et al. 2015). These include:

a) De-vulcanization: This is the process of reversal of the vulcanization process by application of heat and chemical treatment.

b) Crumbing: This is the processing of the tyre into powdered particles using mechanical or cryogenic processes.

c) Shredding and Chipping: this involves shredding of tyres into first bigger sizes and finally into particles of 20 - 30mm.

The classification of scrap rubber tyre in most of the researches has been performed (Topçu et al., 2012). The broad categories of discarded tyre rubber that have been considered in most researches include chipped, crumb and ground rubber obtained in the methods described below. Chopped rubber particles will be adopted in this research as an alternative to the natural course aggregates as there were available to extract.

1. Shredded or chipped rubber to replace the gravel. To produce this rubber, it is needed to shred the tyre in two stages. By the end of stage one, the rubber will have a length of 300-430 mm long and width of 100-230 mm wide. In the second stage, its dimension changes to100-150 mm by cutting. If shredding is further continued, particles of about 13-76 mm in dimensions are produced and these are called ”shredded particles”.
2. Crumb rubber that replaces the sand is manufactured by special mills in which big rubber pieces are reduced to smaller particles. In this procedure, different sizes of rubber particles may be produced depending on the kind of mills used and the temperature generated. In a simple method, particles are made with a high irregularity

in the range of 0.425-4.75 mm. During the recycling process, steel and tyre cord (fluff) is removed leaving tyre rubber with a granular consistency. Continued processing with a granulator and/or cracker mill, possibly with the aid of cryogenics or mechanical means, reduces the size of the particles further. The particles are sized and classified based on various criteria including colour (black only or black and white).

Crumb rubber is non-degradable either above or below the water line under normal conditions. This weighs only 320-640 kg/m^3, (Najim and Hall, 2010):

Because of their low density, crumb rubber can be used to build structural elements where the main force is impact force. Plastic cracking and rigidity of the concrete structures can be reduced by adding crumb rubber

3. Ground rubber that may replace cement is dependent upon the equipment used for size reduction. The processed used tyres are typically subjected to two stages of magnetic separation and screening. Various size fractions of rubber are recovered in more complex procedures. In the micro-milling process, the particles made are in the range of 0.075-0.475 mm. Scrap tyre rubber powder can be obtained from tyres through two principal processes: (a) ambient, which is a method in which scrap tyre rubber is ground or processed at or above ordinary room temperature and (b) cryogenic, a process that uses liquid nitrogen to freeze the scrap tyre rubber until it becomes brittle and then uses a hammer mill to shatter the frozen rubber into smooth particles.

Present scope of this investigation is the study of rubber waste generated from the discarded tyres and possibility of using waste tyre rubber as partial replacement of coarse aggregate in order to produce rubberized concrete that can be used in load bearing elements. The purpose of the investigation is to see the effect on properties of concrete with different proportions of scrap tyre rubber chips. The methodology is to replace different proportions of the coarse aggregate with coarse rubber chips and test the properties of fresh and hardened concrete.

The development of new construction materials using recycled tyre rubber is important to both the construction and the waste recycling industries.

This research will present a detailed review about waste and recycled tyre rubber, waste management options, and research published on the effect of recycled rubber on the fresh and hardened properties of concrete. The effect of recycled tyre rubber on bulk density, air content, workability, and compressive strength, splitting tensile strength, impact resistance, residual strength and permeability is discussed in this dissertation.

1.3 Composition of Tyres

Tyres contain so many different compounds and ingredients because they are engineering miracles, expected to handle the tortures of heat and cold, high speed, abrasive conditions, and often not enough air pressure. They are expected to perform for tens of thousands of miles and retain their essential properties despite horrendous driving habits and sometimes poorly maintained or built roads (Angelin et al., 2017). Table 1.1 shows the composition of a typical rubber tyre.

TABLE 1.1: Summary of the Composition of a Typical Tyre (Source: The Waste & Resources Action Program, 2006)

Ingredients	% Composition
Rubber/Elastomers	45- 47
Carbon Black	21.5- 22
Metal	12- 25
Textile	0- 10
Zinc Oxide	1- 2
Sulphur	1
Additives	5- 7.5
Carbon-based materials, total	67- 76

1.4 Composition of Concrete

Concrete is a composite material composed of coarse granular material (the aggregate or filler) embedded in a hard matrix of material (the cement or binder) that fills the space between the aggregate particles and glues them together, (Mindess, 2013).

Good quality concrete is a very durable material and should remain maintenance free for many years when it has been properly designed for the service conditions and properly placed. Proper use of the structure for the intended function can have a significant role.

1.5 Constituents of Concrete

Concrete is a composite material composed of fine and coarse aggregate bonded together with a fluid cement (cement paste) that hardens (cures) over time.

1.6 Rubcrete Concrete

The concrete mixed with waste rubber added in different volume proportions is called rubcrete concrete (Eldin and Seouci, 1993a). Partially replacing the coarse or fine aggregate of concrete with some quantity of small waste tyre in the form of crumb and chipped can improve qualities such as low unit weight, high resistance to abrasion, absorbing shocks and vibrations, high ductility and brittleness (Eldin and Seouci, 1993b). .

1.7 Statement of the Problem

The mechanical behavior of the prepared concrete was determined experimentally by reinforcing different weight percentages of tyre rubber particulates.

Structural properties such as splitting tensile, compressive, bonding and dynamic properties such as impact value were determined. Physical tests conducted included the slump test, permeability test, water absorption, density test and the behavior of rubcrete concrete at elevated temperature.

Concrete has been a major construction material for centuries. Yet concrete construction so far is mainly based on the use of natural resources. It is very essential to have a look at the different alternatives to natural resources.

This study is aimed at evaluating the use of waste tyre as a partial replacement of coarse aggregates so as to mitigate the environmental issues due to waste rubber tyre and to produce a light-weight and low cost concrete mix. What is needed is an aggregate comprising a material of low commercial value which can be easily used together with natural aggregates to provide a concrete of either equivalent or improved physical properties. Thus the question of using rubber tyre as a partial replacement of aggregates which is more economical and readily available comes into mind.

This research focuses on the use of rubber aggregates of 19mm-20mm sizes to replace natural coarse aggregates used as recycled aggregate in concrete production, with respect to mechanical performance. It addresses the important environmental problem of how to dispose of used tyres. It also sheds light on several properties for which there were insufficient/contradictory data.

1.8 Research Significance

The significance of this research work can be considered on both economical as well as the environmental aspects. In terms of the economic aspects, this study inteded to reduce the cost of concrete production by reducing the quantity of aggregates required in a particular mix. In terms of the environmental aspect, this study aimed at reducing the amount of waste tyre rubber available in order to conserve the environment.

1.9 Research Objectives

The main objective of this research was to study the compressive and splitting tensile strengths of rubberized concrete with respect to other properties of normal concrete such as toughness and ductility and its behaviour at elevated temperatures using different mixes.

The specific objectives are:

1. To establish material properties of rubber concrete, through laboratory testing and determine through laboratory studies where rubberized concrete can be used in the Zambian construction industry
2. To provide laboratory test information that could be used in drafting a practical rubber concrete mix specification for structural and non-structural or low-loading usage in Zambia.
3. Observe and compare crack patterns, residual strain and behavior at elevated temperatures and harsh environments of normal and rubberized concrete.

1.10 Research Questions

i. Are there any unique properties, mechanical or structural that rubberized concrete offers compared to normal concrete?

ii. What cost-effective methods of treatment for rubber can be used to enhance its bonding properties with cement to improve its performance in concrete?

iii. Can rubberized concrete be of benefit to the Zambian construction industry with regards to the current economic status and demand for construction?

iv. What are the crack patterns and behavior of normal and rubberized concrete at elevated temperatures and harsh environments?

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of literature pertaining to the use of rubber aggregates generated from used tyres as a partial substitute for natural coarse aggregates in concrete.

2.2 General overview

Tyre recycling is the process of recycling vehicles tyres that are no longer suitable for use on vehicles due to wear or irreparable damage. Recently, large amounts of waste tyres are being generated following the development of the automotive industry. In the case of landfill or incineration of waste tyres, environmental pollution and economic problems are caused. As one of the ways to prevent these problems, waste tyres are used to compensate for natural materials in manufacturing concrete.

Several publications have been published in concern with the use of rubber from scrap tyres in Portland Cement Concrete (PCC) mixtures for construction applications.

2.3 Review on mechanical properties of rubberized concrete

Eldin and Seouci (1993a) in their paper observed that accumulations of worn- out automobile tyres create fire and health hazards. As a possible solution to the problem of scrap- tyre disposal, he conducted an experimental study to examine the potential of using tyre chips and crumb rubber as aggregate in Portland- cement concrete. They examined the strength and toughness properties of concrete in which different amounts of rubber- tyre particles between 10 and 50 per cent of several sizes were used as aggregate. They observed that the concrete mixtures exhibited lower compressive and splitting- tensile strength than did normal concrete.

However, these mixtures did not demonstrate brittle failure, but rather a ductile, plastic failure, and had the ability to absorb a large amount of plastic energy under compressive and tensile loads. A mathematical model was used to describe the effects of rubber aggregate on the compressive and tensile strength reduction of concrete.

Goulias and Ali (1998) studied the effect of rubber strips on concrete properties. They investigated the effect of rubber strips on compressive and tensile strength of concrete.

The results showed that concrete specimens with rubber strips from scrap tyres exhibit higher compressive strength and stiffness than the specimens with fine and shredded rubber aggregates.

Kaloush et al. (2014) tested various properties of concrete and compared them to concrete with rubber aggregates. They observed that as the rubber content increased, the tensile strength decreased, but the strain at failure increased. Higher tensile strain at failure is indicative of more ductile mixes. It was established that rubberized concrete is more resistant to thermal changes.

Kamil et al. (2005) presented results obtained over 5 years from several rubcrete concrete laboratory tests. Test results included compressive, flexural, and indirect tensile strength tests, thermal coefficient of expansion and microscopic matrix analysis. The results indicated that the unit weight of the crumb rubber concrete decreased approximately 96 kg/m3 for every 23kg of crumb rubber added. The compressive and flexural strength also decreased as the rubber content increased. The laboratory test results also showed that as the rubber content increased, the tensile strength decreased, but the strain at failure increased, an indication of more ductile (energy absorbent) mixes. In all the mechanical tests, the crumb rubber concrete specimens remained intact after failure compared to a conventional concrete mix. The study recommended the use of crumb rubber concrete where high strength concrete is not required.

Kumaran et al. (2008) in their study concluded that the reduction of compressive strength and tensile strength can be reduced by adding some superplasticizers and industrial wastes as partial replacement of cement will definitely increase the strength of waste tyre rubber modified concrete. They concluded that further study will be needed to increase performance against fire.

Zheng et al. (2008) worked on rubberized concrete and replaced the coarse aggregate in normal concrete with ground and crushed scrap tyre in various volume ratios. Ground rubber powder and the crushed tyre chip particles ranging in size from about 15 mm to 4 mm were used. The effect of rubber type and rubber content on strength, modulus of elasticity were tested and studied. The stress-strain hysteresis loops were obtained by loading, unloading and reloading of specimens. Brittleness index values were calculated by hysteresis loops. Studies showed that compressive strength and modulus of elasticity of crushed rubberized concrete were lower than the ground rubberized concrete.

Batayneh et al. (2008) presented test results on using rubber in concrete production. The test results showed that even though the compressive strength is reduced when using the shredded tyres, they can meet the strength requirements of lightweight concrete. In addition, test results and observations indicated that the addition of chipped rubber to the mix had a limited effect toward reducing workability of the mixtures. The mechanical test results demonstrated that the tested specimens of the chipped rubber concrete remained relatively intact after failure compared to the conventional concrete specimens. It was also concluded that rubber modified concrete would contribute to the disposal of the non-decaying scrap tyres.

Selvakumar and Venkatakrishnaiah (2015) in their research paper concluded that the compressive strength of chipped rubber concrete with 5 per cent replacement was 38.66 N/mm2; higher than the strength of normal concrete 36.73N/mm2 on 28th day. The compressive strength of rubberized concrete with 10 per cent replacement, gave acceptable strength of 33.47 N/mm2. In splitting tensile strength, the strength of rubberized concrete was lower than the strength of normal concrete. In the flexural strength test conducted on rubberized concrete, it showed a decrease in strength when compared to the strength of normal concrete. From the test results, it was found that the rubber possesses less bonding ability which had affected the strength of the concrete.

The first publications by Eldin and Senouci (1993a) on the use of rubber from old tyres in concrete date from the early 1990s. Their aim was to investigate the mechanical properties of concrete containing used tyre rubber aggregate. Successive publications extended and consolidated knowledge on the workability, density, compressive strength, tensile strength and modulus of elasticity of these composites. New questions related to the incorporation of rubber have been investigated more recently: the influence of the geometry of rubber aggregate of various shapes; the influence of the surface treatment of the rubber granulate; the response to dynamic actions (fatigue, dynamic modulus of elasticity, impacts); analysis in terms of durability, thermal conductivity and other aspects. The results of previous studies leave no room for doubt that as natural aggregate (NA) is increasingly replaced with used tyre rubber aggregate (TA) workability goes down.

Another research was done by Mangal et al (2013) for the replacement of coarse aggregate with rubber and studied the compressive strength, flexural strength and split tensile strength by using the different proportions as 15 per cent, 25 per cent and 35 per cent for C25 concrete.

He concluded that rubberized concrete is affordable to withstand more pressure and cost-effective, can withstand impact and temperature when compared with conventional concrete. The compressive strength of rubberized concrete was approximately 42 per cent lower than the conventional concrete and split tensile strength was higher than the conventional concrete by approximately 35 per cent.

Hameed and Shashikala, (2016), had done an experimental investigation on crumb rubber by replacing 15 per cent volume fraction of fine aggregate to find the fatigue failure load and impact resistance. Achieved design strength is of 50 MPa and 55 MPa. Test results indicated that there was a reduction in compressive strength and modulus values. Impact resistance and fatigue failure were high for rubber concrete as compared with ordinary high strength concrete. As compared to pre-stressed concrete sleeper, the impact strength of crumb rubber concrete showed an increase of about 60 per cent.

Sofi (2016) tested for the compressive strength, flexural tensile strength, water penetration and water absorption of rubber concrete when the natural aggregate was partially replaced with rubber. Compressive and flexural strength values gradually decreased in the presence of waste tyre rubber in concrete. Abrasion resistance was observed better in rubberized concrete in comparison with the conventional concrete.

Scrap tyre rubber was used in the preparation of concrete by Siddiqui (2014). Conventional coarse aggregate replaced by scrap rubber with the percentages from 0 to 15 per cent also confirmed the decrease in compressive strength for increasing rubber content.

An analysis was done Medina et al. (2017), to check the mechanical and thermal properties of sustainable incorporating concrete crumb rubber. Usually, the compressive strength and bending strengths were less than 20 per cent when compared to conventional concrete. The toughness increased. Moreover, when rubber concrete was exposed to impact in rough surface design, the resistance of concrete was greater. Results indicated that the rubberized concrete could be used as pre-cast concrete because of the considerable bending strength and the lower thermal conductivity.

According to Eldin (1993b), tests conducted on rubberized Concrete behaviour, using tyre chips and crumb rubber as an aggregate substitute of sizes 38.25 mm and 19 mm exhibited a reduction in compressive strength by 85 per cent and tensile splitting strength by 50 per cent but showed the ability to absorb a large amount of plastic energy under tensile and compressive loads.

Biel and Lee (2007) used recycled tyre rubber in concrete mixes made with magnesium oxychloride cement, where the aggregate was replaced by crumb rubber up to 25 per cent by volume. The results of compressive and tensile strength tests indicated that there is better bonding when magnesium oxychloride cement is used. The researchers discovered that structural applications could be possible if the rubber content is limited to 17 per cent by volume of the aggregate.

Kumaran et al. (2008) concluded that recycling technology for concrete has significantly developed in recent years, making the material sufficiently recyclable. It was evident that from the above discussion, the reduction of compressive and tensile strength can be increased by adding some superplasticizers and industrial wastes as partial replacement of cement will definitely increase the strength of waste tire rubber modified concrete. Many studies revealed that there would be an increase in strength enhancements as well as environmental advantages. The future industries using waste tyre rubber could provide one of the environmentally friendly and economically viable products. They suggested that though problems remain regarding the cost of production and awareness among the society, the wastes can be converted into a valuable product but further research is needed to increase performance against fire.

Mavroulidou and Figueiredo (2018) observed that from their experimental study and literature review, and despite the fact that they observed lower values of the mechanical properties of concrete, there is a potentially large market for concrete products in which inclusion of rubber aggregate would be feasible. These can also include non-primary structural applications of medium to low strength requirements, benefiting from other features of this type of concrete. Even if rubber tyre aggregate was used at relatively low percentages in concrete, the amount of waste tyre rubber could be greatly reduced due to the very large market for concrete products worldwide. Therefore the use of discarded tyre rubber aggregates in concrete shows promise for developing an additional route for used tyres.

Eshmaiel et al. (2005) investigated the usage of tyre rubber as an aggregate and as filler in concrete. Chipped rubber was used for coarse aggregate replacement and powdered rubber was used for cement replacement in concrete in 5 per cent, 7.5 per cent and 10 per cent by weight. It was observed that, up to 5 per cent replacement, the mechanical properties were similar to the control mix and beyond that, there were considerable differences.

Al-Mutairi et al. (2010) explained that the use of 5 per cent silica fumes in rubberized concrete helped to minimize the loss in compressive strength at elevated temperatures. At an elevated temperature of above 400 C, the compressive strength was similar to that of control concrete.

Guleria and Dutta (2002) explained that the unconfined compressive strength of rubberized concrete can be increased by treating the tyre chips with carbon tetrachloride and sodium hydroxide.

Mavroulido and Figueiredo (2018) conducted a study ‘discarded tire rubber as a concrete aggregate: a possible outlet for used tyres’. It can be concluded that despite the observed lower values of the mechanical properties of concrete, there is a potentially large market for concrete products in which the inclusion of rubber aggregate would be feasible. These can also include nonprime structural applications of the medium to low strength requirements, benefiting from other features of this type of concrete. Even if the rubber tyre aggregate was used at relatively low percentages in concrete, the amount of waste tyre rubber could be greatly reduced due to the very large market for concrete products worldwide. Therefore the use of discarded tyre rubber aggregates in concrete shows promise for developing an additional route for used tyre rubber.

Except for isolated references to a slight improvement in tensile strength as the tyre aggregate content increased, such as in the flexural tests reported by Cairns et al. (2013), most studies suggest that tensile strength decreases with the replacement of natural aggregates.

Even though only two studies can be referenced, that of Topçu (2012) and Khatib and Bayomy (1999), their results do indicate that tyre aggregates size has no influence on tensile strength. It can therefore be stated that the use of tyre aggregates of different sizes influences tensile strength in a different way from its effect on compressive strength.

2.4 Review on physical properties of rubberized concrete

The effect of adding two kinds of crumb rubber and chipped rubber were studied by Khatib and Bayomy (1999). They prepared three groups of concrete mixtures: in group A, crumb rubber was used to replace fine aggregate, while in group B, chipped rubber was used to replace coarse aggregate, and in group C, both types of rubber were used in equal volumes. All the three groups had eight different rubber contents varying between 5 and 100 per cent. It was noticed that there was a decrease in slump with an increase in the rubber content; admixtures made with fine crumb rubber were more workable than those with coarse tyre chips or those with a combination of tyre chips and crumb rubber.

Khatib and Bayomy (1999) used fine grounded and shredded rubber as a percentage of the aggregates to prepare rubberized concrete mixtures. They found that the efficiency of rubberized concrete mixtures depends on the percentage of rubber in the concrete mixture. They reported that there is a decrease in slump with increase in rubber content as a percentage of total aggregate volume. They further noted that at rubber contents of 40 per cent, slump was almost zero. It was also observed that concrete mixtures made with fine crumb rubber were more workable than those with coarse tyre chips or a combination of tyre chips and crumb rubber. The results showed that the compressive strength decreased as the percentage of rubber increased. The coarse rubber aggregates in concrete lowered the compressive strength more than the addition of fine crumb rubber. They recommended that the percentage of rubber should not be more than 20 per cent of the aggregate weight in the concrete mixture.

Albano et al. (2005) reported results on the influence of scrap rubber addition to portland concrete composite. The results for destructive and non-destructive testing showed that, when weight proportion increased and particle size of scrap rubber decreased, flow and density of the concrete composite in the fresh state decreased, as well as compressive strength and splitting tensile strength in the dry state.

Ganjian et al. (2009) investigated the performance of concrete mixtures incorporating 5.0 per cent, 7.5 per cent and 10.0 per cent of discarded tyre rubber as aggregate and cement replacements. Different percentages by weight of chipped rubber were replaced for coarse aggregates. The results showed that with up to 5 per cent replacement, no major changes on concrete characteristics would occur, however, with further increase in replacement ratios considerable changes were observed.

Aiello and Leuzzi (2010) investigated the properties of various concrete mixtures at fresh and hardened state, obtained by partial substitution of coarse and fine aggregate with different volume percentages of waste tyres rubber particles, having the same dimensions of the replaced aggregate. The results showed a lower unit weight compared to plain concrete and good workability. The results of compressive and flexural tests indicated a larger reduction of mechanical properties of rubber concrete when replacing coarse aggregate rather than the fine aggregate.

Antil (2014) observed that chipped rubber concrete can be used where lightweight mixes are required. Slump only reduced by 1.08 per cent up to 10 per cent use of rubber. Furthermore, he noted that increased content of rubber increased its toughness.

Kotresh and Belachew (2016) concluded that rubberized concrete strength can be improved by improving bond properties of rubber aggregates. They added that tyre recycling factories should supply quality rubber aggregates in 20-10 mm, 10 - 4.75 mm and 4.75 mm downsizes to be used as cement concrete aggregates. They suggested that the light unit weight qualities of rubberized concrete may be suitable for the architectural application, false facades, stone baking, interior construction, in building as an earthquake shock wave absorber, where vibration damping is required such as in foundation pads for machinery, railway station, where resistance to impact or explosion is required, such as in jersey barrier, railway buffers, bunkers and for trench filling. One of the possible applications of rubcrete maybe its application in the rendering of rooftop surfaces for insulation and waterproofing. With proper mix design, a 20 mm thick rendering on rooftop surfaces may be done with 4.75 mm down rubber aggregate.

Shah et al. (2014) did a study on the thermal properties of rubberized concrete in 2014. The testing was done by incorporating 5, 10 and 15 per cent of scrap rubber as volume replacement for coarse aggregate. Thermal behaviour for concrete was examined using the hotbox technique. No remarkable changes in concrete properties up to 5 per cent replacement occurred. Beyond 5 per cent substitution, concrete properties changed appreciably. Compressive strength, flexure strength, workability, stiffness and unit weight of rubberized concrete decreased as rubber content increased. While impact resistance, air content and water absorption of rubberized concrete increased with increase in rubber content. Thermal performance of concrete containing rubber aggregate was improved, and promising results were obtained. It was concluded that rubberized concrete could help in slabs to improve energy efficiency of the building unit.

Yang et al. (2010) conducted a study in which three groups of singly-sized rubber particle samples (3 mm, 0.5 mm and 0.3 mm) and one sample of continuous size grading were used to replace 20 per cent of the natural fine aggregate by volume. It was observed that the rubber particle size affects the concrete's workability and water permeability to a greater extent than the fresh density and strength. Concrete with rubber particles of larger size tends to have a higher workability and fresh density than that with smaller particle sizes. However, the rubber aggregates with smaller or continuously graded particle sizes are shown to have higher strengths and lower water permeability.

More et al. (2015) concluded that the addition of recycled chipped rubber aggregates into normal concrete mix leads to a decrease in workability for the various mix samples. Flexural strength of concrete decreases about 40 per cent when 3 per cent of stones are replaced by chipped rubber aggregates and a further decrease in strength with an increase of the percentage of the chipped rubber aggregates. Split tensile strength of concrete decreases about 30 per cent corresponding to 3 per cent stones replaced by chipped rubber and further decreases the strength with an increase in the percentage of chipped rubber aggregates. They added that one of the reasons that splitting tensile strength of rubberized concrete is lower than conventional concrete is because the bond strength between cement paste and rubber tyre aggregates is poor. The rubberized concrete can be used in non-load-bearing members, i.e., lightweight concrete walls, other light architectural units, thus concrete containing fine rubber aggregates could give a viable alternative to where strength is not a prime requirement. Their experimental results of the study showed that it is possible to use recycled rubber tyre in terms of aggregates in concrete construction as partial replacement to natural coarse aggregates.

Nehdi and Khan (2015) represented the overview of engineering properties and potential applications of cementitious composites containing recycled tyre rubber. They reported about the effect of using rubber in concrete on density (unit weight) and on air content.

Crumb rubber of different sizes was used in the concrete. Due to the low specific gravity of rubber, the unit weight of rubcrete mixtures decreased as the percentage of rubber increased.

The studies of Eldin and Senouci (1993b) concluded that as the size of tire aggregate increases the loss of workability is greater. When fine and coarse aggregates are replaced simultaneously the results are in between those yielded when only fines or coarse are replaced.

Khallo et al. (2008), Guneyisi et al. (2014) and Biel and Lee (2017) noted that the reduced stiffness of rubber in relation to the other materials made a minor contribution to global strength. Consequently, the rubber particles generated high stresses in their periphery which led to cracking which, when widespread, caused a premature rupture of the specimens.

Topçu (2012) explained this phenomenon based on the high tensile stresses in the direction perpendicular to loading, and Turatsinze and Garros (2013) also mentioned the high Poisson coefficient of rubber as a cause of the significant strength loss. Giacobbe (2014), like some of the previous researchers, equalled the space occupied by tyre aggregate to voids. The author backs this comparison with the 1924 Abrams theory that predicts the concrete's compressive strength based on the w/c ratio adopted. The author proposed changing the w/c ratio to the (water + rubber volume)/cement ratio for tyre aggregate and obtained strong correlations with the Abrams model. Conceptually and for comparison purposes, it was considered that excess water from the cement hydration process is replaced by voids when it evaporates and it was found that the rubber volume had similar behaviour to voids. Another widely mentioned reason why the compressive strength of tyre aggregate is lower is the weak adherence between the rubber particles and the binder (cement). This is considered so important that these researchers led their studies with the aim of improving this conditioning factor.

Cairns et al. (2013) tried to envelop tyre aggregate in cement in advance to change the transition between it and the cement matrix. The authors concluded that there was a significant improvement of compressive strength by 10 per cent addition of rubber aggregates. This trend was maintained regardless of the w/c ratio or the different sizes of coarse tire aggregate used.

Guneyisi et al. (2014) tried to understand the consequences of replacing cement with silica fume and whether this variation depended on the w/c ratio adopted. The authors observed that silica fume had a favourable effect on cryogenic tyre aggregate's strength, and this was greater in the w/c ratio. Furthermore, they found that the strength increment was smaller for higher silica fume content. The authors believed that silica fume helps the adherence between cryogenic tyre aggregate and the binder because of the small size of the rubber particles.

The researchers, Guneyisi et al. (2014) also presented the mechanical properties of rubberized concrete. The test results showed a reduction in compressive strength and modulus of elasticity with the increase in rubber content from 0 per cent to 50 per cent.

According to Li et al. (1998), of the various treatments of rubber particles, the alkaline solution of sodium hydroxide (NaOH) stands out as the one that offered the best results. In their conclusion, they stated that it made the surface of the rubber particles adhesive and made binding easy with the cement paste.

Ling et al. (2005) investigated the potential of using crumb rubber as a substitute for coarse sand in the production of the concrete paving block. Crumb rubber was treated by using SBR latex. It was concluded that there was a systematic reduction in the density, compressive strength with the increase in rubber content.

Hasshimghedan and Dinamukheefhamza (2006) studied the compressive strength and thermal conductivity of rubberized concrete and compared with the traditional concrete. In this study, rubber particles were treated by using Silica Fume of 0.1 per cent of water as a coupling agent. The test results showed that by adding rubber particles to the concrete, lightweight concrete was obtained and its compressive strength was reduced.

Ganesan et al. (2013) investigated the flexural fatigue behaviour of self-compacting rubberized concrete (SCRC) with and without steel fibres. With the addition of scrap rubber to self-compacting concrete (SCC), the flexural fatigue strength was increased around 15 per cent and with the addition of steel fibres into SCRC, the fatigue strength was increased to 25-50 per cent.

Concrete mass density can be reduced to as low as 1750 kg/m^3 (Eldin and Senouci, 1993a; Khatib and Bayomy, (1999) and Li et al. 1998). Moreover, concrete mixed with rubber particles up to about 30 per cent of the cement weight was found to improve non-structural crack resistance, shock wave absorption and resistance to acid, offering lower heat conductivity and noise level reduction. In addition, rubberized concrete proved to be lighter in weight with its density reduced compared to conventional concrete (Topcu, 2012). Some authors also discussed the time-dependent properties of rubcrete, which may be critical in some cases.

A study by Mier et al. (1997), for example, revealed that the significant difference in Poisson‘s ratio of rubber particles and the cement-matrix encourages premature cracking.

However, Turatsinze et al. (2013) indicated that the higher the content of rubber shreds, the smaller the crack length and width due to shrinkage, and the onset time of cracking was more delayed. It was further indicated by Hernandez-Olivares et al. (2002) that the variations of the elastic modules experimentally obtained either under static or dynamic load increase with age. Moreover, Hernandez-Olivares et al. (2002) referred to the results of an experimental traffic road built in a residential area in *Gudino* (Spain), made of concrete-filled with small volumetric fractions of crumbed tyre rubber. After three years of heavy use (cars and trucks), it still showed a very good performance. Thus, despite some well-known drawbacks, the results of many authors demonstrated that rubberized concrete exhibited some interesting properties, such as their straining capacity and toughness that encourages its use as a construction material.

Schimizze et al. (2017) developed two rubberized concrete mixes using fine rubber granules in one mix and coarse rubber granules in the second. While these two mixes were not optimized and their design parameters were selected arbitrarily, their results indicated a reduction in compressive strength of about 50 per cent with respect to the control mixture. The elastic modulus of the mix containing coarse rubber granular was reduced to about 72 per cent of that of the control mixture, whereas the mix containing the fine rubber granular showed a reduction in the elastic modulus to about 47 per cent of that of the control mixture. The reduction in elastic modulus indicated higher flexibility, which may be viewed as a positive gain in Rubberized Portland Cement Concrete (RPCC) mixtures used as stabilized base layers in flexible pavements.

TopÇu (2012) investigated the effect of particle size and content of tyre rubbers on the mechanical properties of concrete. The researcher found that, although the strength was reduced, the plastic capacity was enhanced significantly by 20 per cent.

Zaher et al. (2018) concluded that RPCC mixtures can be made using shredded and ground tyre in partial replacement by volume of coarse aggregates and fine aggregates. Based on the workability, an upper level of 50 per cent of the total aggregate volume may be used.

Strength data developed in their investigation (compressive and flexural) indicated a systematic reduction in the strength with the increase of rubber content.

From a practical viewpoint, rubber content should not exceed 20 per cent of the aggregate volume due to severe reduction in strength. Once the aggregate matrix contains non-traditional components such as polymer additives, fibres, iron slag, and other waste materials, special provisions would be required to design and produce these modified mixes. At present, there are no such guidelines on how to include scrap tyre particles in PCC mixtures.

Serge et al. (2018) used saturated NaOH solution to treat waste tyre rubber powders. They found that NaOH surface treatment increased rubber/cement paste interfacial bonding strength and resulted in an improvement in strength and toughness in waste tyre powder modified cement mortar.

Garrick et al. (2018) showed the analysis of waste tyre modified concrete used 15 per cent by volume of coarse aggregate when replaced by waste tyre as a two phase material; as tyre fibre and chips dispersed in concrete mix. The result is that there was an increase in toughness, plastic deformation, impact resistance and cracking resistance. But the strength and stiffness of the rubberized sample were reduced. The control concrete disintegrated when peak load was reached while the rubberized concrete had considerable deformation without disintegration due to the bridging caused by the tyres. The stress concentration in the rubber fibre modified concrete was smaller than that in the rubber chip modified concrete. This means the rubber fibre modified concrete can bear a higher load than the rubber chip modified concrete before the concrete matrix breaks.

Kamil et al. (2005) analyzed the properties of crumb rubber concrete. The unit weight of the crumb rubber concrete mix decreased by approximately 96 kg/m^3 for every 22.68 kilograms of crumb rubber added. The compressive strength decreased as the rubber content increased. Part of the strength reduction was attributed to the entrapped air, which increased with the rubber content. Investigative efforts showed that the strength reduction could be substantially reduced by adding a de-airing agent into the mixing truck just prior to the placement of the concrete.

Li et al. (1998) conducted an investigation on chips and fibres. The tyre surfaces were treated by saturated NaOH solution and physical anchorage by drilling a hole at the centre of the chips were also investigated and they concluded that fibres performed better than chips. NaOH surface treatment did not work for larger sized tyre chips, and introducing some physical anchorage had some positive effects.

Further efforts were geared toward the enlarging of the hole size and ensuring that the hole is through the chip thickness entirely. Fibre length restricted to less than 50 mm to avoid entangle: steel belt wires provided positive effects on increasing the strength of concrete.

Senthil et al. (2012) investigated the behaviour of Waste Tire Rubber Aggregate Concrete (WTRAC) cylindrical specimen under a drop-weight impact testing method.

It was concluded that although WTRAC mixture generally reduced compressive strength at the same time resulted in lower density, it resulted in higher toughness, higher impact resistance and enhanced ductility compared with conventional concrete.

Gintautasskripkiūnas et al. (2015) proposed that rubber waste additives reduced both static and dynamic modulus of elasticity. Strains of the concrete with the same compressive strength with rubber waste from used tyres (3.2 per cent from aggregate by mass) deformations were 56 to 63 per cent higher after the static loading, while set deformations after the unloading was 219 to 360 per cent higher than for the none rubberized concrete. Cyclic loading of 20 cycles had no influence on the prismatic compressive strength of both concrete with and without rubber waste (3.2 per cent from aggregate by mass). The ultimate strains on concrete failure load were 36 to 47 per cent higher for concrete with tyre rubber waste additive.

Sukontasukkulin et al. (2018) published a paper on crumb rubber concrete. In their study, they decided to replace the coarse and fine aggregate in concrete for moulding pedestrian blocks. They believe that the concrete acting as a binder mixed with crumb rubber can make the concrete blocks more flexible and provides softness to the surface. In this study, they saw that the pedestrian blocks with crumb rubber performed quite well in skid and abrasion resistance. In this study, the process of making the concrete was found economical due to the simplicity of the manufacturing process.

Yasin (2017) observed that based on the results of tests, concrete containing crumb tyre particles as aggregates was still not recommended for structural uses because of the low compressive strength comparing with the normal concrete containing natural rock aggregates. During the tests, it was noted that as the percentage amount of shredded tyres increased, the amount of energy required for casting specimens increased substantially, because of the reduction of workability in the concrete. On the other hand, it was observed that the pieces of concrete cubes tested tended not to disintegrate resulting from links provided by the rubber particles, which means that the usage of shredded tyres as aggregates in concrete may produce a much more tough concrete and may reduce the cracks in the ageing concrete. Although synthetic lightweight aggregates specially shredded tyres are more expensive than normal-weight or natural rock aggregates, the increased strength-to-weight ratio offers sufficient overall saving in materials, through the reduction of dead load to more than offset the higher aggregate cost per cubic meter of the concrete. Lower total loads mean reduced supporting sections and foundations, and less reinforcement.

Mehmet and Erhan (2011) investigated the strength development and chloride penetration of rubberized concretes. They pointed out that the unit weight of rubberized concrete decreased with an increasing percentage of rubber added.

There was a reduction in a unit weight of up to 18 per cent. The strength development patterns for plain and rubberized concrete between 3 and 7 days were relatively high, the slower rate was noticed between 7 and 28 days, and the relatively slower rate was observed between 28 and 90 days. The compressive strength reduced systematically as the percentage of rubber was increased irrespective of the w/c ratio and curing period. There was a systematic increase in the depth of chloride penetration for an increase in the rubber content, with and without silica fumes.

Arin and Nurhayat 2007) observed a decrease in the water absorption upon an increase in the size of the rubber particles in the concrete.

Miguel and Jorge (2013) reported that the water absorption (by the process of immersion) of rubberized concrete increases as the percentage of rubber and the particle size of replaced rubber increases. When the capillary water absorption test was done, the results were not conclusive.

Azevedo et al. (2012) explained that it is possible to maintain a low capillary action even at the rubber content of 15 per cent in concrete.

Toutanji (1996) studied the use of rubber tyre particles in concrete to replace mineral aggregate. Cement concrete investigated the effect of replacement of mineral coarse aggregate by rubber tyre aggregate. Shredded rubber tyres used had a maximum size of 12.7mm and a specific gravity of about 0.61. The incorporation of these rubber tyre chips in concrete exhibited a reduction in compressive and flexural strength. The specimens which contained rubber tyre aggregate exhibited ductile failure and underwent significant displacement before fracture. The toughness of flexural specimens was evaluated for plain and rubber tyre concrete specimens. The test revealed that high toughness was displayed by specimens containing rubber tyre chips as compared to control specimens.

Khatib and Bayomy (1999) developed a "Rubberized Portland cement concrete" to conduct an experimental program in which two types of rubber fine crumb rubber and coarse tyre chips were used in Portland Cement Concrete (PCC) mixtures.

Rubberized PCC mixes were developed by partially replacing the aggregate with rubber and tested for compressive and flexural strength in accordance with ASTM C150M, of standards on Standard Specification for Concrete. Tyre chips were elongated particles that ranged in size from about 10 to 50mm. Results showed that rubberized PCC mixes can be made and are workable to a certain degree with the tyre rubber content being as much as 57 per cent of the total aggregate volume. However, strength results showed that large reductions in strength would prohibit the use of such high rubber constant. It was suggested that rubber contents should not exceed 20 per cent of the total aggregate volume.

Al-Bakari et al. (2016) conducted a comparison of rubber as aggregate and rubber as filler in concrete. This research attempted to use rubber waste replacement of coarse aggregates to produce early age concrete. It carried out two different types of concrete which are rubberized concrete and rubber filler in concrete. In rubberized concrete, rubber was used to replace coarse aggregates and sand as fine aggregate. Coarse aggregate usually gravel or crushed stone and crumb rubber as filler in concrete. The compressive strength was reduced in rubberized concrete for several reasons including the inclusion of the waste tyres rubber aggregate acted like voids in the matrix. This is because of the weak bond between the waste tyres rubber aggregate and concrete matrix. With the increase in void content of the concrete, there will be a corresponding decrease in strength. Portland cement concrete strength is dependent greatly on the coarse aggregate, density, size and hardness. Since the aggregates are partially replaced by the rubber, the reduction in strength is only natural.

There are considerably fewer data available in the literature with respect to the modulus of elasticity. It is generally agreed that the modulus of elasticity decreases with higher aggregate replacement percentage, no matter whether the fine or coarse fraction is replaced. This trend can be easily explained by the strong correlation between the concrete's modulus of elasticity and that of the aggregates used. Thus, since the stiffness of tire aggregates is clearly lower than that of natural aggregates, it is assumed that the modulus of elasticity of the concrete is lower, and the more so the greater the replacement.

The results from the study by Guneyisi et al. (2014) showed that for equal replacement ratios, a lower w/c ratio leads to higher values of the modulus of elasticity. The authors noted that the use of silica fume slightly increases the modulus of elasticity but the benefit is less than for compressive or tensile strengths.

Besides confirming an increase in modulus of elasticity with the reduction of the w/c ratio Wong and Ting, (2009) reported that the use of tyre aggregate as fibre improves this property in comparison with its use as granulate.

Similar observations were made by Khatib and Bayomy (1999). Topçu (2012) opted to evaluate separately the recoverable (elastic) and non-recoverable (plastic) energy of deformation through the strain/stress curve. The author concluded that elastic energy decreases with the incorporation of rubber while the plastic energy increases. The rupture behaviour was therefore described as ductile because of the high deformation of the specimens and the greater energy absorbed.

2.5 Summary

Given the importance of compressive strength in the characterization of concrete, the analysis of its correlation with the incorporation of tyre aggregate is by far the most generally reported and discussed. The studies presented here not only cover a great variety of materials and incorporation ratios but they also use specimens of distinct geometries and sizes. Notwithstanding a great scatter in the results of the various studies it is apparent that the incorporation of rubber in concrete clearly lowers its compressive strength. The literature explains the fact mostly on the basis of the difference between the physical properties of natural aggregate and tyre aggregate.

Structural applications involving rubcrete may still be possible if appropriate percentages of rubber aggregates are used. We can also note that it is possible to produce relatively high-strength rubcrete mixtures by using magnesium oxychloride cement silica fume or Sodium Hydroxide, which achieves better bonding characteristics to rubber and greatly improves the performance of rubcrete mixtures according to literature. In addition, the adhesion between the rubber particles and other constituents of the rubcrete matrix can be improved by pre-treating the rubber aggregates. The effect of replacing 5 per cent, 15 per cent and 25 per cent by weight of coarse aggregates with chipped tyres were investigated. The results showed a reduction of 5 per cent for 5 per cent replacement. Replacement of 15 per cent and 25 per cent showed a reduction of 10-23 per cent in compressive strength. The observed reasons for the reduction in strength includes:

- Due to lack of proper bonding between rubber particles and the cement paste (as compared to cement paste and aggregates), a continuous and integrated matrix against exerted loads is not available. Hence applied stresses are not uniformly distributed in the paste. This causes cracks at the boundary between aggregate and cement.
- During casting and vibrating the rubber particles tend to move upwards. A high concentration of these particles does happen on the top surface because of low specific gravity. Non-uniform distribution of these particles at the top surface tends to produce non-homogenous samples and leads to a reduction in concrete strength at those parts resulting in failure at lower stresses.
- As rubber has lower stiffness compared to stone aggregates, the presence of rubber particles in concrete reduces concrete mass stiffness and lowers its load-bearing capacity.

As mentioned previously, most of the literature review has shown a significant decrease in the mechanical properties of concrete after the addition of tyre rubber particles as aggregates. The use of only coarse rubber particles affects the properties of concrete more negatively than do only fine particles. Moreover, the plastic energy capacity of the normal concrete has increased by adding rubber. Due to their high plastic energy capacities, concrete has shown high strains, particularly under the impact effects.

Most of the studies previously mentioned were analytical and/or laboratory-based experimental work. The major findings were that rubber concrete would suffer a reduction in compressive strength while it may increase ductility. Whether rubber concrete is suitable for any practical application has remained to be explored.

The main purpose of this study consists of exploring the feasibility of incorporating scrap tyres in form of chopped rubber coarse aggregates in concrete mixes and to determine its effect on the mechanical properties of the concrete mix. The parameters that were monitored comprised the influence of the rubber content on the mechanical properties of rubberized concrete starting with the 0 per cent rubber content (no rubber) and up to 25 per cent rubber content. The hardened concrete properties like the compressive strength, splitting tensile strength, and impact load were scrutinized.

We may note that Zambia as a developing country proposes a number of multipurpose developmental projects. Every year we observe that the budget proposal usually involves large projects involving the construction of roads, bridges, irrigation schemes, public health engineering schemes, educational buildings and residential buildings. All these construction schemes demand optimum and efficient use of construction resources. Most of the modern heavy constructions require huge quantities of cement, concrete and this incurs depletion of natural resources such as river sand and rock strata. Cost of river sand and crushed rock particles will rapidly increase because of inadequate raw materials and also the rise in transport costs due to the hike in fuel prices and other inputs. Further, mining of river sand causes severe environmental damage by lowering groundwater table and disintegration of rock strata which may cause landslides and earthquakes.

This emerging problem obliges contemporary material usage to balance the ecology. In this essence, the abundant availability of waste tyre rubber can be utilized as an effective replacement for natural aggregates which will be beneficial for both circumstances.

Hence, this research investigates the use of waste tyres in various aspects of construction in Zambia and surrounding regoins. There has been a few numbers of rubber based concrete projects developed in all the corners of civil engineering. A critical review of the existing literature on the utilization of waste rubber has been rightly presented in this review.

2.6 Future trends of rubberized concrete

Several studies confirm that the uses of waste tyre rubber in concrete are sustainable in terms of economy, environment and mechanical performance of concrete. However, there are very limited investigations on applications of rubberized concrete in reinforced structural members so far.

As observed from the present available study, it has shown that the application of rubberized concrete in full-scale reinforced concrete beams and columns that the rubberized concrete can be successfully implemented in those members under service load as well as extreme loading conditions. It was reviewed that the rubberized concrete columns can be able to undergo more than two times lateral deformation without buckling failure compared to the conventional one. Meanwhile, the investigations on uses of advanced materials to confinement on the structural columns incorporating rubberized concrete also have a good potential.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter looks at the research approach which was used, how the data was collected and analyzed.

3.2 Quantitative approach

The research employed a quantitative approach. The quantitative approach enabled the researcher to conduct experimental procedures grounded in empirical measurements. The author used probability sampling methods, reviewed public documents when collecting data and used statistical methods to analyze data. The research employed an experimental programme for various tests in which the steps taken are described.

3.3 Research Instruments

The following are the materials used in the process of data collection:

3.3.1 Documents

During the process of research, documents were reviewed. These were published materials (books, journals,), unpublished works and manuscripts including other scholars /students dissertation or thesis, company and organization's reports and publications as well as the Internet. The relevant documents which addressed the objectives of the study were thoroughly read and notes taken.

3.3.2 Audio-visual materials

Photographs, audio recordings and short video clips were done during the experimental work. This method provided an opportunity to capture the processes at the time when the research was being conducted and make comparisons to the reviewed literature.

3.3.3 Laboratory Procedure

The research studied the viability of addition of waste rubber tire aggregates as a replacement for natural aggregates in concrete.

Moreover, the effect of curing time on engineering properties was studied. Different concrete groups were prepared using plain portland cement, choped rubber as a replacement for coarse aggregates (0 per cent, 15 per cent and 25 per cent) by volume. The sizes of chopped rubber that were used ranged from 20 mm to 19 mm. The specimens from the different groups were investigated after different curing durations namely; 7 days and 28 days. The grade for normal concrete used in the study was C20 as it is used as a minimum standard strength in load bearing members such as beams.

Concrete mixtures produced by adding a mixture of rubber have different values of compressive strength compared to concrete without rubber mixture. Determining the appropriate materials and standards is a key step prior to concrete mixing. Among the materials needed to produce a concrete mix are cement, coarse aggregate, fine aggregate, rubber tyre aggregate and water.

3.3.4 Sampling frame

The sampling frame is simply the set of source of ‘materials’ from which the sample is selected. In this case, the source of materials used in the experiments was Kafue Quarry for fine and course aggregates, Lafarge Plc for cement and ordinary garages for tyres.

3.4 Data Analysis

Most of the data was analyzed through experimental procedures and principally organized and presented as Tables, Diagrams, Charts and Graphs.

3.5 Materials Used

a) Cement& aggregates

The cement used for the present investigation was ordinary Portland cement, Mphanvu, from Lafarge. Mphamvu cement is used in Zambia and must meet the requirements of CEM II B-L-32.5N. The quarry dust obtained from Kafue Quarry and the locally available crushed stone aggregates of size 20mm were used as fine aggregates and coarse aggregates respectively in the present investigation. Their physical properties such as specific gravity, bulk density, percentage of water absorption and fineness modulus were tested in concurrence with BS 882:199 as shown in Table 3.1.

b) Water

Potable water was used for mixing and curing specimens throughout the experimentation. Clean portable water at room temperature, free from suspended particles, chemical substances and biological elements was used both for mixing concrete and curing.

c) Chopped Rubber

The tyre rubber used in the experiments was applied in the following two size grading and it was obtained from the nearest tyre rubber centre in Lusaka. Chopped rubber was used for the replacement of coarse aggregate in concrete. The rubber tyre aggregate was cut with a cutter and hacksaw to the size between 10-20 mm as shown in Figure 3.1. The rubber aggregates used to replace coarse aggregate in the present investigation were made by manually cutting the tyre into the required sizes as shown in Figure 3.2. It was laborious and difficult to handle at the initial stages. However, all these complications can be easily sorted out if a large scale production is devised and proper cutting tools and machinery are made for this particular usage.

Figure 3.1: Process used to produce rubber aggregates from used tyres

Figure 3.2: Coarse rubber aggregates obtained from used tyres

The standards used included; BS EN 12620:2013 on Grading Sand and Aggregates; BS 812 on Impact Value; BS EN 12390-3:2019 on Testing Concrete for determination of Compressive Strength of Concrete and Bulk Density.

Several tests were done on the rubber aggregates and Table 3.1 shows a summary of results obtained. Figure 3.3 shows the selection and grading of aggregates used for the impact value test while Figure 3.4 shows the experiment done to determine the Impact Value on Natural Aggregates.

Figure 3.3: Selection and grading aggregates for aggregate impact value test

Figure 3.4: Impact Value Test on natural aggregates

The methodology started with the collection of used tyre rubber waste as a raw material. Several tests were conducted to obtain the strength and durability of the concrete, and the types of tests conducted include slump test, vibration test, compression test and density test. The water-cement ratio used in this study was set to be 0.48 for C25, 0.55 for C20 and 0.62 for C15 and measured by the weight of water to solidify. Too much water-cement ratio results in weak concrete and not durable. Water-cement ratio was determined by taking the weight of the water divided by the weight of cement. The lower the water-cement ratio the higher the concrete strength.

Concrete mix designs must be taken into consideration as stipulated in the design standards in order to produce quality concrete. The ratios stipulated in the concrete mix are 1:2:3 for C25, 1:2:2 for C20 and 1:3:3 for C15 by weight. A design based on the weight ratio was used to provide equality between aggregate gross weight and the weight of the tyre rubber aggregate. The strength and durability of concrete depend on the materials and methods chosen with adequate mixing. By selecting the right mix proportions of concrete, good concrete workability can be achieved. The strength of concrete mixing depends on the water-cement ratio. In order to obtain good quality concrete, the water-cement ratio was reduced as much as possible. Mix designs for all groups were similar. A total of 3 groups of samples were prepared in this experiment. For the mixing experiment, samples with rubber tyre waste as a replacement for coarse aggregate were determined by weight method.

The replacement was done with the addition of different percentages of 5 per cent, 15 per cent and 25 per cent by weight of rubber waste. The rubber aggregates used in the experiment were roughened on the surfaces using a wire brush and soaked in water for twenty-four hours and later sun-dried for six hours. This was done to increase the bond properties between the rubber particles and cement paste. Figure 3.5 shows the process of grading the rubber aggregates while Table 3.2 shows the percentage replacement of coarse aggregates used in the present investigation.

Figure 3.5: Grading of the rubber aggregates used in the present investigation

TABLE 3.1: Per cent replacement of coarse aggregates

Samples	A	B	C	D
Per cent replacement of coarse aggregates by mass (%)	0	5	15	25

Wet curing was applied for test cubes. The curing period of this experiment was set for 7 days and 28 days. All the test procedures were based on established procedures prescribed in BS EN 12390-3:2019.

The tests included a slump test, compression test, tensile splitting test, acid attack test and density test. Two samples were also subjected to elevated temperatures and their behaviour was observed. The cube samples, without the addition of rubber waste, acted as a control sample. Sources of error in sample preparation included incomplete sample tamping, over vibration, and error in the calibration tests which may result in the incorrect application of pressure. This was reduced by increasing the number of tests taken to achieve consistent data, thus increasing the accuracy and validity of the test results.

3.6 Mix proportion

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required strength, durability and workability as economically as possible, is termed as concrete mix design. The proportioning of ingredients of concrete is governed by the required performance of concrete in two states, namely plastic and hardened states. The mix designs and proportions for each grade of concrete are shown in in the tables provided in appendices A, B, C and D. The tables also show the amount of tyre aggregates and natural aggregates in different percentage proportions for mix ingredients for one cubic meter of concrete. Figure 3.6 shows the process of mixing of concrete specimens using natural aggregates. Figure 3.7 shows the preparation, mixing and moulding of rubberized concrete specimens.

Figure 3.6: Preparation and mixing of concrete specimens (0 % Rubber)

Figure 3.7: Preparation and mixing of concrete specimens (15% Rubber)

3.7 Experimental procedures

3.7.1 Slump test procedure

The slump test is used in determining the workability of fresh concrete. The slump test procedure was as per BS EN 12350-2:2019.

3.7.2 Compressive strength test Procedure:

- The standard BS EN 12390-3:2019 was complied with in carrying out the compressive strength tests.
- Compressive strength was determined using the following formula:

$$\text{Compressive strength} = \frac{Maximum\ load}{Cross\ sectional\ area}\ ,\ (\text{MPa})\ldots\ldots\ldots\ldots\ (1)$$

3.7.3 Tensile Splitting Strength test

Cylindrical specimens 150 × 300 mm were tested according to BS EN 12390-6:2009.From this experimental study, it was observed that normal concrete split into well-defined failure pattern than the rubberized concrete. It was noted that the strength of tyre rubber concrete decreased compared to the addition of tyre rubber waste. The strength did not change with up to 15 per cent crumb rubber.

3.7.4 Density

The density of concrete is found by measuring the weight of concrete cube and then by dividing it by volume of the cube. The density test was conducted in accordance BS EN 12390-7:2019.

3.7.5 Residual Strength Test

Fire resistance and thermal conductivity

The concrete cubes after curing for 28 days were heated for 48 hours and 1 hour at 100 ^{o} C and 400 ^{o} C respectively and later subjected to compression tests. The samples included the control concrete and 5 per cent, 15 per cent and 25 per cent rubber concrete for grade C20.

3.7.6 Resistance to aggressive environment

Six rubberized concrete specimens were cured in sodium sulphate solution simulating the effect of seawater. The other six specimens were kept in normal curing for 28 days. After curing theur were all subject to compression tests and results were recored.

3. 8 Number of specimens

A total of 6 mixes were prepared in this study and 36 cube samples were prepared (150mm x 150mm x 150mm) for conducting the compression test. Also, 18 samples of cylinders (150mm diameters x 300mm height) for tensile splitting test were prepared. The samples included 6 cubes and 3 cylinders of each percentage replacement of coarse aggregate with tyre scrap by volume. The percentages included 5 per cent, 15 per cent and 25 per cent. Compaction factor test for fresh mixes and compression strength at 7 days and 28 day and tensile splitting strength tests were conducted on respective specimens.

Figure 3.8 shows the casting of the control concrete and rubberized concrete specimens in moulds. Figure 3.9 shows the curing of concrete specimens.

Figure 3.8: Casting of the control concrete and rubberized concrete specimens

Figure 3.9: Curing of concrete specimens

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Results on Physical and Mechanical Properties

TABLE 4.1: Physical properties of rubber, coarse and fine aggregates

Test No	Properties	Rubber	Coarse Aggregate	Fine Aggregate
1	Specific gravity	1.232	2.792	2.818
2	Water absorption (%)	0.181	0.313	0.414
3	Impact value	15 blows done, did not crush		17.01
4	Bulk density-loose (%)	0.48	1.547	1.759
5	Bulk density-compacted (%)	0.61	1.694	1.955
6	Fineness modulus			2.86
8	Natural moisture content (%)		0.06	0.07

4.1.1. Workability test

Slump test is important to check the workability of concrete. The test results are illustrated in Figure 4.1.

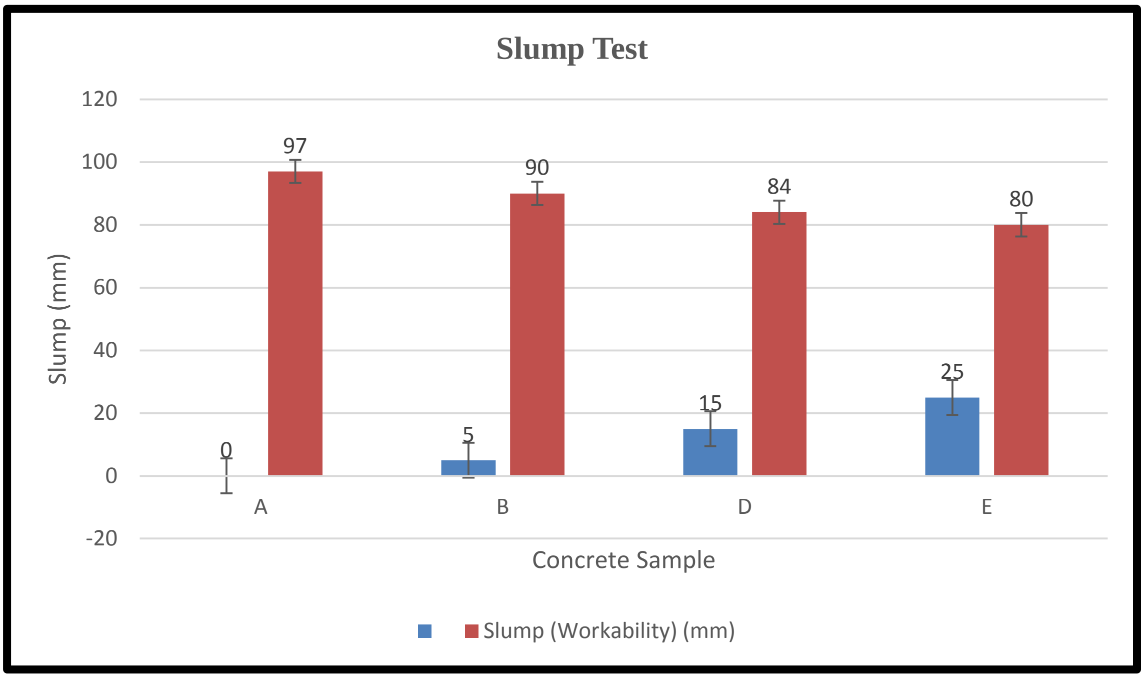

Figure 4.1: Slump test results for different rubber contents.

The design mix had a targeted slump of 80mm to 100mm. The replacement of coarse aggregate by scrap tire rubber affected the workability of the concrete. The result indicated reduced workability as compared to the normal concrete.

It may be summarized that the workability in normal concrete and rubberized concrete fall within the designed limits as shown in Figure 4.2.

(a)

Figure. 4.2a: Slump of normal concrete

(b)

Figure. 4.2b: Slump of Rubberized concrete

4.1.2 Compressive Strength Test

Table 4.2 and Figure 4.3 illustrate the different strength of concrete in terms of compressive strength of concrete and control concrete with rubber additives from the test result after 7 and 28 days.

TABLE 4.2: Compression of test results of grade C20 concrete at 7 days and 28 days

COMPRESSIVE STRENGTH OF RUBBERIZED CONCRETE (C20)		
Type of mix by % substitution (w/c = 0.55)	**Compressive Strength (MPa) by Age**	
	7 days	**28 days**
0	16.08	21
5	15.92	20
15	14.50	19
25	12.06	16

The test results of compressive strength are shown in Table 4.2. From the literature, it has been found that on replacing natural coarse aggregates with rubber aggregates, there is a significant reduction in compressive strength of concrete with respect to control concrete. The loss of compressive strength might be attributed to: 1) low specific gravity of the chopped rubber as compared to the natural coarse aggregates, 2) increase in percentage of air voids, 3) low adhesion between chopped rubber aggregates and the cement matrix and 4), possible reduction in concrete bulk density. However, for treated rubber modified concrete, the compressive strength of concrete decreases, but the reduction in compressive strength was less significant compared to if the tyres were untreated to make rubber modified concrete for 7 days and 28 days, as shown in Table 4.2. The strength of treated rubber modified concrete also increases with the increase in curing time but decreases with the increase in rubber aggregate content. Figure 4.3 shows the variations of compression test results with respect to the rubber content.

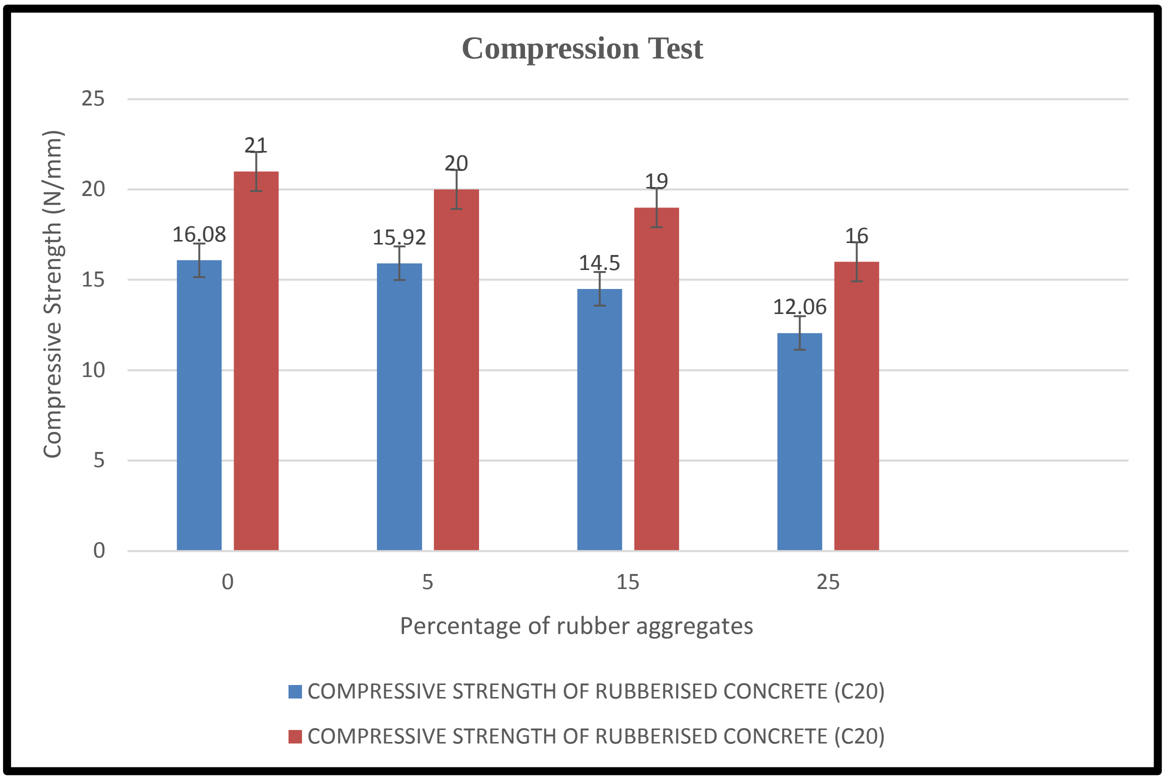

Figure 4.3: Compression test results of concrete at 7 days and 28 days.

4.1.3 Tensile Splitting Test Strength

The results of tensile splitting strength of cubes for 28 days curing are presented in Table 4.3 and Figure 4.4.

Table 4.3: Tensile splitting strength test results

TENSILE SPLITTING STRENGTH OF RUBBERIZED CONCRETE	
Type of mix by % substitution (w/c = 0.50)	**Tensile Strength (MPa) at 28 days**
0	4.1
5	4.0
15	3.7
25	3.0

After 28 days curing of concrete cylinder, the tensile splitting strength test was carried out on each concrete cylinder of each blend and results were as follows:

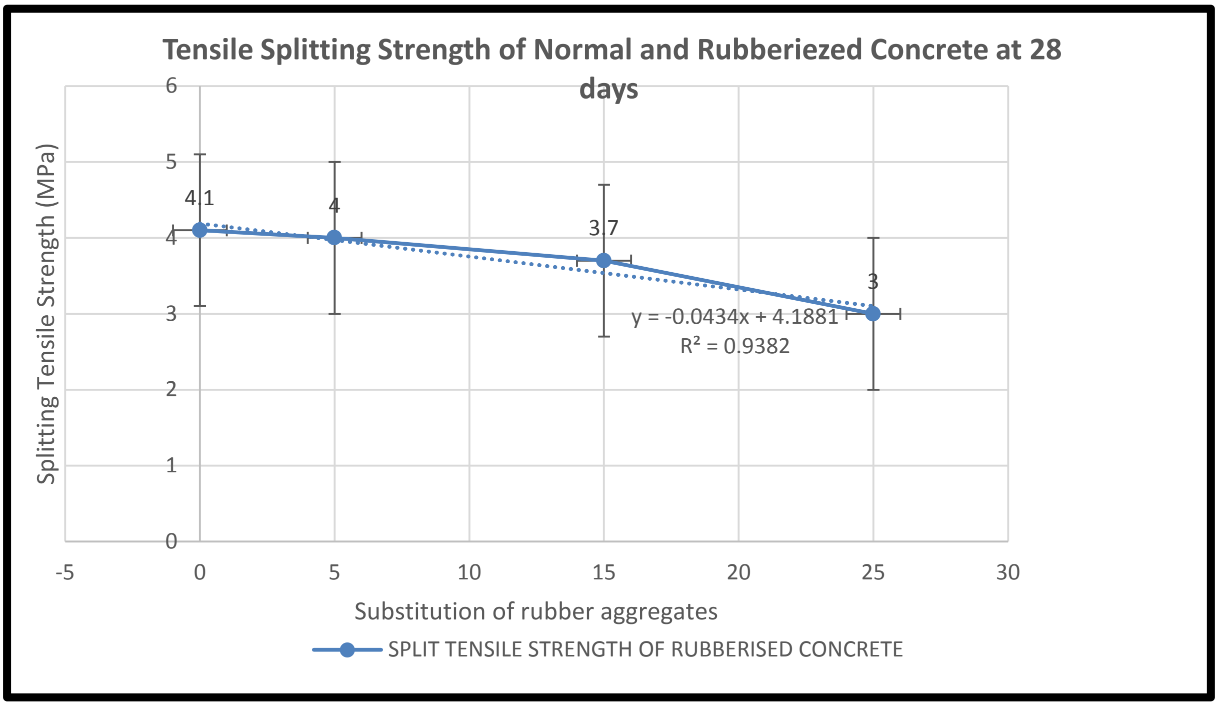

Figure 4.4: Tensile splitting strength results of concrete at 28 days.

4.1.4 Determination of Unit weight

The unit weight values used for the analysis in this section were determined from the concrete cube samples after 28 days of standard wet curing. From the results, it was found out that a reduction of unit weight up to 4 per cent was observed when 25 per cent by volume of the coarse aggregate was replaced by rubber aggregate in a sample and the results are shown in Table 4.4.

Table 4.4: Change in unit weight of rubberized and normal concrete

UNIT WEIGHT OF RUBBERIZED AND NORMAL CONCRETE			
Type of Concrete	**Initial Unit Weight (g)**	**Soaked in Sodium Sulphate for 7 days**	**Heated at 400°C for 48 Hours**
Normal	8506	8640	8300
Rubberized (5% replacement)	8332	8416	8100
Rubberized (15% replacement)	7950	8001	7357
Rubberized (25% replacement)	7800	7920	7130

4.1.5 Density

The density was computed and the results are shown in Table 4.5 and Figure 4.5.

Table 4.5: Density variation with change in percentage of rubber aggregate content

Type of Concrete	**Density (kN/m^3)**
Normal	26.5
Rubberized (5% replacement)	23.73
Rubberized (15% replacement)	22.17
Rubberized (25% replacement)	18.32

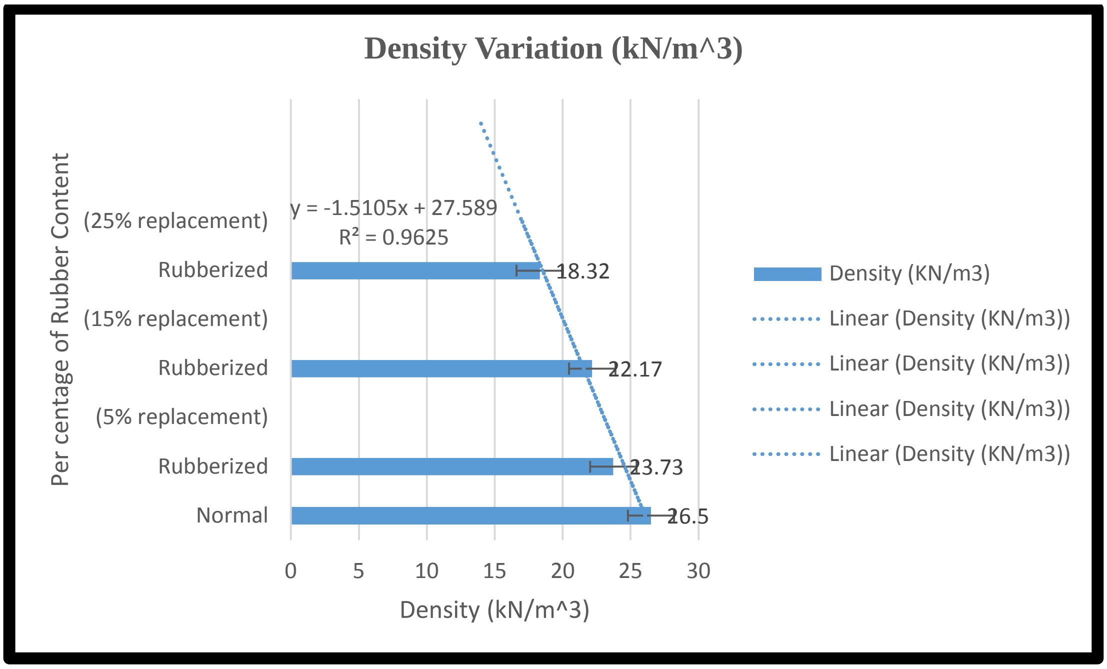

Figure 4.5: Density variation with change in percentage of rubber aggregate content.

The density of the concrete is decreasing as the percentage of tyre scrap increases. This could be due to the rubber's air adhesion, i.e. increase in the air content as well as the difference in the specific gravity of natural aggregate and waste tyre rubber aggregate.

4.1.6 Residual Strength Test

The results residual strength test were as follows; 19.8 N/mm^2, 18.1 N/mm^2, 16.87 N/mm^2 and 14.21 N/mm^2, respectively as shown in Table 4.6.

Table 4.6: Results of C20 Grade Concrete Average Compressive Strength

Rubber content (%)	**Residual compressive strength (N/mm^2)**
	100 ^{o}C for 48 hours
0	19.8
5	18.1
15	16.87
25	14.21

Rubber is combustible under fire and has low decomposition temperature. Therefore, rubberized concrete is not safe compared to normal concrete under a direct fire condition. However, the structural component made by rubberized concrete exhibited lower spalling damage under fire. After exposing the rubberized concrete specimens with 5 per cent, 15 per cent and 25 per cent chopped rubber to 100 °C for 48 hours, the residual compressive strength was found as recorded in Table 4.6 and illustrated in Figure 4.6. Photographs showing pattern failures are presented in Appendix E. When the specimens were subjected to compression loading, it was observed that normal concrete did not crack, however, failure was rapid and brittle. On the other hand, the rubberized concrete had some cracks after heated but the failure was gradual and uniform.

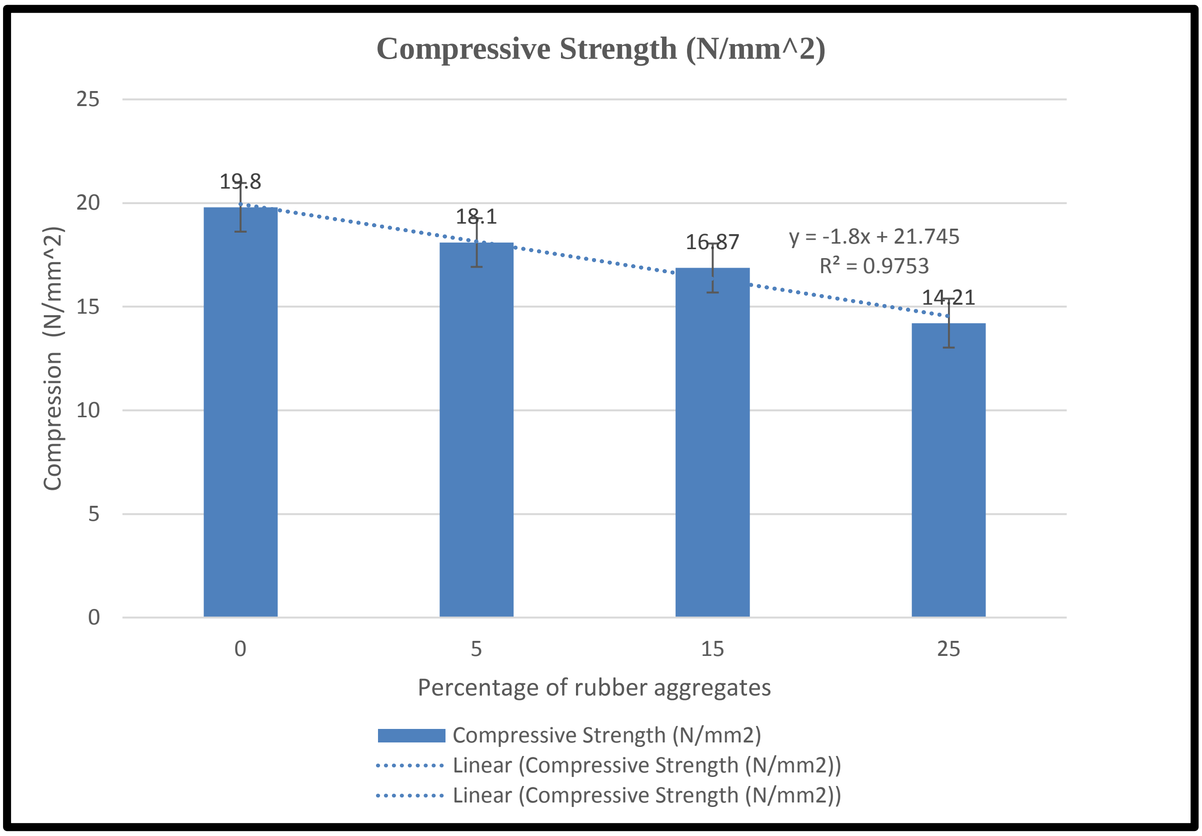

Figure 4.6: Variation of compression strength of concrete after heating for different rubber contents at 100 °C for 48 hours.

After exposing the rubberized concrete specimens with 5 per cent, 15 per cent, and 25 per cent at 400 °C for 1 hour, the residual compressive strength were found to lose 6.3 per cent, 13.4 per cent, and 26.5 per cent of the control specimens.

Table 4.7: Results of C20 Grade Concrete Average Compressive Strength

Rubber content (%)	**Residual compressive strength (N/mm^2)**
	400 °C for 1 hour
0	16.8
5	15.7
15	14.5
25	12.3

4.1.7 Resistance to aggressive environment (sulphate attack)

The compressive strength after submerging the specimen in 10-liter water + 100 ml Sodium Sulphate for 7 days for the control concrete and that with replacement of 5 per cent, 15 per cent and 25 per cent rubber concrete are as shown in Table 4.7 and Figure 4.7.

Table 4.8: Results of C20 Grade Concrete Average Compressive Strength Submerged in Sodium Sulphate

Result of C20 Grade Concrete Average Compressive Strength	
Rubber Content (%)	**Compressive Strength (N/mm^2)**
	28 days + 7 days in NaSO4
0	20.3
5	19.5
15	17.9
25	16.25

Sulfate attack on concrete can lead to expansion, cracking, strength loss, and disintegration of the concrete. While the porosity of rubberized concrete is higher than that of normal concrete, the chemical absorption of the former is generally higher than the latter. Some previous experiments have returned positive results and confirmed the high resistance of rubberized concrete to sodium sulphate and water penetration.

From the literature review, rubberized concrete faces a lower long-term loss in strength compared with normal concrete under sulphate exposure conditions, and such loss in strength decelerates as the amount of rubber increases.

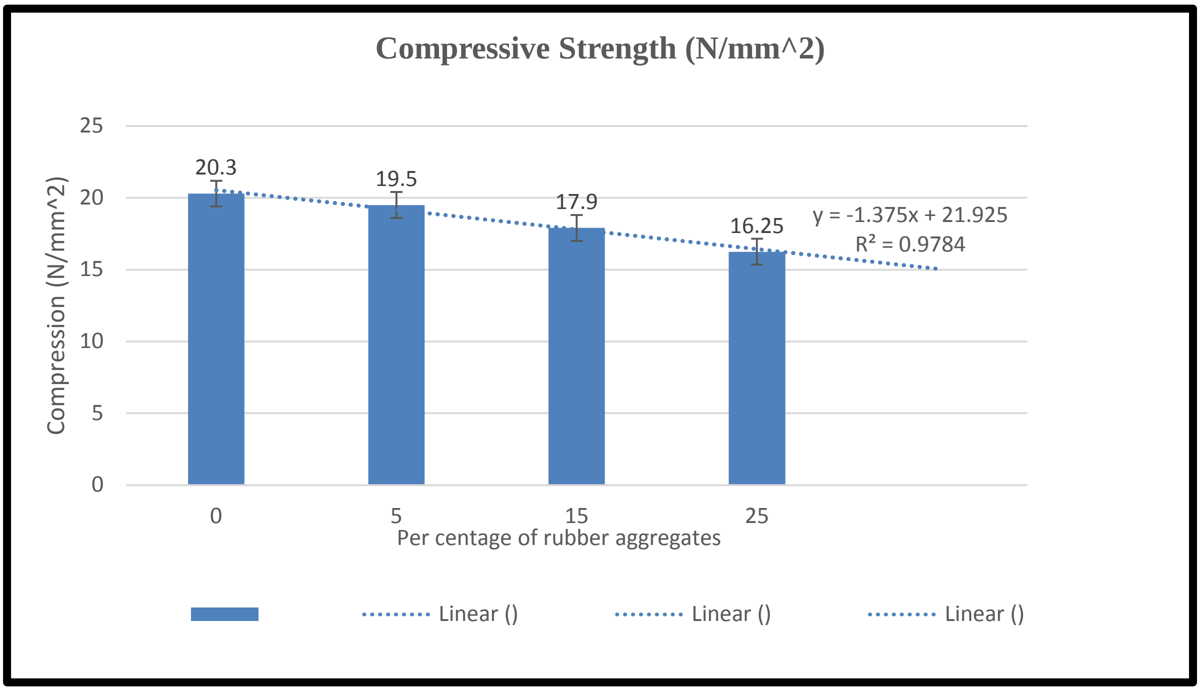

Figure 4.7: Variation of compression strength of concrete after treatment in sodium sulphate solution for different rubber contents.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the conclusions from the findings of the research. It has been established from the literature that tyre production is continuously increasing in parallel with the economic and industrial development in the world. In 2004, $80 billion of tyres were sold worldwide. In 2010 it was $140 billion. (Approximately 34% growth adjusting for inflation), and was expected to grow to $258 billion per year by 2019. In 2015, the US alone manufactured almost 170 million tyres. Over 2.5 billion tyres are manufactured annually, making the tyre industry a major consumer of natural rubber. It was estimated that by 2019, 3 billion tyres will be sold globally every year, according to a report by "World Tyres", Freedonia Group, retrieved 19 May 2017. This shows that there is a massive growth production of tyre waste per year. Disposal and burning of waste tyres have been proven as harmful for environmental safety and therefore, recycling of rubber is the most desirable alternative. The application of recycled waste tyre rubber in concrete construction is an effective and sustainable process. Waste tyre rubber can be utilized in concrete as a replacement of fine aggregates, coarse aggregates, binders, and fibres. However, in this research, a replacement of coarse aggregates was used to determine the suitability of using rubber aggregates in concrete production..

5.2 Conclusions

From the test results and analysis of this experimental work, the following conclusions were arrived at:

1. In general, the addition of rubber in concrete reduces mechanical properties and this trend is more severe with an increase in the rubber size and content. The compressive strength of the concrete rubber tyre has a slightly lower strength compared to the control concrete. This percentage reduction is due to the low adhesion of rubber with cement paste. However, the strength achieved was acceptable as the results obtained could still be used in load bearing memebers such as beams. The reduction observed in splitting tensile strength was lower compared to the observed reduction in compressive strength. The analysis of the experimental results showed that rubber modified concrete can find its application as standard concrete, up to 15 per cent replacement of coarse aggregate. By treating the surfaces of the tyre rubber, the

compressive strength of the concrete is least affected but replacing more than 25 per cent of coarse aggregate appreciably reduces the concrete strength.

Rubberized concrete strength was improved by improving the bond properties of rubber aggregates with the cement paste. In this study, this was achieved by surface treatment which involved roughening the rubber surface with a wire brush and thorough cleaning in water only.

2. Concrete physical and mechanical properties
    a) Slump value was reducing as the percentage of replacement of tyre rubber waste increased. So a slight reduction in workability was observed, however, a workable mix within the designed limits was achieved in both normal and rubberized concrete.
    b) From this experimental study, it was noted that the unit weight of cube specimens slightly decreased by increasing the percentage value of rubber into the concrete. It is concluded that rubberized concrete can be very useful in lightweight concrete structures which is economical and has low handling costs.
    c) After being subjected to high temperatures, the normal concrete barely exhibited cracks but after being subjected to compression forces, failure was rapid and brittle. However, the rubberized concrete developed cracks after being heated, and when subjected to compression forces, the failure was gradual and uniform. In conclusion, Strength loss was observed in both rubberized and normal concrete at elevated temperature but was gradual in rubberized concrete. For this reason structural application of rubberized concrete was feasible when subjected to high temperatures and Sulphur attacks. Brittle and catastrophic failure is also minimized in rubberized concrete than normal concrete under these conditions.
    d) There is a potentially large market for concrete products in which rubber aggregates from discarded rubber tyres could be utilized to mitigate the issue of disposal of tyres which is projected to be a big problem in times of environment pollution if not handled well.
    e) After being subjected to sodium sulphate test, results showed a reduction in the dynamic elasticity modulus with the inclusion of rubber. It can be noted that the inclusion of rubber in the matrix increased its resistance against sodium sulphate and seawater.

5.3 Recommendations

1. Since the use of rubber aggregates in concrete construction is not common in most developing countries like Zambia, many studies and research works need to be carried out in this area by research and academic institutions.
2. Most of the time, it is observed that designers and contractors opt for high strength and expensive concrete to gain few improved properties such as impact resistance in parking areas and lightweight structures for particular applications. Nevertheless, these properties can be achieved through the application of rubberized concrete by first conducting laboratory tests regarding the desired properties. Therefore, the use of rubberized concrete as an alternative concrete making material needs support by designers, contractors and clients.
3. Since the long-term performance of rubberized concrete was not investigated in the present study, research and academic institutions need to study the long term behaviour of concrete produced by rubberized concrete.
4. This research was done by preparing single graded rubber aggregates of size 19 mm - 20 mm. The effect of different sizes should be studied by other researchers. Besides to this, the effects in different percentage replacements other than those made in this study needs to be investigated. Additional research must be conducted, taking into account the type, age and quality of tyres used to manufacture the crumb rubber in rubberized concrete.
5. Pre-treatment of waste tyre rubber using different methods may add unique properties to the concrete mix and may produce different impacts on the physical and strength parameters. Different methods of waste tyre rubber pretreatment must be studied extensively by academic institutions and concrete making companies.
6. The aggressive environmental resistance of concrete containing rubber aggregates still needs more investigations. This can be a major topic for future investigations by research candidates.

REFERENCES

Aiello, M. A. and F. Leuzzi, 2010. Waste tyre rubberized concrete: Properties at fresh and hardened state. Journal of Waste Management, 30, pp. 1699-1704.

Albano, G., N. I. Fattuhi and L. A. Clarck, 2005. Rubberized concrete: a green structural material with enhanced energy - dissipation capability, Construction Building Materials, 10(4), pp. 229-236.

Al-Bakari, S., D. Kyser and N. Ravichandran, 2016. Properties of chipped rubber roofing membrane and sand mixtures for civil engineering applications, Journal of Building Engineering, Journal of Building Engineering 7, pp. 103-113.

Al-Mutairi, C. K., M. M. Al-Tayeb and H. M. Akil, 2010. Performance of rubberized and hybrid rubberized concrete structures under static and impact load conditions. Explore Mechanics, 53, pp. 377–384.

Antil, Y., 2014. An Experimental Study on Rubberized Concrete, International Journal of Emerging Technology and Advanced Engineering, Volume 4, Issue 2, pp. 309-316.

Arin, C. D. and K. Nurhayat 2007. Utilization of crumb rubber as partial replacement in sand for cement mortar. Eur. J. Sci. Res. 51 (2), pp. 203– 210.

Azevedo, F., T. Pacheco-Torgal, and C. Jesus, 2012. Properties and durability of HPC with tire rubber wastes. Construction Building Materials. 34, pp. 186–191.

Batayneh, M. K., I. Marie and I. Asi, 2008. Promoting the use of crumb rubber concrete in developing countries, Journal of Waste Management, ELSEVIER, 28, pp. 2171-2176.

Biel, J. S. and H. S. Lee, 2007. Development of tyre added latex concrete. ACI Mater. J. 95 (4), pp. 356–364.

British Standard Institution (BSI), BS 1881-104, 1983. Vibration test method, BSI, London.

Cairns, R., H. Kew and M. Kenny, 2013. The use of recycled rubber tyres in concrete construction, Final 575 Report, University of Strathclyde, Glasgow, 91 p.576.

California University, USA, Accession No 829841.

Eldin, N. N. and A. B. Senouci, 1993a. Rubber-tyre particles as concrete aggregate, Journal of Material in Civil Engineering, ASCE, 5(4), pp. 478-496.

Eldin, N. N. and A. B. Senouci, 1993b. Crushed Rubber Waste Impact of Concrete Basic Properties, Journal of Construction and Building Materials, Construction and Building Materials 140, pp 36-42.

Eshmaiel, K. N., E. L. Gammal and S. Sherbini, 2005. Compressive strength of concrete utilizing waste tyre rubber. Engineering Trends. (1), pp. 96–99.

ETRMA’s statistics on scrap tyre collection and recycling in Europe, (n.d.). https://weibold.com/etrmas-statistics-on-scrap-tyre-collection-and-recycling-in-europe/ (accessed April 8, 2019).

Ganesan, N., R. J. Bharati, and A. P. Shashikala, 2013. Flexural fatigue behavior of self-compacting rubberized concrete, Construction Building Materials, 44, pp. 7–14.

Ganjian, E., M. Khorami and A. A. Maghsoudi, 2009. Scrap-tyre-replacement for aggregate and filler in concrete, Construction and Building Materials Journal, ELSEVIER, 23, pp.1 828-1836.

Garrick, C. J., N. K. Ghaly and J. D. Ashraf, 2018. Correlation of strength, rubber content, and water to cement ratio in rubberized concrete. Can. J. Eng. 32, pp. 1075–1081.

Giacobbe, E. K., 2014. Investigating properties of pervious concretes containing waste tyre rubbers, Construction Building Materials. 63, pp. 206–213.

Gintautasskripkiūnas, S. and G. A. Musselman, 2015. Ten-year performance evaluation of asphalt-rubber surface mixes. Transportation Research Record No. 1681, Transportation Research, Washington, DC, pp. 10–18.

Global Tire Recycling Market Share, Size, Trends Analysis | Forecast 2024, (n.d.). https://www.goldsteinresearch.com/report/global-tyre-recycling-industry-market-trends-analysis (accessed April 8, 2019).

Goulias, D. G. and A. H. Ali, 1998. Cement-based materials containing shredded scrap truck tyre rubber, Construction Building Materials, 10(4), pp. 229–236.

Grinys, P., G. Girskas and D. Nagrockiene, 2012. Crushed Rubber Waste Impact of Concrete Basic Properties, Journal of Construction and Building Materials, Construction and Building Materials 140, pp 36-42.

Guleria, T. A. and C. H. Dutta, 2002. Designing Building Products Made With Recycled Tyres,
Report No. 433-04-008, Integrated Waste Management Board Public Affairs Office, Publications clearing house (MS–6), Sacramento, CA.

Guneyisi, E., M. Gesoglu and T. Ozturan, 2014. Properties of rubberized concretes containing silica fume. Journal of Cement and Concrete Research, ELSEVIER, 34, pp 2309-2317.

Hasshimghedan, G. and K. Dinamukheefhamza, 2006. Quasi-elastic behavior of rubber included concrete (RIC) using waste rubber tyres. In Proceedings of the International Conference on Solid Waste Technology and Management, 8 pp 485-571.

Hernandez-Olivares, F. and C. Barluenga, 2002. Static and dynamic behavior of recycled tyre rubber-filled concrete, Cement Concrete Research 32, pp. 1587–1596.

(https://www.ustires.org/, accessed April 8, 2019) and (https://weibold.com/etrmas-statistics-on-scrap-tyre-collection-and-recycling-in-europe/, accessed April 8, 2019).

Kaloush, K. M., M. Getahun and A. Belachew, 2014. Study on Waste Tyre Rubber as Concrete Aggregate, International Journal of Scientific Engineering and Technology, Volume No.3 Issue No.4, pp: 433-436.

Kamil, K., L. Zanzotto and R. Wirth, 2005. Performance of asphalt binders and paving mixes modified by crumb rubber, 21st Canadian Waste Management Conf. (CD-ROM), Calgary, Canada.

Khallo, A. M., C. Dehestani and P. Rahmatabadi, 2008. Mechanical properties of concrete containing a high volume of tyre-rubber particles, Waste Management, Volume 8, Issue 12, pp. 2472-2482.

Khatib, Z. K. and F. M. Bayomy, 1999. Rubberized Portland cement concrete, Journal of Materials in civil engineering, ASCE, 11(3), pp. 206-213.

Kotresh, R. and B. Belachew, 2016. Performance of asphalt binders and paving mixes modified by crumb rubber. Proc., 21st Canadian Waste Management Conference. (CD-ROM), Calgary, Canada.

Kumaran, K., G. G. Dimitrios and C. Al-Hosain, 2008. Non Destructive Evaluation of Rubber Modified Concrete, Infrastructure Condition Assessment, Rubber Modified Concrete Evaluation, Polytechnic University, Six Metro-tech, Brooklyn, NY,11201, pp. 111-120.

Li, G., M. A. Stubblefield, J. E. Abadie and C. Huang, 1998. Development of waste tyre modified concrete. Cement Concrete Research 34, pp 2283–2289.

Ling, H. L., B. Chanbane, G. A. Sholar and J. A. Musselman, 2005. Ten-year performance evaluation of asphalt-rubber surface mixes. Transportation Research Record No. 1681, pp. 10–18.

Malladi, C. D., 2004. Valorization of post-consumer waste plastic in cementitious concrete composites, Waste Management 27, pp. 310–318.

Mangal, B. C., A. M. Ghaly and J. D. Cahill, 2013. Correlation of Strength, Rubber Content, and Water to Cement Ratio in Rubberized Concrete, Can. J. Civ. Eng., Vol. 32(6), pp. 1075–1081.

Marzouk, O.Y., R. M. Dheilly and M. Queneudec, 2007. Valorization of post-consumer waste plastic in cementitious concrete composites. Waste Management 27, 310–318.

Mavroulidou, G. and J. Figueiredo, 2018. Effect of Particle Sizes on Mechanical Properties of Concrete Containing Crumb Rubber. Innovative Systems Design and Engineering, 6(2): pp. 114-125.

Medina, M. N., T. C. Maher and B. H. Hanafi, 2017. Effect of partial replacement of sand by fine crumb rubber on impact load behavior of concrete beam: experiment and nonlinear dynamic analysis. Materials and Structures, 46, pp. 1299–1307.

Mehmet, M. V. and J. N. Erhan, 2011. Physical and mechanical properties of foamed Portland cement composite containing crumb rubber from worn tyres, 59, pp. 550–557.

Mier, V. N., A. C. Valadares and F. M. Bravo, 1997. Concrete with used tyre rubber aggregates: mechanical performance. ACI Materials, J. 109–M26, pp. 283–292.

Miguel, C. E. and M. C. Jorge, 2013. Potential of scrap tyre rubber as lightweight aggregate in flowable fill. Waste Management. 23, pp. 197–208.

Mindness, S., J. F. Young and D. David, 2013. Rubberized Concrete, second edition, Practice Hall, New Jersey.

More, S., F. Valadares and J. Brito, 2015. Concrete with Used Tyre Rubber Aggregates: Mechanical Performance, ACI Materials Journal, 109(3), pp. 283-292.

Nehdi, R. and K. Khan, 2015. Achieving Sustainability of concrete by recycling of solid waste materials, Mechanical Testing and Diagnosis, ISSN 2247-9635, (II), Volume 1, pp 22-39.

Saviour, N. M., 2012. Environmental impacts of Soil and Sand Mining: A Review. International Journal of Science, Environment and Technology. 1, 3, pp. 125-134.

Schimizze, R., R. Lepore, and I. Zandi, 2017. Use of waste rubber in light-duty concrete pavements in Infrastructure@ New Materials and Methods of Repair. ASCE.

Selvakumar. S. and R. Venkatakrishnaiah, 2015. Effects of Concrete by using waste tyre rubber (Solid Waste), International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 5 pp. 13221-13230.

Senthil, G., K. Kumaran, N. Mushule and M. Lakshmipathy, 2012. A review on Construction Technologies that enables environmental protection: Rubberized Concrete, Advanced Materials Research, Volume 367, pp. 49-54 © Trans Tech Publications.

Serge, N. and I. Joekes, 2018. Use of tyre rubber particles as addition to cement paste. Cement and Concrete Research, 30(9): pp. 1421-1425.

Shah, F. A., A. Naseer, and M. Ashraf, 2014. Evaluation of Thermal and Structural Behavior of Concrete Containing Rubber Aggregate, Volume 39, Issue 10, pp. 6919-6926.

Siddique, R. and T. R. Naik, 2014. Properties of concrete containing scrap tyre rubber – an overview, Waste Management 24, pp. 563–569.

Sofi, S. P., 2016. Use of crumb rubber to improve thermal and sound properties of pre-cast concrete panels in Construction Building Materials, 23, pp. 1084–1092.

Sukontasukkulin, P. C., G. Papakonstantinou and M. J. Tobolski, 2018. Use of waste tyre steel beads in Portland cement concrete. Cement and concrete research, 36(9): pp. 1686-1691.

Topcu, I. B., 2012. The properties of rubberized concrete; Cement and Concrete Research, 25(2): pp. 304-310.

Toutanji, H. A, 1996. The use of rubber tyre particles in concrete to replace mineral aggregates. Journal of Cement & Concrete Composites, ELSEVIER, 18, pp. 135-139.

Turatsinze, T. M. and R. D. Garros, 2013. Strength Appraisal of Concrete containing Waste Tyre Crumb Rubber, Volume 4, No. 1.

Yang, L., H. Zhu and Y. Li, 2015. Theoretical Analysis of the Effect of Crumb Rubber on the Sectional Ductility of Reinforced Concrete Beam, China. J. Basic Sci. Eng., Volume 18(4), pp. 609.

Yasin, W. T., 2017. Use of recycled rubber tyres in normal- and high-strength concretes. ACI Mater. J. 106–M37, pp. 325–332.

Zaher, K., G. G. Dimitrios and H. Al-Hosain, 2018. Non Destructive Evaluation of Rubber Modified Concrete, Infrastructure Condition Assessment, Rubber Modified Concrete Evaluation, Polytechnic University, Six Metro-tech, Brooklyn, NY,11201, pp. 111-120.

Zheng, L., X. S. Huo and Y. Yuan, 2008. Experimental investigation on dynamic properties of rubberized concrete, Construction and Building Materials 22(5), pp. 939–947.

APPENDIX A: SUMMARY OF TEST RESULTS – STUDY ON COMPRESSIVE, TENSILE AND BOND PROPERTIES OF USED TYRE RUBBER REINFORCED CONCRETE

1.0 COARSE AGGREGATES

Table A.1: Physical and Mechanical Test

No	Description	Results	Specification	Remarks
	14mm Stone			
01	Bulk Density (Rodded)	1694Kg/m^3	-	-
02	Bulk Density (Loose)	1547Kg/m^3	-	
02	Specific Gravity (SG)	2.792	≥2.0	-
03	Water Absorption	0.31%	≤2.5%	-
04	Natural Moisture Content	0.06%	-	-
05	Aggregate Crushing Value (ACV)	17.0%	-	-

Table A.2: Grading for 14mm Stone - BS 882:1992 Table 3

Sieve Size (mm)	% Passing	Percentage Passing 20mm	Percentage Passing 14mm	Percentage Passing 20-5mm
50.0				
37.5		100		100
20.0	100	85-100	100	90-100
14.0	86	0-70	85-100	40-80
10.0	34	0-25	0-50	30-60
5.0	2	0-5	0-10	0-10
2.36	-	-	-	-
Remark		**Within Specification for 14mm nominal size**		

2.0 FINE AGGREGATES (QUARRY DUST)

Table A.3: Physical and Mechanical Test

No	Description	Results	Specification	Remarks
01	Bulk Density (Rodded)	1955Kg/m^3	-	
02	Bulk Density (Loose)	1759Kg/m^3	-	
03	Specific Gravity	2.818	≥2.0	
04	Water Absorption	0.41%	≤2.5%	
05	Natural Moisture Content	0.07%	-	
06	Sand Equivalent Test	%		
07	Silt Content	%		

Table A.4: Grading for Sand (Quarry Dust) - BS 882:1992 Table 4

Sieve Size mm	% Passing	Overall Limits Spec	Spec - Additional limits for Grading			Remarks
			C	M	F	
10.00	100	100	-	-	-	Ok
5.00	92	89 - 100	-	-	-	Ok
2.36	75	60 - 100	60 - 100	65 - 100	80 - 100	Ok
1.18	59	30 - 100	30 - 90	45 - 100	70 - 100	Ok
0.60	46	15 - 100	15 - 54	25 - 80	55 - 100	Ok
0.30	30	5 - 70	5 - 40	5 - 48	5 - 70	Ok
0.15	12	0 - 15	-	-	-	Ok
Remark:		**Within Specification for Overall Limits**				
Fineness Modulus:		**2.86**				

APPENDIX B: STUDY ON COMPRESSIVE, TENSILE AND BOND PROPERTIES OF USED TYRE RUBBER REINFORCED CONCRETE - CONCRETE MIX DESIGN CERTIFICATE (CLASS 15)

TEST: Concrete Mix **DATE OF CASTING**: 17.09.19 **DATE OF TESTING: 15.10.19** (28 days)

TEST METHOD: American Concrete Institute Standards. **VOLUME CONSIDERED**: 1m^3

DESIGNED BY: Theresa Bwalya **CLIENT**: UNZA

Table B.1: Material Characteristics

Ingredient	**Rodded Bulky Density (Kg/m^3)**	**Specific Gravity**	**Water Absorption (%)**	**Field Moisture (%)**	**Aggregate Crushing Value (%)**
Coarse Aggregate	1694	2.792	0.31	0.06	17.0%
Fine Aggregates **(Quarry Dust)**	1955	2.818	0.41	0.07	
Concrete		**Actual Slump Recorded = mm**			

Specific Gravity of Cement = 3.15 (Mphamvu Cement CEM II B-L-32.5N)

Table B.2: Design Parameters

1.1	Type of Concrete	Non-Air Entrained	
1.2	Size of Coarse Aggregate	14.0mm	
1.3	Slump	80-100mm	
1.4	Characteristic strength	15 N/mm^2	Standard Deviation: No Data 8N/mm^2
1.5	Design Margin	10 N/mm^2	K= (1.64x8) = 13N/mm^2
1.6	Target mean strength	20 N/mm^2	
1.7	Water/Cement Ratio (Table 7.4)	0.62	
1.8	Free Water Content (Table 7.5)	215Kg	
1.9	Cement Content (215Kg/0.62)	347Kg	
1.10	Volume of Coarse Aggregates (Table 7.6)	0.55	With ref to Fineness Modulus
1.11	Mass of Coarse Aggregate (0.55 x 1694)	932Kg	1694 is Bulk Density of Aggregate
1.12	Fineness Modulus of Sand (Quarry Dust)	2.86	

Table B.3: Absolute Volumes

Item	Ingredient	Mass (Kg)	Calculation	Volume (m^3)
2.1	Cement	347	(347/3.15)10^3	0.110
2.2	Water	215	(215/1.0) 10^3	0.215
2.3	Coarse Aggregate	932	(932/2.792) 10^3	0.334
2.4	Entrapped Air (2.0%)	-	(20) 10^3	0.020
2.5	**Total Volume of above**			**0.679**
2.6	Volume of Sand needed		1-0.693	0.321
2.7	Sand Weight (0.321 x 2.818)10^3	905		

Table B.4: Estimated Batch Quantities per m^3 of concrete

3.1	Cement	347 Kg
3.2	Water	215 Kg
3.3	Coarse Aggregates	932 Kg
3.4	Sand	905 Kg
3.5	**Density of Fresh Concrete**	**2399 Kg/m^3**

Table B.5: Adjustment of Moisture

Moisture content for Fine Aggregates	0.07%	Moisture content for Coarse Aggregates	0.06%
Wt of Coarse Aggregates	932 + (932 x 0.06%)	**933Kg**	
Wt of Fine Aggregates	905+ (905 x 0.07%)	**906Kg**	
Coarse Aggregates will contribute	(0.31% – 0.06%)	**0.25%**	
Fine Aggregates will contribute	(0.41% – 0.07%)	**0.34%**	
Estimated Water required	215 - (933 x 0.25%) + (906 x 0.34%)	**210 Litters**	

Table B.6: Actual & Recommended Batch Quantities for 1m^3 of Batch

5.1	Cement	347 Kg
5.2	Water	210 Liters
5.3	Sand	906 Kg
5.4	Coarse Aggregates	933 Kg

By ratio: 1:2.2:2.4 (1:2:2) and Water/Cement ratio: 0.62

Actual Slump Recorded = mm

Table B.7: Lab Trial by weight of 6 Cubes (30% increase in Qty)

6.1	Cement	347 Kg	0.02025	**7Kg**	**9.1Kg**
6.2	Water	210 liters	0.02025	**4.3Liters**	**5.6Liters**
6.3	Sand	906 Kg	0.02025	**18.3Kg**	**23.8Kg**
6.4	Coarse Aggregates	933 Kg	0.02025	**18.89Kg**	**24.6Kg**

NOTE: If the first trial is made and strength is not achieved, the cement content can be increased or decreased if the desired strength is too high.

APPENDIX C: STUDY ON COMPRESSIVE, TENSILE AND BOND PROPERTIES OF USED TYRE RUBBER REINFORCED CONCRETE - CONCRETE MIX DESIGN CERTIFICATE (CLASS 20)

TEST: Concrete Mix **DATE OF CASTING**: 17.09.19 **DATE OF TESTING**: 15.10.19 (28 days)

TEST METHOD: American Concrete Institute Standards. **VOLUME CONSIDERED**: 1m^3

DESIGNED BY: Theresa Bwalya **CLIENT**: UNZA

Table C.1: Material Characteristics

Ingredient	**Rodded Bulky Density (Kg/m^3)**	**Specific Gravity**	**Water Absorption (%)**	**Field Moisture (%)**	**Aggregate Crushing Value (%)**
Coarse Aggregate	1694	2.792	0.31	0.06	17.0%
Fine Aggregates **(Quarry Dust)**	1955	2.818	0.41	0.07	
Concrete		**Actual Slump Recorded = mm**			

Specific Gravity of Cement = 3.15 (Mphavu Cement CEM II B-L-32.5N)

Table C.2: Design Parameters

1.1	Type of Concrete	Non-Air Entrained	
1.2	Size of Coarse Aggregate	14.0mm	
1.3	Slump	80-100mm	
1.4	Characteristic strength	20 N/mm^2	Standard Deviation: No Data 8N/mm^2
1.5	Design Margin	10 N/mm^2	K= (1.64x8) = 13N/mm^2
1.6	Target mean strength	30 N/mm^2	
1.7	Water/Cement Ratio (Table 7.4)	0.55	
1.8	Free Water Content (Table 7.5)	215Kg	
1.9	Cement Content (215Kg/0.55)	391Kg	
1.10	Volume of Coarse Aggregates (Table 7.6)	0.55	With ref to Fineness Modulus
1.11	Mass of Coarse Aggregate (0.55 x 1694)	932Kg	1694 is Bulk Density of Aggregate
1.12	Fineness Modulus of Sand (Quarry Dust)	2.86	

Table C.3: Absolute Volumes

Item	Ingredient	Mass (Kg)	Calculation	Volume (m^3)
2.1	Cement	391	(391/3.15)10^3	0.124
2.2	Water	215	(215/1.0) 10^3	0.215
2.3	Coarse Aggregate	932	(932/2.792) 10^3	0.334
2.4	Entrapped Air (2.0%)	-	(20) 10^3	0.020
2.5	**Total Volume of above**			**0.693**
2.6	Volume of Sand needed		1-0.693	0.307
2.7	Sand Weight (0.307 x 2.818)10^3	865		

Table C.4: Estimated Batch Quantities per m^3 of concrete

3.1	Cement	391 Kg
3.2	Water	215 Kg
3.3	Coarse Aggregates	932 Kg
3.4	Sand	865 Kg
3.5	**Density of Fresh Concrete**	**2403 Kg/m^3**

Table C.5: Adjustment of Moisture

Moisture content for Fine Aggregates	0.07%	Moisture content for Coarse Aggregates	0.06%
Wt of Coarse Aggregates	932 + (932 x 0.06%)	**933Kg**	
Wt of Fine Aggregates	865+ (865 x 0.07%)	**866Kg**	
Coarse Aggregates will contribute	(0.31% – 0.06%)	**0.25%**	
Fine Aggregates will contribute	(0.41% – 0.07%)	**0.34%**	
Estimated Water required	215 - (933 x 0.25%) + (866 x 0.34%)	**209 Litters**	

Table C.6: Actual & Recommended Batch Quantities for 1m^3 of Batch

5.1	Cement	391 Kg
5.2	Water	209 Liters
5.3	Sand	866 Kg
5.4	Coarse Aggregates	933 Kg

By ratio: 1:2.2:2.4 (1:2:2) and Water/Cement ratio: 0.55

Actual Slump Recorded = mm

Table C.7: Lab Trial by weight of 6 Cubes (30% increase in Qty)

6.1	Cement	391 Kg	0.02025	**7.9Kg**	**10.3Kg**
6.2	Water	209 liters	0.02025	**4.2Liters**	**5.5Liters**
6.3	Sand	866 Kg	0.02025	**17.5Kg**	**22.8Kg**
6.4	Coarse Aggregates	933 Kg	0.02025	**18.89Kg**	**24.6Kg**

NOTE: If the first trial is made and strength is not achieved, the cement content can be increased or decreased if the desired strength is too high.

APPENDIX D: STUDY ON COMPRESSIVE, TENSILE AND BOND PROPERTIES OF USED TYRE RUBBER REINFORCED CONCRETE - CONCRETE MIX DESIGN CERTIFICATE (CLASS 25)

TEST: Concrete Mix **DATE OF CASTING**: 17.09.19 **DATE OF TESTING**: 15.10.19 (28 days)

TEST METHOD: American Concrete Institute Standards. **VOLUME CONSIDERED**: 1m^3

DESIGNED BY: Theresa Bwalya **CLIENT**: UNZA

Table D.1: Material Characteristics

Ingredient	**Rodded Bulky Density (Kg/m^3)**	**Specific Gravity**	**Water Absorption (%)**	**Field Moisture (%)**	**Aggregate Crushing Value (%)**
Coarse Aggregate	1694	2.792	0.31	0.06	17.0%
Fine Aggregates **(Quarry Dust)**	1955	2.818	0.41	0.07	
Concrete		**Actual Slump Recorded = mm**			

Specific Gravity of Cement =3.15 (Mphavu Cement CEM II B-L-32.5N)

Table D.2: Design Parameters

1.1	Type of Concrete	Non-Air Entrained	
1.2	Size of Coarse Aggregate	14.0mm	
1.3	Slump	80-100mm	
1.4	Characteristic strength	25 N/mm^2	Standard Deviation: No Data 8N/mm^2
1.5	Design Margin	10 N/mm^2	K= (1.64x8) = 13N/mm^2
1.6	Target mean strength	35 N/mm^2	
1.7	Water/Cement Ratio (Table 7.4)	0.48	
1.8	Free Water Content (Table 7.5)	200Kg	
1.9	Cement Content (200Kg/0.48)	417Kg	
1.10	Volume of Coarse Aggregates (Table 7.6)	0.62	With ref to Fineness Modulus
1.11	Mass of Coarse Aggregate (0.62 x 1694)	1050Kg	1694 is Bulk Density of Aggregate
1.12	Fineness Modulus of Sand (Quarry Dust)	2.86	

Table D.3: Absolute Volumes

Item	Ingredient	Mass (Kg)	Calculation	Volume (m^3)
2.1	Cement	417	$(417/3.15)10^3$	0.132
2.2	Water	200	$(200/1.0)\ 10^3$	0.200
2.3	Coarse Aggregate	1050	$(1050/2.792)\ 10^3$	0.376
2.4	Entrapped Air (2.0%)	-	$(20)\ 10^3$	0.020
2.5	**Total Volume of above**			**0.728**
2.6	Volume of Sand needed		1-0.693	0.272
2.7	Sand Weight $(0.272 \times 2.818)10^3$	766		

Table D.4: Estimated Batch Quantities per m^3 of concrete

3.1	Cement	417 Kg
3.2	Water	200 Kg
3.3	Coarse Aggregates	1050 Kg
3.4	Sand	766 Kg
3.5	**Density of Fresh Concrete**	**2433 Kg/m^3**

Table D.5: Adjustment of Moisture

Moisture content for Fine Aggregates	0.07%	Moisture content for Coarse Aggregates	0.06%
Wt of Coarse Aggregates	1050 + (1050 x 0.06%)	**1051Kg**	
Wt of Fine Aggregates	766 + (766 x 0.07%)	**767Kg**	
Coarse Aggregates will contribute	(0.31% – 0.06%)	**0.25%**	
Fine Aggregates will contribute	(0.41% – 0.07%)	**0.34%**	
Estimated Water required	200 - (1051 x 0.25%) + (767 x 0.34%)	**195 Litters**	

Table D.6: Actual & Recommended Batch Quantities for 1m^3 of Batch

5.1	Cement	417 Kg
5.2	Water	195 Liters
5.3	Sand	767 Kg
5.4	Coarse Aggregates	1051 Kg

By ratio: 1:1.84:2.5 (1:2:3) and Water/Cement ratio: 0.48

Actual Slump Recorded =   mm

Table D.7: Lab Trial by weight of 6 Cubes (30% increase in Qty)

6.1	Cement	417 Kg	0.02025	**8.44Kg**	**11Kg**
6.2	Water	195 liters	0.02025	**3.94Liters**	**5.1Liters**
6.3	Sand	767 Kg	0.02025	**15.53Kg**	**20.2Kg**
6.4	Coarse Aggregates	1051 Kg	0.02025	**21.28Kg**	**27.7Kg**

NOTE: If the first trial is made and strength is not achieved, the cement content can be increased or decreased if the desired strength is too high.

APPENDIX E: COMPRESSIVE TEST RESULTS OF THE RUBBERIZED AND NORMAL CONCRETE AFTER HEAT (48 HOURS AT 100 ^{O} C)

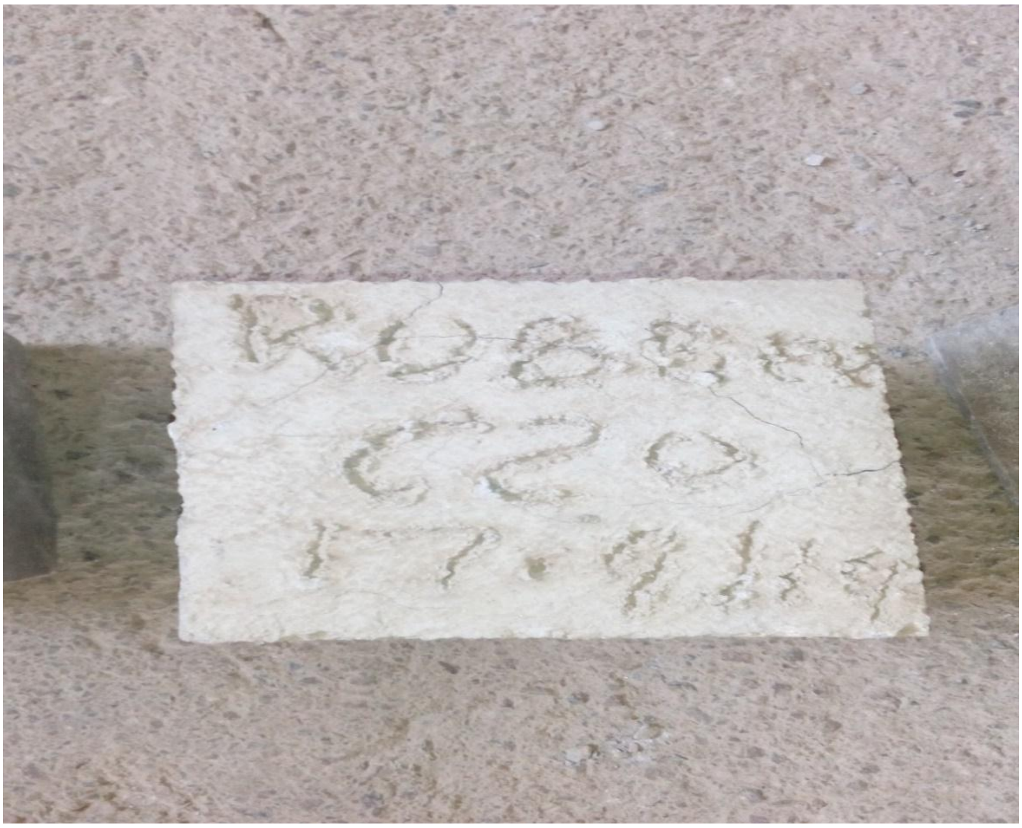

Figure E.1: Rubber reinforced concrete exhibiting some cracks after being subjected to heat at 100 ^{o} C for 48 hours

Figure E.2: Normal concrete not exhibiting cracks after being subjected to heat at 100 ^{o} C for 48 hours

Figure E.3: Compression test of heated rubber reinforced concrete

Figure E.4: Compression test of heated normal concrete

Figure E.5: Failure pattern of heated rubber reinforced concrete after being subjected to compression forces

Figure E.6: Failure pattern of heated normal concrete after being subjected to compression forces